Självkompakterande betong med goda brandspjälkningsegenskaper

Forskningsrapport

SLUTRAPPORT

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SBUF-rapport nr 11522, 11801 och 12013
Brandforsk-projekt 331-041 och 301-061

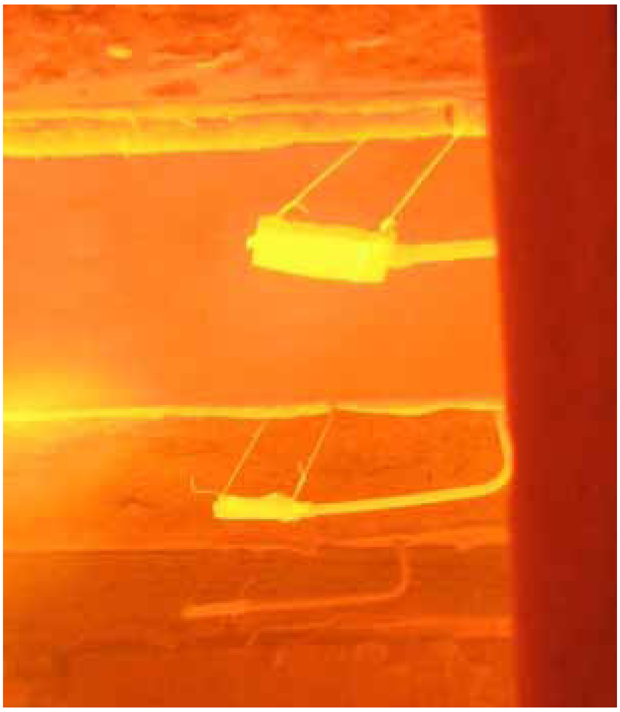

Foto: Lars Boström, SP

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Förord

Projektet kunde genomföras genom finansiering och stöd från följande finansiärer.

- SBUF – Svenska Byggbranschens Utvecklingsfond
- Brandforsk – Styrelsen för svensk brandforskning
- Statens Vegvesen
- Vägverket
- Banverket
- CBI Betonginstitutet AB
- Cementa AB
- SP Brandteknik
- Skanska Sverige AB - Teknik
- Skanska Sverige AB - Stomsystem
- Nordkalk AB
- Sika Sverige AB

Efter en lång och stundtals tuff resa tackar vi i projektgruppen alla finansiärer som gjort det möjligt att genomföra detta projekt.

Göteborg, juni 2009

Sammanfattning

Självkompakterande betong är en betong, med högpresterande reologiska egenskaper, som kompakteras utan yttre vibreringsinsats. Av erfarenhet och från provningar vet man att betongkonstruktioner av tät betong med stor andel finmaterial kan påverkas negativt vid brand. Självkompakterande betong, som ofta innehåller mycket finmaterial, är ett exempel på en tätare betong. Betongkonstruktioner som utsätts för brand kan förstöras på många olika sätt men i detta projekt tittar vi endast på brandspjälkning. Utgångspunkten i detta projekt är att hantera brandspjälkningen genom att tillsätta och blanda in polypropylenfiber (PP-fiber) i betongmassan.

Brandtesterna utfördes av SP Brandteknik i Borås och överslagsmässigt har 200 brandtest utförts på mer än 50 olika betongsammansättningar. Projektet omfattar brandtester av element av såväl anläggningsbetong som husbyggnadsbetong. Brandförsöken utfördes till största delen på små provkroppar med dimensionen 500×600×200mm. I detta projekt har vi undersökt olika faktorers inverkan på den självkompakterande betongens benägenhet att spjälka. Exempel på undersökta faktorer är bl.a. tryckbelastning, fuktinnehåll, brandkurva och betongsammansättning.

Erfarenheten från tillverkningen av element på fabrik är att det är mycket svårt tillverka självkompakterande betong med större mängder PP-fiber än ca 2 kg/m^3 oavsett fiberdimension ∅18µm eller ∅32µm. Orsaken är att större mängder fiber påverkar betongens reologiska egenskaper negativt.

Resultaten från brandtesterna visade att inblandning av PP-fiber ger den självkompakterande betongen goda brandspjälkningsegenskaper. I princip all självkompakterande betong utan PP-fiber spjälkade. Motståndet mot brandspjälkning ökar också med ökad fiberinblandning. En tillsats av 1,0 till 1,5 kg/m^3 av fibertypen ∅18µm eller ∅32µm gav ett bra skydd mot progressiv (gradvis ökande) spjälkning.

Fiberinblandningen visade sig inte heller vara negativ för beständighetsegenskaperna, såsom karbonatisering och kloriddiffusion, under förutsättning att dispergeringen av cement och filler är god. En riktigt proportionerad självkompakterande betong med PP-fiber och med god dispergering av cement och filler har beständighetsegenskaper som minst motsvarar SKB utan PP-fiber. Värt att nämnas är också att saltfrostbeständigheten förbättrades markant med andelen fibrer. Fibrerna i detta projekt var bestrukna med dispergeringsmedel.

En viss spjälkning kan i de flesta fall accepteras då det oftast rör sig om estetiska skador.
I dessa fall bör inte fibertillsatsen vara större än nödvändigt med tanke på svårigheterna med att tillverka en bra och robust självkompakterande betong med större mängder fiber. Rekommendationen avseende fiberdosering, i de fall en viss spjälkning kan accepteras, är därför 1,5 kg/m^3 av fibertypen ∅18µm eller ∅32µm. Rekommendationen gäller för såväl anläggningsbetong som husbyggnadsbetong. Önskas lägre dosering än 1,5 kg/m^3 skall detta påvisas genom provning.

I fall där ingen spjälkning accepteras krävs oftast större mängder fiber än 1,5 kg/m^3. Rekommendationen i dessa fall är att genom provning påvisa att ingen spjälkning sker.

INNEHÅLLSFÖRTECKNING

Rapport WP2 Tillverkning av självkompakterande betong med PP-fiber
Rapport WP3 Self-Compacting Concrete Exposed to Fire
Rapport WP4 Mikrostruktur- och beständighetsanalys

1 INLEDNING

Betong används i stor omfattning vid såväl bostadsbyggande som anläggningskonstruktioner. Materialet betong utvecklas ständigt och under det senaste decenniet har självkompakterande betong blivit en betongprodukt som används i allt större utsträckning inom byggbranschen.

Självkompakterande betong är en betong, med högpresterande reologiska egenskaper, som kompakteras utan yttre vibreringsinsats. Från historiska erfarenheter och provningar vet man att betongkonstruktioner med tät betong och betong med stor andel finmaterial kan påverkas negativt vid brand. Självkompakterande betong, som ofta innehåller mycket finmaterial, är ett exempel på en tätare betong.

Betongkonstruktioner som utsätts för brand kan förstöras på många olika sätt. Det kan t.ex. ske genom minskad styrka hos betongen eller armeringen, brandspjälkning eller minskad vidhäftning mellan betong och armering. I detta projekt tittar vi endast på brandspjälkning.

I Sverige används ofta finmalt kalkfiller för att erhålla de önskade reologiska egenskaperna för självkompakterande betong. Den tätare strukturen som därigenom uppkommer genom tillsättning av finmaterial medför att man kan behöva finna alternativ och lösningar för att hantera en eventuell brandspjälkning. En sådan lösning är att tillsätta och blanda in polypropylenfiber (PP-fiber) i betongmassan.

Inblandning av dessa PP-fibrer medför dock stora negativa konsistensförändringar som kan förstöra den självkompakterande betongens reologiska egenskaper. Utifrån egna erfarenheter i detta projekt kan problemen uppstå redan vid inblandning av 1,0 kg/m^3 PP-fiber. Detta ställer i slutändan högre krav på sammansättningen av betongen. Det är därför av stor vikt att riktlinjer tas fram för tillverkning av självkompakterande betong med goda brandspjälkningsegenskaper.

2 ORGANISATION

Projektets projektledare samt ansvariga för respektive delprojekt ses nedan:

Projektledare:	Henrik Nilsson, Skanska Sverige AB, Göteborg
Receptframtagning och tillverkning:	Iad Saleh, Sika Sverige AB, Stockholm
Brandprovning:	Lars Boström / Robert Jansson, SP, Borås
Beständighetsprovning:	Jan Trägårdh / Mariusz Kalinowski, CBI Stockholm

Projektgruppens organisation såg ut enligt följande:

Henrik Nilsson, Skanska Sverige AB, projektledare
Iad Saleh, Sika Sverige AB
Claus K. Larsen, Statens Vegvesen
Robert Jansson, SP Brandteknik, LTH Byggnadsmaterial
Lars Boström, SP Brandteknik
Jan Trägårdh CBI Stockholm
Lars-Olof Nilsson, LTH Byggnadsmaterial

Projektets referensgrupp var sammansatt av följande personer:

Lars-Olof Nilsson, LTH Byggnadsmaterial
Lars Boström, SP Brandteknik
Katarina Kieksi, Banverket
Daniel Rydholm, Brandforsk
Hans-Erik Gram, Cementa
Bernt Freiholz / Samir Redha, Vägverket
Göran Fagerlund, LTH Byggnadsmaterial

3 UNDERSÖKNINGAR

3.1 Tillverkning av betongelement

Projektet omfattar totalt 52 betongrecept, ungefär lika del husbyggnadsbetonger (CEM II) och anläggningsbetonger (CEM I). Förundersökningen av betongen utfördes i Skanskas betonglaboratorium i Solna och tillverkning i full skala skedde i Skanskas elementfabrik i Strängnäs. Samtliga recept har tagits fram genom samarbete mellan Skanska Sverige AB och Sika Sverige AB. Recepten redovisas i sin helhet i delrapporten ”Tillverkning av självkompakterande betong med polypropylenfiber” av Iad Saleh, Sika Sverige AB [1].

Tillverkade element brandprovades sedan av SP i Borås. Betongen analyserades också m.a.p. mikrostruktur och beständighet av CBI Betonginstitutet AB i Stockholm.

3.2 Brandprovning

Brandprovningen, den mest omfattande delen i detta projekt, utfördes av SP i Borås. Överslagsmässigt har 200 brandtest utförts på mer än 50 olika betongsammansättningar.
I detta projekt har vi undersökt olika faktorers inverkan på den självkompakterande betongens benägenhet att spjälka. Exempel på undersökta faktorer är bl.a. tryckbelastning, fuktinnehåll, brandkurva och betongsammansättning. Provuppställning redovisas i sin helhet i delrapport “Self-Compacting Concrete Exposed to Fire” av Boström/Jansson, SP Brandteknik i Borås [2].

Brandförsöken utfördes på små provkroppar med dimensionen 500×600×200mm. I ett tidigare projekt rapporterat av Boström (2004) [3] undersöktes olika brandprovningsmetoder och provkroppars form. Detta projekt visade att småskaliga provkroppar gav ett liknande resultat som större provkroppar. Vissa recept kompletterades med större provkroppar för att verifiera resultaten.

3.3 Mikrostruktur och beständighetsanalys

Anläggningskonstruktioner har ofta en livslängd på minst 100 år varför det är av stor vikt att utreda om fibern har någon inverkan på den självkompakterande betongens mikrostruktur och beständighet. Dessa analyser utfördes av CBI Betonginstitutet AB i Stockholm. Tolv stycken självkompakterande anläggningsbetonger (CEM I) och sex stycken husbyggnadsbetonger (CEM II) provades och analyserades i detta projekt.

Analyser som genomfördes var bl.a. mikrostrukturanalys, kloriddiffusion, saltfrostbeständighet, tryckhållfasthet och karbonatiseringsdjup. Provuppställning presenteras i sin helhet i delrapport ”Mikrostruktur- och beständighetsanalys” av Trägårdh/ Kalinowski, CBI Betonginstitutet [4].

4 RESULTAT OCH UTVÄRDERING

Resultaten från undersökningarna i detta projekt redovisas i stora drag i följande avsnitt. I respektive delrapport [1, 2 och 4] redovisas resultaten med slutsatser i sin helhet.

4.1 Tillverkning av självkompakterande betong

Målsättningen i detta delprojekt var att i möjligaste mån ta fram recept för självkompakterande betong som är möjliga att tillverka även med relativt stor mängd PP-fiber utan att arbetbarheten förstörs. Detta samtidigt som betongen skall vara stabil och möjlig att tillverka med god repeterbarhet samt vara ekonomisk med avseende på framför allt cementhalter.

Resultaten i detta delprojekt pekar på att det är fullt möjligt att tillverka en stabil självkompakterande betong med en fibermängd mellan 1 och 2 kg/m^3. I detta projekt nåddes gränsen vid 1,5 kg/m^3 vid användning av fibertypen ∅18µm/6mm för såväl anläggningsbetongen som husbyggnadsbetongen. Det var dock möjligt att tillsätta 2 kg/m^3 av den grövre fibertypen ∅32µm/6mm i såväl anläggningsbetongen som husbyggnadsbetongen.

Större mängder fiber än ca 2 kg/m^3 är mycket svårt rent tillverkningsmässigt och rekommenderas endast för konstruktioner där ingen spjälkning accepteras. Orsaken är att större mängder fiber påverkar betongens reologiska egenskaper negativt och dessutom resulterar i en dyrare betong, som i de flesta fall inte kan motiveras.

Självkompakterande anläggningsbetong (vct=0,40) med PP-fiber visade sig få bäst reologiska egenskaper med ett vattenpulvertal kring 0,30. Självkompakterande husbyggnadsbetong bör ha ett vpt som inte överstiger 0,50 förutsatt att kalkfiller används för att ge robusthet till betongen. Ett högre vpt gör betongen för känslig för separation.

4.2 Brandprovning

Målsättningen i detta delprojekt var att genom brandförsök få svar på hur självkompakterande betong skall vara sammansatt för att ha goda brandspjälkningsegenskaper.

Det visade sig att i princip all självkompakterande betong utan PP-fiber spjälkade. En tillsats av 1,0 till 1,5 kg PP-fiber per kubik av typen ∅18 µm eller ∅32 µm gav ett bra skydd mot progressiv (gradvis ökande) spjälkning. Att helt skydda betongen mot spjälkning kan i många fall vara omotiverat dyrt då det oftast rör sig om estetiska skador. Men det finns naturligtvis fall där ingen spjälkning accepteras av olika skäl som t.ex. konstruktiva skäl. Det kan t.ex. vara i tunnlar eller andra optimerade konstruktioner där utnyttjandegraden av betongens konstruktiva egenskaper är hög.

Belastningens storlek hos belastade provkroppar påverkade inte spjälkningen. Dock spjälkade de obelastade provkropparna något mindre än de belastade.

Det var inte möjligt att se någon signifikant skillnad i spjälkning avseende mängden kalkfiller eller olika vattenpulvertal.

Det visade sig att typen av brandkurva inte hade någon märkbar effekt på risken för spjälkning. Spjälkningens storlek var dock större ju långsammare brandkurva/brandförlopp som betongen utsattes för.

Ingen påverkan av lagringstiden kunde påvisas när det gäller spjälkningen. En förklaring kan vara att fuktinnehållet aldrig sjönk till en kritisk nivå för att spjälkning skall uppträda.

4.3 Mikrostruktur och beständighetsanalys

Målsättningen i detta delprojekt var att analysera om fiberinblandningen har någon inverkan på den självkompakterande betongens mikrostruktur och beständighet.

Det visade sig att finheten i kapillärporsystemet varierade relativt mycket för den självkompakterande betongen med vct 0,40 jämfört med konventionell betong med lika vct. Den sannolikt direkta orsaken till kapillärporstrukturens variation anses vara dispergeringsgraden av cement och filler i pastan. Den indirekta orsaken är fibermängden. Ju mer fiber desto mer flyttillsatsmedel tillsätts vilket i sin tur ökar dispergeringen av cement och filler.

Fiberinblandningen är inte negativ för beständighetsegenskaperna, såsom karbonatisering och kloriddiffusion, under förutsättning att dispergeringen av cement och filler är god. En riktigt proportionerad självkompakterande betong med PP-fiber och med god dispergering av cement och filler har beständighetsegenskaper som minst motsvarar SKB utan PP-fiber.

Saltfrostbeständigheten förbättrades markant med andelen fibrer i SKB (utan lufttillsats). Med fiberhalter mellan 1-2 kg/m^3 var frostbeständigheten mycket god efter 56 fryscykler. Orsaken till den förbättrade frostbeständigheten är sannolikt det luftporsystem som skapas av PP-fibrerna vid själva blandningen av betongen. Dessutom är fibrernas mantelyta bestrukna med ett dispergeringsmedel som också verkar som en luftporbildare.

Mikrostrukturanalysen visade att kring PP-fibrerna bildades ett ca 2-3 µm tjockt portlanditskikt som medförde att övergångszonen mellan fiber och cementpasta blev tätare. När Portlanditen bryts ner vid brand bildas kalciumoxid och vatten. Eftersom detta vatten, som bildas momentant, övergår i ångfas vid brand kan detta lokalt påverka ångtrycket kring fibrerna. Möjligen kan detta vara en bidragande faktor för sprickpropagering från fibrerna vid brand.

5 REKOMMENDATION OCH RIKTLINJER

Inblandning av PP-fiber ger den självkompakterande betongen goda brandspjälknings-egenskaper. Motståndet mot brandspjälkning ökar också med ökad fiberinblandning. Inblandning av PP-fiber, bestrukna med dispergeringsmedel, är inte negativ för beständigheten, snarare tvärtom.

I de flesta fall kan viss spjälkning accepteras då det oftast rör sig om estetiska skador. I dessa fall bör inte fibertillsatsen vara större än nödvändigt med tanke på svårigheterna och riskerna med att tillverka självkompakterande betong med större mängder fiber. Rekommendationen avseende fiberdosering, i de fall en viss spjälkning kan accepteras, är därför 1,5 kg/m^3 av fibertypen $\varnothing$18µm eller $\varnothing$32µm. Rekommendationen gäller för såväl anläggningsbetong som husbyggnadsbetong. Önskas lägre dosering än 1,5 kg/m^3 skall detta påvisas genom provning.

I fall där ingen spjälkning accepteras krävs oftast högre mängder fiber och rekommendationen är att detta då skall påvisas genom provning.

REFERENSER

[1] Saleh, I, Nilsson, H. ”Tillverkning av självkompakterande betong med polypropylenfiber”, SIKA Sverige AB, Stockholm, Sweden, 2009

[2] Boström L., Jansson R. “Self-Compacting Concrete Exposed to Fire”, SP Report 2008:53, Borås, Sweden, 2008.

[3] Boström L. (2004) “Innovative self-compacting concrete - Development of test methodology for determination of fire spalling”, SP Report 2004:06, Borås

[4] Trägårdh J., Kalinowski M. ”Mikrostruktur- och beständighetsanalys” Uppdragsrapport 2009-43, CBI Stockholm, Sweden, 2009

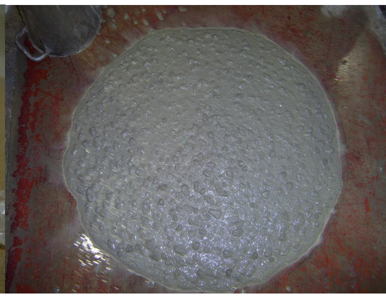
BILAGOR

Bilaga 1-3: Delrapporter

Rapport WP2 Tillverkning av självkompakterande betong med PP-fiber
Rapport WP3 Self-Compacting Concrete Exposed to Fire
Rapport WP4 Mikrostruktur- och beständighetsanalys

Construction

TILLVERKNING AV SJÄLVKOMPAKTERANDE BETONG MED POLYPROPYLENFIBER


Iad Saleh — Sika Sverige AB
Henrik Nilsson — Skanska Sverige AB

SAMMANFATTNING

Självkompakterande betong innehåller mer finmaterial jämfört med normal betong, vilket ger den självkompakterande betongen en tätare struktur. För detta ändamål används i Sverige ofta finmalt kalkfiller. Denna tätare strukturen har medfört att man varit tvungen att hitta lösningar för att minska eller förhindra risken för brandspjälkning. En sådan lösning är att blanda in polypropylenfiber (PP-fibrer). Inblandning av PP-fibrer - som idag är den vanligaste åtgärden för att erhålla goda brandspjälkningsegenskaper - medför dock ofta andra oönskade konsekvenser för den färska betongens egenskaper.

Syftet med detta delprojekt (WP2) har varit att ta fram betongrecept för självkompakterande betong och därefter tillverka betongelement som senare skall brandtestas. I projektet har det tagits fram recept både utan PP-fibrer samt med PP-fibrer för olika inblandningsmängder och olika fiberdimensioner. Projektet omfattar 27 husbyggnadsbetonger (CEM II) och 25 anläggningsbetonger (CEM I). Av de provade anläggningsbetongerna innehåller fem recept norskt anläggningscement.

Förundersökningen utfördes i Skanskas betonglaboratorium i Solna. Tillverkningen av element skedde därefter vid Skanska Stomsystems elementfabrik i Strängnäs utifrån de recept som utvecklats på labb.

Av de försök som utfördes kan konstateras att inblandning av 2,0 kg/m^3 fiber med Ø18 µm och längden 6mm inte var möjlig utan att de självkompakterande egenskaperna förlorades. De självkompakterande egenskaperna var däremot möjlig att tillgodose med en grövre dimension (Ø32 µm och längden 6mm).

Vidare noterades att betong med mikrosilika och hög lufthalt - även med PP-fiber - gav betongen goda självkompakterande egenskaper. Ytterligare en nämnvärd notering har varit att lufthalten varierat kraftigt då PP-fiber används i betongmassa med båda flyttillsatsmedel och luftporbildare.

SUMMARY

Self-compacting concrete contains more fine material than conventional concrete. This gives self-compacting concrete a more dense structure. In Sweden it is common to use limestone powder in self-compacting concrete for this purpose. This denser structure has forced us to find solutions in order to decrease or to prevent the risk of spalling when exposed to fire. Such a solution is to use polypropylene fibre (PP-fibre) in the concrete. Use of PP-fibres - that today is the most common measure in order to produce concrete with good fire spalling properties – usually means other undesirable consequences for the properties of fresh concrete.

The aim of this part of the project (WP2) is to develop the mix designs for self-compacting concrete and to produce concrete specimens required for fire testing. In this project, it has been developed recipes both without PP-fibres and with PP-fibres with different quantities and different fibre dimensions. The project covers 27 recipes for housing applications (CEM II) and 25 recipes for infrastructures (CEM I). Five of the concrete recipes for infrastructures contain Norwegian cement.

The development of the mix designs was performed at Skanskas concrete laboratory in Solna. The specimens were produced at Skanska Stomsystem in Strängnäs.

The results from this project showed that it was not possible to add more than 2.0 kg/m^3 fibre with Ø18 μm and the length 6mm, without loosing the self-compacting properties. The self-compacting properties were on the other hand possible to meet with a coarser dimension (Ø32 μm and the length 6mm).

Furthermore, it was noted that concrete with silica fume and high air content - also with PP-fibre - gave the concrete good self-compacting properties. Another comment, worth mentioning, is that the air content varied strongly when using PP-fibres together with super-plasticisers and air-entraining agents.

INNEHÅLLSFÖRTECKNING

1 Inledning

Betong används i stor omfattning vid såväl bostadsbyggande som vid anläggningar. Materialet betong utvecklas ständigt och under det senaste decenniet har självkompakterande betong blivit en betongprodukt som används i allt större utsträckning inom byggbranschen.

Självkompakterande betong är en betong, med högpresterande reologiska egenskaper, som kompakteras utan yttre vibreringsinsats. Från historiska erfarenheter och provningar vet man att betongkonstruktioner med tät betong och betong med stor andel finmaterial kan påverkas negativt vid brand. Självkompakterande betong, som ofta innehåller mycket finmaterial, är ett exempel på en tätare betong. I Sverige används ofta finmalt kalkfiller för att erhålla de önskade reologiska egenskaperna för självkompakterande betong. Den tätare strukturen som därigenom uppkommer genom tillsättning av finmaterial medför att man kan behöva finna alternativ och lösningar för att hantera en eventuell brandspjälkning. En sådan lösning är att tillsätta och blanda in polypropylenfiber (PP-fibrer) i betongmassan.

Inblandning av dessa PP-fibrer medför dock stora negativa konsistensförändringar som kan förstöra den självkompakterande betongens reologiska egenskaper. Utifrån egna erfarenheter i detta projekt kan problemen uppstå redan vid inblandning av 1.0 kg/m^3 PP-fiber. Detta ställer i slutändan högre krav på sammansättningen av betongen.

2 Syfte

Syftet med detta delprojekt (WP2) har varit att ta fram gjutbara betongrecept för självkompakterande betong och därefter tillverka betongelement, som senare utsätts för kontrollerad brand. Målet är att betongen skall fungera både tekniskt och ekonomiskt. Med betongens tekniska mål avses att konsistensen skall uppfylla kriterierna i avsnitt 4.4 Provtagning. Ekonomiskt sett skall betongen anses vara kommersiellt gångbar och då främst avseende cementhalten.

3 Metodik

Projektet omfattar totalt 52 betongrecept varav 27 är husbyggnadsbetonger (CEM II) och 25 är anläggningsbetonger (CEM I) där fem stycken recept innehåller norskt anläggningscement (CEM I). De flesta recepten utvecklades i betonglaboratorium innan de provades i full skala på betongfabriken. Samtliga recept, både på labb och i fabrik, har tagits fram genom samarbete mellan Skanska Sverige AB och Sika Sverige AB.

Provblandningarna på labb utfördes i Skanskas betonglaboratorium i Solna. Betongblandningarna tillverkades i en labblandare av typen ROJO 75 där satsstorleken varit minimum 25 liter för samtliga recept. Samtliga planerade recept för tillverkning av element tillverkades inte i labb. Några av dessa togs fram genom interpolering eller extrapolering utifrån närliggande betongsammansättningar.

Tillverkningen av element skedde på Skanska Stomsystems elementfabrik i Strängnäs utifrån de recept som utvecklats vid förundersökningen på Skanskas betonglabb.

Både vid tillverkning i labb och på fabrik visade sig några av de planerade recepten vara omöjliga att tillverka av praktiska skäl. Anledningen till detta var vanligtvis att de höga fiberhalterna gjorde att betongen inte blev självkompakterande. Vissa recept utgick också för att de krävde orimligt stora mängder cementpasta och därför inte ansågs vara kommersiellt gångbara.

I tabell 3-1 och tabell 3-2 på följande sida redovisas den planerade receptmatrisen för anläggningsbetong respektive husbyggnadsbetong. De fem recepten med norskt anläggningscement är i receptmatrisen angivna som recept nr 45-49. Avsikten med dessa recept har varit att prova silika och olika fiberhalter vid hög lufthalt. Vissa recept var inte möjliga att tillverkas enligt planen utan fick modifieras avseende fibermängd och fibertyp. De slutliga recepten med ingående mängder av respektive delmaterial redovisas i bilaga A.

Tabell 3-1 *Anläggningsrecept*

Recept Nr	w/p	Cement	Filler	Typ av fiber	Mängd fiber (kg/m3)	Fiber längd	Luftinnehåll
1	0,25	CEM I	Lime	Non	Non	Non	Std
2	0,25	CEM I	Lime	Ø=18 um	0,5	6mm	Std
3a	0,25	CEM I	Lime	Ø=18 um	1,5	6mm	Std
4	0,25	CEM I	Lime	Ø=32 um	1,0	6mm	Std
6	0,30	CEM I	Lime	Non	Non	Non	Std
7c	0,30	CEM I	Lime	Non	Non	Non	8%
7d	0,30	CEM I	Lime	Ø=32 um	1,0	6mm	8%
8	0,30	CEM I	Lime	Ø=18 um	0,5	6mm	Std
9	0,30	CEM I	Lime	Ø=18 um	1,5	6mm	Std
10	0,30	CEM I	Lime	Ø=32 um	1,0	6mm	Std
11	0,30	CEM I	Lime	Ø=32 um	3,0	6mm	Std
12	0,30	CEM I	Cement	Non	Non	Non	Std
13	0,30	CEM I	Lime	Ø=18 um	1,0	6mm	Std
14	0,30	CEM I	Lime	Ø=32 um	2,0	6mm	Std
16	0,30	CEM I	Lime	Ø=18 um	1,0	12mm	Std
17	0,35	CEM I	Lime	Non	Non	Non	Std
18	0,40	CEM I	Lime	Non	Non	Non	Std
19	0,40	CEM I	Lime	Ø=18 um	0,5	6mm	Std
21	0,40	CEM I	Lime	Ø=32 um	1,0	6mm	Std
22	0,40	CEM I	Lime	Ø=32 um	3,0	6mm	Std
45	0,41	CEM I	Silika	Non	Non	Non	MAX
46	0,41	CEM I	Silika	Ø=18 um	0,5	6mm	MAX
47	0,41	CEM I	Silika	Ø=18 um	1,0	6mm	MAX
48	0,41	CEM I	Silika	Ø=18 um	2,0	6mm	MAX
49	0,41	CEM I	Silika	Ø=18 um	Non	6mm	std

Tabell 3-2 *Husbyggnadsrecept*

Recept Nr	w/p	Cement	Filler	Typ av fiber	Mängd fiber (kg/m3)	Fiber längd	Luftinnehåll
23a	0,40	CEM II	Lime	Non	Non	Non	Std
23b	0,43	CEM II	Lime-40kg	Non	Non	Non	Std
23c	0,37	CEM II	Lime+40kg	Non	Non	Non	Std
23d	vpt0,31 vct 0,40	CEM II	Lime	Non	Non	Non	Std
24	0,40	CEM II	Cement	Non	Non	Non	Std
25	0,40	CEM II	Lime	Ø=18 um	1,0	6mm	Std
26	0,40	CEM II	Lime	Ø=32 um	2,0	6mm	Std
27	0,40	CEM II	Lime	Ø=18 um	0,5	6mm	Std
28	0,40	CEM II	Lime	Ø=18 um	1,5	6mm	Std
29	0,40	CEM II	Lime	Ø=32 um	1,0	6mm	Std
30	0,40	CEM II	Lime	Ø=32 um	3,0	6mm	Std
32	0,40	CEM II	Lime	Ø=32 um	2,0	12mm	Std
34	0,45	CEM II	Lime	Non	Non	Non	Std
35	0,45	CEM II	Lime	Ø=18 um	0,5	6mm	Std
36	0,45	CEM II	Lime	Ø=18 um	1,5	6mm	Std
37	0,45	CEM II	Lime	Ø=32 um	1,0	6mm	Std
38	0,45	CEM II	Lime	Ø=32 um	3,0	6mm	Std
39	0,50	CEM II	Lime	Non	Non	Non	Std
40	0,50	CEM II	Lime	Ø=18 um	0,5	6mm	Std
41a1	0,50	CEM II	Lime	Ø=18 um	1,0	6mm	Std
41a2	0,50	CEM II	Lime	Ø=18 um	1,0	6mm	Std
41c	0,50	CEM II	Lime	PP-filler	5,0kg PP-filler	-	Std
41f	0,50	CEM II	-	PP-filler	10,0kg PP-filler		Std
41g	0,50	CEM II	Lime	PP-filler	0,5kg PP-filler	-	Std
42	0,50	CEM II	Lime	Ø=32 um	1,0	6mm	Std
43	0,50	CEM II	Lime	Ø=32 um	3,0	6mm	Std
44	0,55	CEM II	Lime	Non	Non	Non	Std

4 Tillverkning av element i fabrik

Tillverkningen av element har utförts i Skanska Stomsystems elementfabrik i Strängnäs. För samtliga recept göts små plattor med måtten 500×600×200mm. För vissa av recepten göts även större plattor och balkar. De större plattorna har måtten 1700×1200×200mm och balkarna har måtten 3200×600×200mm. I tillverkningsjournalen framgår typ och antal element som gjutits för respektive recept, se bilaga B.

Figur 4-1 *Mindre betongelement 500×600×200mm*

Betongen som tillverkats i fabrik har blandats utifrån recepten som tagits fram i labb. I fabriken har 2 olika typer av planblandare använts. Detta för att det av praktiska skäl inte fanns möjlighet att tillverka alla betongtyper i en och samma blandare. Husbyggnadsbetongen tillverkades i en planblandare av typen SKAKO Apollo-3000 och anläggningsbetongen tillverkades i en planblandare av typen SKAKO SM 3000B. Minsta satsstorlek bestämdes till 1 m3 för att minska risken för att randeffekter från blandaren påverkar betongens egenskaper.

Tillverkning av samtliga element har skett enligt en förutbestämd tillverkningsprocedur för att resultaten vid brandprovningarna inte skall påverkas av olikheter i tillverkningsprocessen.

Tillverkningen av element omfattar följande steg.

- Formning
- Armering och montage av rör, lyftöglor samt temperatur- och tryckgivare
- Betongtillverkning
- Provtagning av färsk betong samt uttag av kuber för tryckhållfasthet och beständighetsanalys
- Gjutning, härdning och formrivning

4.1 Formar

Förtillverkade formar av plywood och träreglar användes för gjutningarna av element, se figurer 4-2 och 4-3. Formarna var utformade så att de lätt kunde återanvändas genom hela projektet. Formolja av typen T08 från BASF användes på samtliga formytor.

Figur 4-2 *Form för små plattor*

Figur 4-3 *Stor form för gjutning av stora element*

4.2 Armering, rör och givare

De små plattorna 500x600mm tillverkades oarmerade och innehåller rör för uppspänning vid själva brandprovningen. Plattorna med rörens placering framgår av bilaga C. Några små plattor tillverkades dock helt utan ingjutningsgods.

De större plattorna och balkarna är armerade enligt bilaga C. Även i dessa element göts rör in för uppspänning. Rörens placering framgår även de av bilaga C.

Betongklossar med likvärdig hållfasthet har använts som distanser för armeringen i elementen. Täckande betongskikt är 30 mm.

Temperatur- och/eller tryckgivare, som används för att registrera temperatur respektive tryck vid själva brandprovet, monterades i de flesta elementen, se figur 4-4.

Figur 4-4 *Närbild av temperaturgivare*

4.3 Betongtillverkning

De betongrecept som blandats på fabrik framgår av bilaga A. Recepten är ursprungligen framtagna i Skanskas betonglaboratorium i Solna.

4.3.1 Delmaterial

Vid tillverkning av element i Strängnäs har följande material använts:

- 0-8mm grus och 8-16mm sten, naturmaterial (ej kross)
- Byggcement Slite och Anläggningscement Degerhamn (Cementa)
- Norskt anläggningscement (NORCEM)
- Kalkfiller Limus 25 (Nordkalk)
- Silika (Elkem)
- Flyttillsatsmedel Sikament 20HE/50 (Sika)
- Stabiliserande medel, Sika Stabilizer 100 och 4R (Sika, i vissa fall)
- Luftporbildare Sika Aer-s 10% (Sika)
- PP-filler diameter 18 µm-40µm (Sika)
- PP-fiber: diameter 18 µm/ längd 6mm (Sika)
  diameter 18 µm/längd 12mm (Sika)
  diameter 32 µm/ längd 6mm (Sika)
  diameter 32 µm/längd 12mm (Sika)

Två olika diametrar respektive längder på fibrerna har testats, vilka även framgår av receptmatriserna i tabell 3-1 och 3-2. För tre olika husbyggnadsbetonger, som framgår av receptmatrisen, har vi testat att blanda i PP-filler istället för PP-fiber. Tanken med PP-filler var att få bättre reologi genom de runda kornen och samtidigt erhålla en god brandbeständighet. PP-fillern visade sig ge en god reologi men brandbeständigheten förbättrades inte nämnvärt.

Figur 4-5 *PP-filler och PP-fiber*

I receptmatrisen finns tre olika lufthaltsnivåer. Den vanligaste nivån är standard (std), vilket innebär att ingen luftporbildare är tillsatt till betongen. Standardlufthalten motsvarar en lufthalt på omkring 2%. Utöver standardalternativet finns 8% och MAX som lufthaltsnivåer där MAX motsvarar maximal inblandning av luft med den aktuella luftporbildaren. Det luftporbildande tillsatsmedlet är ett tillsatsmedel baserat på syntetiska tensider.

För att erhålla en stabil självkompakterande betong har vi i vissa fall använt oss av ett stabiliserande tillsatsmedel. Dessa recept framgår av bilaga.

4.3.2 Blandningsprocedur

Vid tillverkning i fabrik har vissa justeringar utförts av de i labb framtagna recepten. Den vanligaste åtgärden har varit att justera flytmängden. Detta med hänsyn till att blandning i en laboratorieblandare vanligtvis kräver en högre dosering av flyttillsatsmedel än vid tillverkning i fabrik. Vissa större justeringar av de ursprungliga recepten har gjorts i form av t.ex. minskad mängd fibrer eller justering av cement- eller kalkmängd. De verkliga uppvägda mängderna av varje delmaterial för varje blandning framgår av bilaga A.

Fukthalten i ballastmaterialen kontrollerades direkt före blandning av betong. Tillverkning av betong till dessa element skedde ej heller som dagens första blandning. Detta för att blandaren skulle bli insmord av tidigare tillverkad betong och inte ”stjäla” cementpasta från betongen. Blandad volym för respektive recept framgår av tillverkningsjournalen, se bilaga B.
I projektet eftersträvades så lika betongvolym som möjligt för de olika recepten.

Husbyggnadsrecepten blandades enligt nedanstående blandningssekvens.

Blandningssekvens för husbyggnadsbetongen (med och utan PP-fiber) utfördes enligt nedan. Total blandningstid efter att samtliga delmaterial tillsats är 30 sekunder.

1. Cement + filler + Ballast + i förekommande fall PP-fiber (2 sek)
2. Vatten (2 sek efter alla torrmaterial)
3. Tillsatsmedel (11 sek efter torrmaterialen, tillsammans med vatten)

Anläggningsrecepten blandades enligt en egen blandningssekvens pga att fabrikens silokapacitet inte räckte till. Detta innebar i praktiken att storsäckar med anläggningscement (CEM I) fick lyftas in manuellt. Det medförde att fibern blandades med cementet innan dosering av övriga material skedde.

Blandningssekvens för anläggningsbetongen utfördes enligt nedan. Total blandningstid efter att samtliga delmaterial tillsats är 120 sekunder.

1. Cement + filler + i förekommande fall fiber
2. Vatten (4 sek efter alla torrmaterial)
3. Tillsatsmedel (11 sek efter torrmaterialen, tillsammans med vatten)

Innan klartecken gavs, för leverans till gjutstället, gjordes en bedömning av konsistensen utifrån wattmätaren. Innan leverans gjordes även en okulär besiktning av betongen vid blandaren.

Vid upprepning av ett och samma recept kan wattmätaren användas som styrmedel för spädning av betongen till rätt konsistens. I detta projekt där vi i stort sett bara blandat ett och samma recept en gång har vi inte kunnat nyttja wattmätaren till mer än som en indikation på om betongen var självkompakterande eller ej. I vissa fall, då betongen t ex innehöll mycket finmaterial, gav wattmätaren ingen extra information.

Efter blandning tömdes betongen i en betongbask för transport till gjutstället. En okulärbesiktning utfördes av betongen i basken, före transport till gjutstället, för att se att betongen var homogen och såg ut att vara självkompakterande.

4.4 Provtagning

Före gjutning utfördes ett antal prover på den färska betongen. Följande kontroller utfördes vid gjutstället för samtliga recept för att slutligen godkänna betongen.

- Flytsättmått (målvärde 650±100 mm)
- T50 (målvärde 2-6 sek)
- Lufthalt

Lägre flytsättmått än ovanstående målvärden accepterades i de fall då betongen ändå ansågs vara självkompakterande. Högre flytsättmått accepterades också om betongen ansågs vara tillräckligt stabil och inte separerade. På samma sätt accepterades lägre och högre värden på måttet T50.

Den hårdnade betongen kontrolleras med avseende på tryckhållfasthet och beständighet där 16st kuber togs ut för varje recept. Tryckhållfastheten (28 dygn) provades på Skanskas betonglaboratorium i Solna. Betongens beständighet provades av CBI och behandlas vidare i delprojekt WP4.

Provningsresultat samt bedömningar/kommentarer för utförda blandningar framgår av tillverkningsjournalen, bilaga B.

4.5 Gjutning, härdning och formrivning

Gjutning av elementen skedde med hjälp av bask. När formarna var fyllda avjämnades betongens överyta för hand.

Figur 4-6 *Gjutning av element*

Fukthärdning av betongen har skett enligt normalt förfarande vid tillverkning av element på fabrik. Betongytan täcktes, så snart ytan var avjämnad, med plastfolie för att förhindra tidig uttorkning. Avformning skedde tidigast 1 dygn efter gjutning. Efter avformning har elementen lagrats i ca 3 dygn täckta med plast. Därefter flyttades elementen till dess upplagsplats på fabriksområdet. Elementen förvarades utomhus under tak eller presenning fram till transport med lastbil till SP i Borås.

5 Diskussion och erfarenheter

I detta avsnitt diskuteras erfarenheter från receptframtagning och tillverkningen av element på fabrik.

5.1 Receptframtagning

Målsättningen har varit att i möjligaste mån ta fram recept för självkompakterande betong som är:

- möjlig att tillverka även med relativt stor mängd PP-fiber utan att arbetbarheten förstörs.
- stabil och möjlig att tillverka med god repeterbarhet.
- ekonomisk med avseende på framför allt cementhalter.

Problemet som uppstår när PP-fiber används i betongmassa och kanske framför allt i självkompakterande betong är att de reologiska egenskaperna förändras mot en styvare massa. Detta kan bero på den höga specifika ytan som fibern har och/eller volymen som den upptar. T ex så har fibern med Ø18µm (6mm längd) en specifik yta på ca 240 m^2/kg fiber. Detta kan till viss del åtgärdas med extra flytmedel men vid en viss punkt börjar betongen att separera utan att extra rörlighet erhålls. När detta sker är man ofta tvungen att tillsätta mer pasta, antingen i form av cement eller i form av filler (i det här fallet kalkfiller). Höga cementhalter (>430 kg/m^3) är inte alltid önskvärt då det i t.ex. anläggningskonstruktioner kan innebära hög temperaturutveckling som i sin tur kan resultera i oönskad sprickbildning. Dessutom innebär en ökad cementhalt att kostnaden för betongen ökar. Vid för hög fillermängd blir betongen för viskös och dess rörlighet blir lidande. I detta projekt insågs relativt snart att taket för mängden fiber i bästa fall låg omkring 1,5 kg/m^3 för fibern med Ø18µm och 6mm längd. Vid högre fiberhalter krävdes oftast orimligt höga pastamängder för att komma i närheten av den självkompakterande betongens reologiska egenskaper. En fiberhalt omkring 1,5-2 kg/m^3 är troligtvis ett realistiskt riktvärde för vad man max kan blanda i betongen men skall för den del inte ses som ett generellt tak. Med andra ballastmaterial och/eller annan fiberdimension, än vad som använts i detta projekt, kan taket ligga på en annan nivå.

I vissa fall kan en kemisk stabilisator vara till hjälp för att erhålla extra stabilitet, t ex mot pastaseparation.

För den norska anläggningsbetongen var förhållandet något bättre. Betongen innehöll silika och i de flesta fall en förhöjd lufthalt. Det gav betongen bra stabilitet och god arbetbarhet, även med höga halter PP-fiber. Silika och hög lufthalt sågs i projektet ha en positiv inverkan på betongens färska egenskaper.

5.2 Tillverkning och gjutning

Tillverkningen av de totalt 52 olika recepten utfördes i de flesta fall under ordinarie arbetstid vilket innebar ett väldigt pressat tidsschema. Det stora antalet recept tillsammans med tidspressen gjorde att det inte fanns möjlighet till att optimera eller förbättra recepten fullt ut som man normalt gör på en betongfabrik. Lassen kasserades i de fall då betongen inte ansågs vara tillräckligt stabil eller på annat sätt inte ansågs uppfylla krav på SKB. De grundläggande kraven för gjutning var:

- rätt delmaterial, rätt vct
- självkompakterande reologiska egenskaper, utfyllnad i form
- stabilitet

I bilaga B, ”Tillverkningsjournalen”, är alla gjutningar presenterade, inklusive de misslyckade. Detta för att spegla svårigheterna som kan uppstå i vissa fall.

I detta projekt förlängdes blandningstiden för att säkerställa att PP-fibern dispergerades i betongmassan. Detta gällde speciellt för den svenska anläggningsbetongen med höga kalkfillerhalter.

Ett problem som kan uppstå när PP-fiber används är att lufthalten kan variera, ibland kraftigt. Detta blir speciellt påfallande när PP-fiber, flyttillsatsmedel och luftporbildare används tillsammans. Som följd av detta blir även repeterbarheten av ett recept lidande. Av denna anledning är det viktigt med en kontrollplan som innefattar en noggrann kontroll och dokumentation av lufthalten. I betongproduktion används normalt lufthaltsmätare för att mäta mängden luft i betongen. Vanligtvis räcker det med att t ex noga dokumentera luft före- och efter PP-fiber. I vissa fall, som vid kraftiga variationer i lufthalt, bör dock denna mätning kompletteras med en planslipsanalys alternativt en AVA-mätning (Air Void Analyzer). De båda sista typerna av mätning ger inte bara mängden luft, utan även på struktur, specifik yta, avstånd mellan luftporerna osv. De ger ofta ett mer fullständigt svar på om typen av luft i en betong är gynnsam eller ej för betongens beständighet.

Utifrån ovanstående diskussioner och erfarenheter kan följande riktlinjer dras för tillverkning av självkompakterande betong med polypropylenfiber och framför allt kalkfiller:

Självkompakterande anläggningsbetong (vct=0,40) med polypropylenfiber bör ha ett vattenpulvertal (vpt) kring 0,30. Ofta vill man begränsa cementhalten till omkring 430 kg. Vid denna cementhalt fås att kalkfillerhalten max bör vara 130-140kg för att erhålla ett vpt kring 0,3. Ett högre vpt, genom mindre kalkfiller, visade sig ge en mer separationsbenägen betong och ett lägre vpt gav en för seg betong.

Vid framtagning av en självkompakterande anläggningsbetong med luft bör ett recept med stabil lufthalt och utan fiber tas fram först. Därefter tas en betong med fiber fram. Detta för att vara säker på grundnivån för luften i betongen och för att luften annars kan variera kraftigt.

Maximal fiberhalt för fiber med ∅18μm och 6mm längd bör om möjligt hållas kring 1,5 kg/m^3. Vid längre fiber med samma diameter visade sig blockeringen bli mer påfallande. För en fiber med ∅32mm och längden 12 resp. 6mm kan omkring 2-2,5kg fiber användas. Ovanstående resultat gällande fibermängd gäller såväl anläggnings- som husbyggnadsbetong.

Självkompakterande husbyggnadsbetong bör ha ett vpt som inte överstiger 0,50 förutsatt att kalkfiller används för att ge robusthet till betongen. Ett högre vpt gör betongen för känslig för separation.

6 Slutsatser

Vid receptframtagning samt tillverkning av element har vi, i detta projekt, dragit följande slutsatser.

- Inblandning av 2 kg/m^3 av typen ∅18 µm/6mm längd var inte möjlig utan att de självkompakterande egenskaperna förlorades. Gränsen nåddes vid 1,5 kg fiber per kubik för såväl anläggningsbetongen som husbyggnadsbetongen vid användning av denna fibertyp.

- Inblandning av drygt 2 kg/m^3 av typen ∅32 µm/6mm längd var möjlig, för såväl anläggningsbetongen som husbyggnadsbetongen, utan att de självkompakterande egenskaperna förlorades. Den troliga orsaken till detta är att den har lägre specifik yta än den tidigare nämnda fibern ∅18 µm/6mm. Högre doseringar av denna fiber innebar att betongens reologiska egenskaper blev otillräckliga eller att lufthalten ökade markant.

- All PP-fiber bör torrblandas med ballasten innan övriga delmaterial kommer in. Detta bör göras för att fördela fibern i ett tidigt skede och därmed bädda för en god dispergering av fibern i den färdiga betongmassan.

- Självkompakterande anläggningsbetong med polypropylenfiber visade sig få bäst reologiska egenskaper med ett vattenpulvertal (vpt) kring 0,30. Då man ofta vill begränsa cementhalten till omkring 430 kg fås att kalkfillerhalten bör vara max 130-140kg.

- Självkompakterande husbyggnadsbetong bör ha ett vpt som inte överstiger 0,50 förutsatt att kalkfiller används för att ge robusthet till betongen. Ett högre vpt gör betongen för känslig för separation.

- Silika och hög lufthalt ger den självkompakterande betongen även med PP-fiber goda reologiska egenskaper.

- Lufthalten kan variera kraftigt då PP-fiber används tillsammans med flyttillsatsmedel och luftporbildare. Speciellt tydligt är detta vid högre doseringar av polypropylenfiber.

Ovanstående slutsatser baseras på betongrecept innehållande delmaterial som används vid elementfabriken i Strängnäs. Med t.ex. ett annat ballastmaterial kan eventuellt resultaten avvika något från resultaten i detta projekt. Slutsatserna skall därför ses som riktvärden inför egna provblandningar.

Bilagor

A ***Recept från receptutvecklingen i labb samt tillverkningen i Strängnäs***

B ***Tillverkningsjournal***

C ***Ritningar på de olika typerna av element***

A Recept från receptutvecklingen i labb samt tillverkningen i Strängnäs

Anläggningsrecept

Recept /m³	1	2	3a	4	6	7c	7d
Vatten (kg)	168	168	168	168	168	168	168
CEM I 42,5N BV/LA/SR (kg)	420	420	420	420	420	420	420
Limus 25 (kg)	252	252	252	252	140	140	140
w/p	0,25	0,25	0,25	0,25	0,30	0,30	0,30
w/c	0,40	0,40	0,40	0,40	0,40	0,40	0,40
Sikament 20HE 50 (20% torrhalt), kg	7,0	7,0	12,0	10,0	6,3	7,0	7,0
% av cementvikten	1,67%	1,67%	2,86%	2,38%	1,50%	1,67%	1,67%
Sika Stabilizer 100	-	-	-	-	-	-	-
Sika Aer-S(10%-ig), kg	-	-	-	-	-	4,0	3,5
% av cementvikten	-	-	-	-	-	0,95%	0,84%
Sika Crackstop (ϕ18µm, 6mm), kg	-	0,50	1,50	-	-	-	-
Sika Crackstop (ϕ32µm, 12mm), kg	-	-	-	-	-	-	-
Sika Crackstop (ϕ32µm, 6mm), kg	-	-	-	1,00	-	-	1,00
Sika IgniFill, kg	-	-	-	-	-	-	-
(0 - 8mm Grus)	56%	56%	56%	56%	56%	56%	56%
(8 - 16mm Delkross)	44%	44%	44%	44%	44%	44%	44%

Recept /m³	8	9	10	11	12	13	14
Vatten (kg)	168	172	170	170	168	168	168
CEM I 42,5N BV/LA/SR (kg)	420	435	430	430	560	420	420
Limus 25 (kg)	140	145	143	143	0	140	140
w/p	0,30	0,30	0,30	0,30	0,30	0,30	0,30
w/c	0,40	0,40	0,40	0,40	0,30	0,40	0,40
Sikament 20HE 50 (20% torrhalt), kg	5,4	8,0	7,0	9,5	5,3	8,00	8,00
% av cementvikten	1,29%	1,84%	1,63%	2,21%	0,94%	1,90%	1,90%
Sika Stabilizer 100	-	-	-	-	-	-	-
Sika Aer-S(10%-ig), kg	-	2,8	-	-	-	-	-
% av cementvikten	-	-	-	-	-	-	-
Sika Crackstop (ϕ18µm, 6mm), kg	0,50	1,50	-	-	-	1,00	-
Sika Crackstop (ϕ32µm, 12mm), kg	-	-	-	-	-	-	-
Sika Crackstop (ϕ32µm, 6mm), kg	-	-	1,00	2,00		-	1,50
Sika IgniFill, kg	-	-	-	-	-	-	-
(0 - 8mm Grus)	56%	56%	56%	56%	56%	56%	56%
(8 - 16mm Delkross)	44%	44%	44%	44%	44%	44%	44%

Anläggningsrecept

Recept /m³	16	17	18	19	21	22
Vatten (kg)	168	168	168	168	220	220
CEM I 42,5N BV/LA/SR (kg)	420	420	420	420	550	550
Limus 25 (kg)	140	60	0	0	0	0
w/p	0,30	0,35	0,40	0,40	0,40	0,40
w/c	0,40	0,40	0,40	0,40	0,40	0,40
Sikament 20HE 50 (20% torrhalt), kg	9,00	5,00	6,00	6,50	5,00	8,00
% av cementvikten	2,14%	1,19%	1,43%	1,55%	0,91%	1,45%
Sika Stabilizer 4R, kg	-	-	1,00	-	-	-
% av cementvikten	-	-	0,24%	-	-	-
Sika Aer-S(10%-ig), kg	-	-	-	-	-	-
% av cementvikten	-	-	-	-	-	-
Sika Crackstop (ϕ18µm, 6mm), kg	-	-	-	0,50	-	-
Sika Crackstop (ϕ18µm, 12mm), kg	1,00	-	-	-	-	-
Sika Crackstop (ϕ32µm, 12mm), kg	-	-	-	-	-	-
Sika Crackstop (ϕ32µm, 6mm), kg	-	-	-	-	1,35	3,00
Sika IgniFill	-	-	-	-	-	-
(0 - 8mm Grus)	56%	56%	63%	63%	63%	63%
(8 - 16mm Delkross)	44%	44%	37%	37%	37%	37%

Norska anläggningsrecept

Recept nr	45 (no1)	46 (no4)	47 (no2)	48 (no3)	49 (no5)
Vatten (kg)	183	183	183	183	184
Norskt ANL (kg)	410	410	410	410	411
Silika (kg)	32	32	32	32	33
w/p	0,41	0,41	0,41	0,41	0,41
w/c	0,45	0,45	0,45	0,45	0,45
Sikament 20HE 50 (20% torrhalt), kg	6,0	7,0	7,0	11,5	6,0
% av cementvikten	1,46%	1,71%	1,71%	2,80%	1,46%
Sika Aer-s, kg	2,5	2,1	1,6	0,8	0,0
% av cementvikten	0,60%	0,50%	0,40%	0,20%	0,00%
Sika Crackstop (18µm, 6mm), kg	0,0	0,5	1,0	2,0	0,0
(0 - 8mm Grus)	58%	58%	58%	58%	58%
(8 - 16mm Delkross)	42%	42%	42%	42%	42%

Husbyggnadsrecept

Recept /m³	**23a**	**23b**	**23c**	**23d**	**24**	**25**
Vatten (kg)	198	198	198	180	198	212
CEM II 42,5R A-LL "Byggcement" (kg)	380	380	380	450	500	410
Limus 25 (kg)	120	80	160	50	0	122
w/p	0,40	0,43	0,37	0,36	0,40	0,40
w/c	0,52	0,52	0,52	0,40	0,40	0,52
Sikament 20HE 50 (20% torrhalt), kg	5,5	5,5	5,8	6,7	4,0	6,2
% av cementvikten	1,45%	1,45%	1,53%	1,49%	0,80%	1,50%
Sika Stabilizer 100, kg	-	-	-	-	-	-
Sika Crackstop (ϕ18µm, 6mm), kg	-	-	-	-	-	1,00
Sika Crackstop (ϕ32µm, 12mm), kg	-	-	-	-	-	-
Sika Crackstop (ϕ32µm, 6mm), kg	-	-	-	-	-	-
Sika IgniFill	-	-	-	-	-	-
(0 - 8mm Grus)	63%	63%	63%	56%	63%	56%
(8 - 16mm Delkross)	37%	37%	37%	44%	37%	44%

Recept /m³	**26**	**27**	**28**	**29**	**30**	**32**
Vatten (kg)	222	201	222	222	224	224
CEM II 42,5R A-LL "Byggcement" (kg)	430	390	430	430	430	430
Limus 25 (kg)	124	110	124	124	124	124
w/p	0,40	0,40	0,40	0,40	0,40	0,40
w/c	0,52	0,52	0,52	0,52	0,52	0,52
Sikament 20HE 50 (20% torrhalt), kg	5,9	5,4	5,2	5,3	6,0	4,9
% av cementvikten	1,36%	1,38%	1,21%	1,23%	1,40%	1,14%
Sika Stabilizer 100, kg	-	-	-	-	-	
Sika Crackstop (ϕ18µm, 6mm), kg	-	0,50	1,50	-	-	-
Sika Crackstop (ϕ32µm, 12mm), kg	1,5 (ändr från 2	-	-	1,00	-	-
Sika Crackstop (ϕ32µm, 6mm), kg	-	-	-	-	1,00	2,00
Sika IgniFill	-	-	-	-	-	-
(0 - 8mm Grus)	56%	56%	56%	56%	56%	56%
(8 - 16mm Delkross)	44%	44%	44%	44%	44%	44%

Husbyggnadsrecept

Recept /m³	**34**	**35**	**36**	**37**	**38**	**39**
Vatten (kg)	198	198	198	198	198	230
CEM II 42,5R A-LL "Byggcement" (kg)	380	380	380	380	380	355
Limus 25 (kg)	60	60	60	60	60	105
w/p	0,45	0,45	0,45	0,45	0,45	0,50
w/c	0,52	0,52	0,52	0,52	0,52	0,65
Sikament 20HE 50 (20% torrhalt), kg	5,6	5,7	6,6	5,7	6,0	4,50
% av cementvikten	1,47%	1,50%	1,74%	1,50%	1,58%	1,27%
Sika Stabilizer 100, kg						4,00
Sika Crackstop (ϕ18µm, 6mm), kg	-	0,50	1,50	-	-	-
Sika Crackstop (ϕ32µm, 12mm), kg	-	-	-	-	-	-
Sika Crackstop (ϕ32µm, 6mm), kg	-	-	-	1,00	1,5	-
Sika IgniFill, kg	-	-	-	-	-	-
(0 - 8mm Grus)	63%	63%	63%	63%	63%	65%
(8 - 16mm Delkross)	37%	37%	37%	37%	37%	35%

Recept /m³	**40**	**41a1**	**41a2**	**41c**	**41f**	**41g**
Vatten (kg)	236	230	236	230	230	230
CEM II 42,5R A-LL "Byggcement" (kg)	365	355	365	355	355	355
Limus 25 (kg)	109	105	109	105	96	105
w/p	0,50	0,50	0,50	0,50	0,51	0,50
w/c	0,65	0,65	0,65	0,65	0,65	0,65
Sikament 20HE 50 (20% torrhalt), kg	4,93	5,10	Glenium	3,90	4,14	3,80
% av cementvikten	1,35%	1,44%	2,45kg	1,10%	1,17%	1,07%
Sika Stabilizer 100, kg				-	-	-
Sika Crackstop (ϕ18µm, 6mm), kg	0,50	1,00	1,00	-	-	-
Sika Crackstop (ϕ32µm, 12mm), kg	-	-	-	-	-	-
Sika Crackstop (ϕ32µm, 6mm), kg	-	-	-	-	-	-
Sika IgniFill, kg	-	-	-	5,00	10,00	0,50
(0 - 8mm Grus)	65%	65%	65%	65%	65%	65%
(8 - 16mm Delkross)	35%	35%	35%	35%	35%	35%

Husbyggnadsrecept

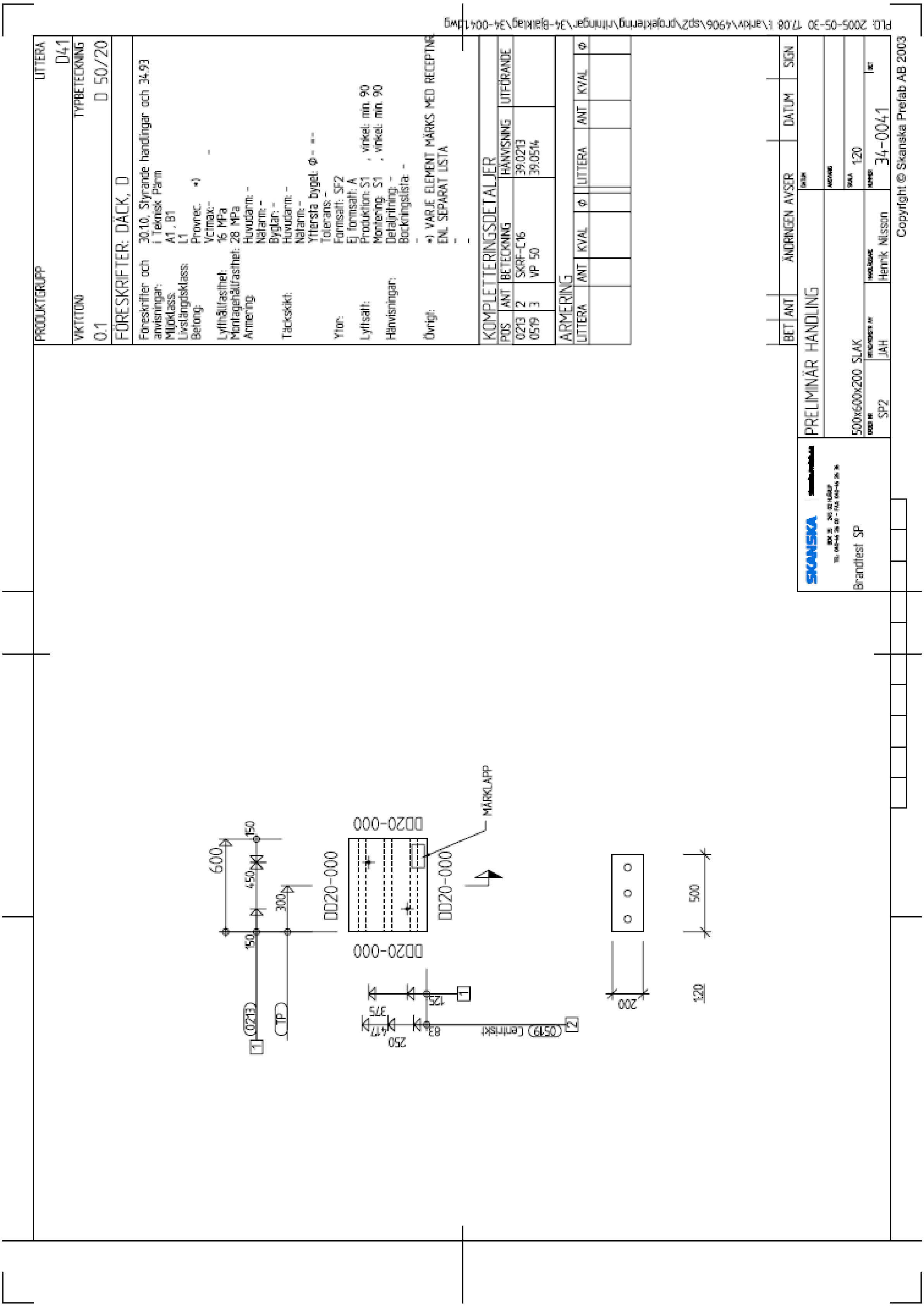
Recept /m³	**42**	**43**	**44**
Vatten (kg)	236	236	212
CEM II 42,5R A-LL "Byggcement" (kg)	365	365	300
Limus 25 (kg)	109	109	87
w/p	0,50	0,50	0,55
w/c	0,65	0,65	0,71
Sikament 20HE 50 (20% torrhalt), kg	5,20	5,2	4,1
% av cementvikten	1,42%	1,42%	1,37%
Sika Stabilizer 100, kg	-	-	-
Sika Crackstop (ϕ18µm, 6mm), kg	-	-	-
Sika Crackstop (ϕ32µm, 12mm), kg	1,0	-	-
Sika Crackstop (ϕ32µm, 6mm), kg	-	2,00	-
Sika IgniFill, kg	-	-	-
(0 - 8mm Grus)	65%	63%	63%
(8 - 16mm Delkross)	35%	37%	37%

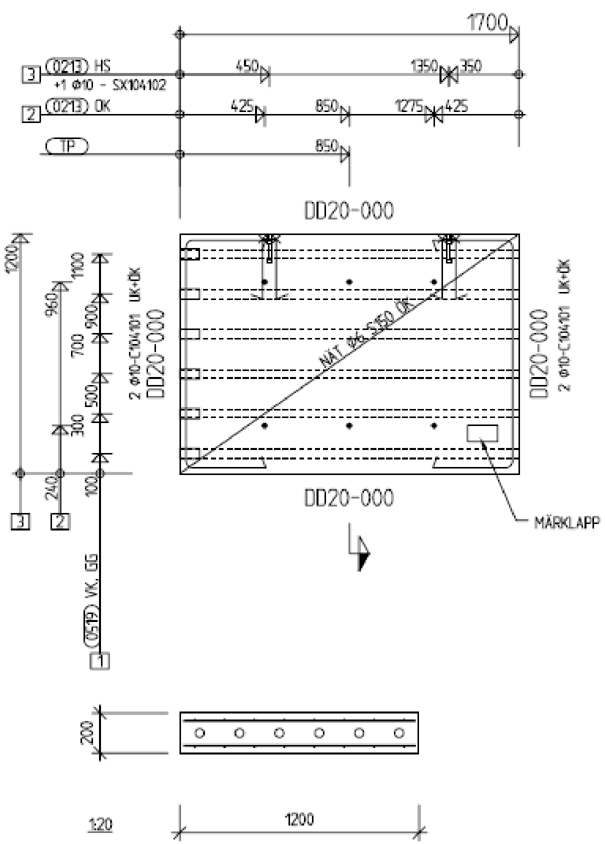
B Tillverkningsjournal

Datum	Receptnr	Vol (m3)	Fibermängd	Flytsättmått (r	Lufthalt (	T50 (sek)	Märkn	Anm	Element	28d - 1	28d - 2	28d - 3
2005-05-31	23b		0kg	560	3,1	3-4	-	Kastades, för trög, ökar på flyttillsats				
2005-05-31	23b - lass2	1,0	0kg	690	1,7	2-3	1-n	Ngt blöt, men ingen separation	Små 1/1 - 1/10 & kuber	52,0	51,7	52,4
2005-06-01	23c	1,0	0kg	690	2,4	1-2	2-n	OK	Små 2/1 - 2/10 & kuber	50,4	50,7	48,9
2005-06-01	24	1,0	0kg	605	2,1	1	3-n	Mycket snabb btg trots lågt FSM	Små 3/1 - 3/10 & kuber	50,9	52,3	51,0
2005-06-02	27		0,5kg 18um 6mm	350-400	-	-	-	Misslyckat! Slängs. För lite vatten och flyttillsats				
2005-06-02	27	1,0	0,5kg 18um 6mm	630	1,7	2-3	4-n	OK, bra, snabb, kanske ngt trög	Små 4/1 - 4/10 & kuber	45,5	45,0	45,1
2005-06-02	29		1,0kg 32um, 12mm	600		1-2		Slängdes, ej tillr. Bra. Ökar pastamängden				
2005-06-07	29	1,0	1,0kg 32um, 12mm	670	1,7	1-2	5-n	Bra btg	Små 5/1 - 5/10 & kuber	47,6	46,0	48,3
2005-06-07	41c	1,0	5kg PP-filler	610	1,2	1	6-n	Bra, snabb.	Små 6/1 - 6/10 & kuber	35,4	35,3	35,0
2005-06-08	25 - lass 1		1,0kg 18um 6mm	640	2,1	2-3	7-n	Bra skb, stabil	Små 7/1 - 7/10 & kuber	43,3	44,3	44,3
2005-06-08	25 - lass 2		1,0kg 18um 6mm	655	1,6	2-3	7-n	Fin skb	Små 7/11 - 7/20 + 4 pottor	-	-	-
2005-06-09	25 - lass 3		1,0kg 18um 6mm	650	1,7	2-3	7-n	Fin skb	stora 2 st	-	-	-
2005-06-09	25 - lass 4		1,0kg 18um 6mm	655	1,4	2-3	7-n	Fin skb	stora 2 st	-	-	-
2005-06-14	26 - lass 1		2kg 32um, 12mm	550				Misslyckat! Sänker fiberhalten				
2005-06-14	26 - lass 2		1,5kg 32um, 12mm	630	1,5	3	8-n	OK	Små 8/1 - 8/10 & kuber	46,3	44,7	44,2
2005-06-14	26 - lass 3		1,5kg 32um, 12mm	625	1,6	3	8-n		Små 8/11 - 8/20	-	-	-
2005-06-14	26 - lass 4		1,5kg 32um, 12mm	640	1,5	2	8-n		4 stora	-	-	-
2005-06-15	41f	1,0	10 kg PP-filler	650	1,7	>1	9-n	OK. Smidig, snabb	Små 9/1 - 9/10 & kuber	33,4	33,8	34,1
2005-06-28	39 - lass 1	1,0	0kg	650	2,1	<1	10-n	Bra, snabb, lättarbetad (24,5 C)	Små 10/1 - 10/10 & kuber	36,2	36,9	36,6
2005-06-28	39 - lass 2	1,0	0kg	630	1,8	<1	10-n	Bra, snabb, lättarbetad (24,5 C)	Små 10/11 - 10/20 & små 10/28 - 10/30	-	-	-
2005-06-28	39 - lass 3	1,0	0kg	630	1,8	<1	10-n	Bra, snabb, lättarbetad (24 C)	Små 10/21 - 10/27 & Stor 10/1	-	-	-
2005-06-28	39 - lass 4	1,0	0kg	610	1,7	<1	10-n	Bra, snabb, lättarbetad (23,5 C)	Stora 10/2 - 10/3	-	-	-
2005-06-29	39 - lass 5&6	1,0 + 1,2	0kg	600	1,7	<1	10-n	Bra, snabb, lättarbetad (23 C)	Stora 10/4 - 10/8	-	-	-
2005-07-01	39 - lass 7&8	1,0 + 1,0	0kg	610	1,8	<1	10-n	Bra, snabb, lättarbetad (23 C)	Balkar 10/1 - 10/4	-	-	-
2005-08-24--25	40	1,0	0,5kg 18um 6mm	430-570	-	<1	-	Samma recept som 39 men med fiber. 3 lass kasserades, misstänkt förhöjd fillerhalt i 0-8				
2005-08-25	40	1,0	0,5kg 18um 6mm	650	1,9	2 sek	11-n	OK.	Små 11/1 - 11/10 & 16 kuber	40,6	41,2	39,0
2005-09-01	44	1,0	0kg	400	-	-	-	För stabil.				
2005-09-01	44	1,0	0kg	680	2,3	1-2	12-n	Ngt blaskig, men annars helt ok	Små 12/1 - 12/10 & 16 kuber	34,7	34,4	34,4
2005-09-20	41g (nytt recept)	1,0	0,5 kg PP-filler	670	1,9	1-2	13-n	OK btg	Små 13/1 - 13/10 & 16 kuber	37,9	36,9	37,1
2005-09-29	42	1,0	1,0kg 32um, 12mm	760	-	-	-	Separation, drar ner flyttillsats				
2005-10-04	42	1,0	1,0kg 32um, 12mm	670	1,7	1-2	14-n	Liten tendens till sep, men ändå ok	Små 14/1 - 14/10 & 16 kuber	34,8	35,6	35,1
2005-10-13	23d	1,0	0kg	650	2,7	3-4	15-n	Ngt seg, men ok.	Små 15/1 - 15/10 & 16 kuber	54,9	55,2	52,5
2005-10-18	34	1,0	0kg	550	-	-	-	För trög, görs om men med mer flyt				
2005-10-18	34	1,0	0kg	710	1,8	2-3	16-n		Små 16/1 - 16/10 & 16 kuber	42,9	43,7	42,2
2005-10-18	35	1,0	0,5kg 18um 6mm	690	2,8	2-3	17-n		Små 17/1 - 17/10 & 16 kuber	39,6	39,4	38,5
2005-11-08	41a1	1,0	1,0kg 18um 6mm	700	1,6	2	18-n	Blöt på gränsen till sep men höll ihop	Små 18/1 - 18/10 & 16 kuber	32,1	32,2	32,5
2005-12-08	41a2	1,0	1,0kg 18um 6mm	610	1,6	1-2	19-n	Ok btg	Små 19/1 - 19/10 & 16 kuber	32,8	34,6	33,8
2006-03-04	37	1,0	1,0kg 32um, 6mm	650	2,0	2-3	25-n	bra btg	Små 25/1 - 25/10 & 16 kuber	45,0	43,3	43,5
2006-03-30--04-07	28	1,0	1,5kg 18um 6mm	600	2,0	4-5	26-n		Små 26/1 - 26/10 & 16 kuber	40,8	41,4	26,6
2006-03-30--04-07	38	1,0	1,5kg 32um 6mm	620	2,6	3-4	27-n		Små 27/1 - 27/10 & 16 kuber	43,3	44,8	44,3
2006-06-17	8	1,0	0,5kg 18um 6mm	665	2,9	6	28-n	helt ok	Små 28/1 - 28/10 & 16 kuber	64,1	65,4	65,2
2006-06-17	9	1,0	1,5kg 18um 6mm				29-n	inte bra, känns trög! Ökar pastamängden				
2006-06-17	12	1,0	0kg	710	2,8	6	30-n	ok	Små 30/1 - 30/10 & 16 kuber	83,3	77,6	85,3
2006-06-26	17	1,0	0kg	700	2,7	7-8	31-n	ok	Små 31/1 - 31/10 & 16 kuber	69,4	71,1	64,7
2006-06-29	10	1,0	1,0kg 32um, 6mm	700	3,0	7	32-n	ok	Små 32/1 - 32/4 (2 instr) & 16 kuber	72,9	68,1	72,8
2006-06-29	11	1,0	2,0kg 32um, 6mm	600	3,3	6-7	33-n	ok	Små 33/1 - 33/4 (2 instr) & 16 kuber	68,6	69,3	67,2
2006-09-02	1	1,0	0kg	735	1,6	5	34-n	ok	Små 34/1 - 34/4 (2 instr) & 16 kuber	59,5	60,1	59,2
2006-09-02	2	1,0	0,5kg 18um 6mm	680	2,3	6	35-n	ok	Små 35/1 - 35/4 (2 instr) & 16 kuber	67,3	66,1	69,4
2006-09-02	13	1,0	1,0kg 18um, 6mm	630	3,5	6	38-n	ok, men ngt seg	Små 38/1 - 38/10 & 16 kuber	52,0	58,1	55,7
2006-09-02	13	2,0	1,0kg 18um, 6mm	620	3,5	6	38-n	ok, men stelnade snabbt	4 stora plattor 38/1-38/4	-	-	-

Datum	Receptnr	Vol (m3)	Fibermängd	Flytsättmått (r	Lufthalt (	T50 (sek)	Märkn	Anm	Element	28d - 1	28d - 2	28d - 3
2006-11-23	6	1,0	0kg	750	2,3	4	39-n	ok, men segade till sig fort	2 plattor 39/1-39/2+16 kuber	69,4	66,9	65,1
2006-11-23	6	1,0	0kg	730	2,4	4	39-n	ok, men segade till sig fort	2 plattor 39/3-39/4	-	-	-
2006-11-23	6	1,0	0kg	720	2,8	5	39-n	ok, men segade till sig fort	10 små 39/1-39/10. 4 blanka/4 temp	-	-	-
2006-11-23	6	1,0	0kg	770	2,4	4	39-n	ok, men segade till sig fort	10 små 39/11-39/20. 4 blanka/4temp+tryckav.	-	-	-
2006-11-23	3a	1,0	1,5kg 18um 6mm	630	3,2	6	40-n	ok, men något för mkt flyt, liten sep	4 små(2 temp) 40/1-40/4 + 16 kuber 40/1-40/16	71,4	70,4	67,1
2006-11-23	4	1,0	1,0kg 32um 6mm	660	1,8	7	41-n	helt ok bra energi, men seg	4 små(2 temp) 41/1-41/4 + 16 kuber 41/1-41/16	79,0	78,9	74,0
2006-11-29	6 forts	1,0	0kg	740	3,2	5	39-n	ok	2 stora plattor 39/5-39/6+ extra 12 kuber	75,4	75,0	77,5
2006-11-29	6 forts	1,0	0kg	740	3,1	5	39-n	ok	2 plattor 39/7-39/8	-	-	-
2006-11-29	6 forts	1,0	0kg	710	3,1	5	39-n	ok	10 små 39/21-39/30. alla instr	-	-	-
2006-11-29	6 forts	1,0	0kg	700	2,5	5	39-n	ok	10 små 39/31-39/40. alla instr	-	-	-
2006-11-29	9	1,0	1,5kg 18um 6mm	600	3,7	6	42-n	ok, men ngt seg	4 små(2 temp) 42/1-42/4 + 16 kuber 42/1-42/16	66,9	68,3	65,8
2006-12-04	14	1,0	1,5kg 32um 6mm	620	3,1	6	43-n	bra skb	2 stora plattor 43/1-43/2	-	-	-
2006-12-04	14	1,0	1,5kg 32um 6mm	610	2,7	7	43-n	bra skb		-	-	-
2006-12-04	14	1,0	1,5kg 32um 6mm	630	2,5	6	43-n	bra skb	4 små(2 temp) 43/1-43/4 + 16 kuber 43/1-43/16	73,3	69,5	72,5
2006-12-04	19	1,0	0,5kg 18um 6mm	600	4,7	5	44-n	bra smidig skb, ngt hög slölufthalt	4 små(2 temp) 44/1-44/4 + 16 kuber 44/1-44/16	60,8	69,7	68,8
2006-12-04	18	1,0	0kg	610	2,7	7	45-n	slaskig skb, blek, gränsfall	1 stor platta 45/1, del av 10 småplattor 45/1-10 (6 instr)+16 kuber 45/1-45/16	65,7	66,8	68,4
2006-12-04	18	1,0	0kg	610	3,5	7	45-n	ok skb (använde stabilator)	2 stora plattor 45/2-45/3	60,3	60,0	-
2006-12-04	18	1,0	0kg	610	2,7	7	45-n	ok skb (använde stabilator)	1 stor platta 45/4, 10 småplattor 45/11-20 (6 instr)	-	-	-
2006-12-04	18	1,0	0kg	610	2,4	7	45-n	ok skb (använde stabilator)		-	-	-
2006-12-13	23a	1,0	0kg	660	4,5	3	46-n	Bra skb, men ngt för mkt slöluft	4 stora plattor 46/1-46/4	-	-	-
2006-12-13	23a	2,0	0kg	670	3,5	3	46-n	bra skb	20 småplattor varav 12 instr 46/1-46/12+16 kuber	45,8	47,6	47,4
2006-12-13	23a	2,0	0kg	660	3,1	3	46-n	bra skb	(de med hög slölufthalt markerade med ett "L")	-	-	-
2006-12-18	23a	1,0	0kg	600	3,5	3	46-n	bra skb	4 stora plattor 46/5-46/8	-	-	-
2006-12-18	23a	2,0	0kg	660	3,1	3	46-n	bra skb	20 småplattor varav 12 instr 46/1-46/12	-	-	-
2006-12-18	23a	2,0	0kg	610	2,7	3	46-n	bra skb	4 balkar med tempgivare i mitten	-	-	-
2007-01-08	16	1,0	1,0kg 32um 6mm	580	2,9	7	47-n	trög	4 små(2 temp) 47/1-47/4 + 16 kuber 47/1-47/16	72,2	71,9	73,9
2007-01-11	21	1,0	1,0kg 32um 6mm	720	3,5	3	48-n	snabb, men släpper mkt vatten, slängs!				
2007-01-11	22	1,0	2,5kg 32um 6mm	560	4,4	4	49-n	lite trög, lågt FSM, släpper lite vatten men ok	slängs, de gjutna elementen såg inte bra ut.			
2007-01-18	36	1,0	1,5kg 18um 6mm	580	6	3	50-n	ok skb, men lite väl hög slöluftshalt.	4 små(2 temp) 50/1-50/4 + 16 kuber 50/1-50/16	35,1	34,8	36,8
2007-01-31	21	0,74	1,0kg 32um 6mm	680	4,5	3	51-n	ok skb, men lite väl hög slöluftshalt.	4 små(2 temp) 51/1-51/4 + 16 kuber 51/1-51/16	62,9	59,3	62,3
2007-01-31	22	0,81	3,0kg 32um 6mm	570	8	3	52-n	ok skb, men lite väl hög slöluftshalt.	4 små(2 temp) 52/1-52/4 + 16 kuber 52/1-52/16	56,6	58,3	59,0
2007-02-08	7c	1,00	0kg	700	12	3	53-n	bra skb med sökt hög lufthalt	4 små(2 temp) 53/1-53/4 + 16 kuber 53/1-53/16	36,9	38,5	37,2
2007-02-08	7d	1,00	1,0kg 32um 6mm	640	14	5	54-n	bra skb med sökt hög lufthalt	4 små(2 temp) 54/1-54/4 + 16 kuber 54/1-54/16	33,2	34,4	34,4
2007-02-13	30	1,0	1,0kg 32um 6mm	630	3,5	2	55-n	ok skb	4 små(2 temp) 55/1-55/4 + 16 kuber 55/1-55/16	48,2	47,7	48,6
2007-02-13	32	1,0	2,0kg 32um 6mm	700	2	2	56-n	ok skb	4 små(2 temp) 56/1-56/4 + 16 kuber 56/1-56/16	47,7	49,3	51,4
2007-03-23	43	1,0	2,0kg 32um 6mm	700	3	1	57-n	ok skb	4 små(2 temp) 57/1-57/4 + 16 kuber 57/1-57/16	26,9	29,7	29,1
2007-03-28	no1	1,0	0kg	640	10	2	58-n	ok skb med sökt hög lufthalt, "gräddig"	4 små(2 temp) 58/1-58/4 + 16 kuber 58/1-58/16	43,2	42,0	41,6
2007-04-02	no2	1,0	1,0kg 18um 6mm	550	12,5	3	59-n	ngt trög skb med sökt hög lufthalt, "gräddig"	4 små(2 temp) 59/1-59/4 + 16 kuber 59/1-59/16	46,7	40,0	41,1
2007-04-02	no3	1,0	2,0kg 18um 6mm	530	12	4	60-n	ngt trög skb med sökt hög lufthalt, "gräddig"	4 små(2 temp)60/1-60/4 + 16 kuber 60/1-60/16	46,6	44,1	45,3
2007-04-11	no4	1,0	0,5kg 18um 6mm	650	12	2	61-n	ok skb med sökt hög lufthalt, "gräddig"	4 små(2 temp)61/1-61/4 + 16 kuber 61/1-61/16	40,1	38,5	41,1
2007-04-11	no5	1,0	0kg	670	3,9	2	62-n	ngt slaskig skb (jfrt med tidigare) men ok	4 små(2 temp)62/1-62/4 + 16 kuber 62/1-62/16	73,7	73,7	72,8

C Ritningar på de olika typerna av element





PRODUKTGRUPP	LITTERA
	D21
VIKT(TON)	TYPBETECKNING
1.0	D 120/20

FÖRESKRIFTER: DÄCK, D

Föreskrifter och anvisningar:	30.10, Styrande handlingar och 34.93 i Teknisk Pärm
Miljöklass:	A1 , B1
Livslängdsklass:	L1
Betong:	Provrec. *)
	Vctmax:- -
Lyfthållfasthet:	16 MPa
Montagehållfasthet:	28 MPa
Armering:	Huvudarm: B500BT
	Nätarm: Nps50
	Byglar: B500BT
Täckskikt:	Huvudarm: 30
	Nätarm: 30
	Yttersta bygel: Φ 10=30
	Tolerans: 10 mm
Ytor:	Formsatt: SF2
	Ej formsatt: A
Lyftsätt:	Produktion: SS41 , vinkel: min. 60
	Montering: SS41 , vinkel: min. 60
Hänvisningar:	Detaljritning: -
	Bockningslista: -
	-
Övrigt:	*) VARJE ELEMENT MÄRKS MED RECEPTNR ENL. SEPARAT LISTA
	-
	-

KOMPLETTERINGSDETALJER

POS	ANT	BETECKNING	HÄNVISNING	UTFÖRANDE
0213	8	SKRF-C16	39.0213	
0519	6	VP 50	39.0514	

ARMERING

LITTERA	ANT	KVAL	Φ	LITTERA	ANT	KVAL	Φ
C104101	4	B500BT	10	SX104102	2	B500BT	10

BET	ANT	ÄNDRINGEN AVSER	DATUM	SIGN

SKANSKA

BOX 35 245 02 HJÄRUP

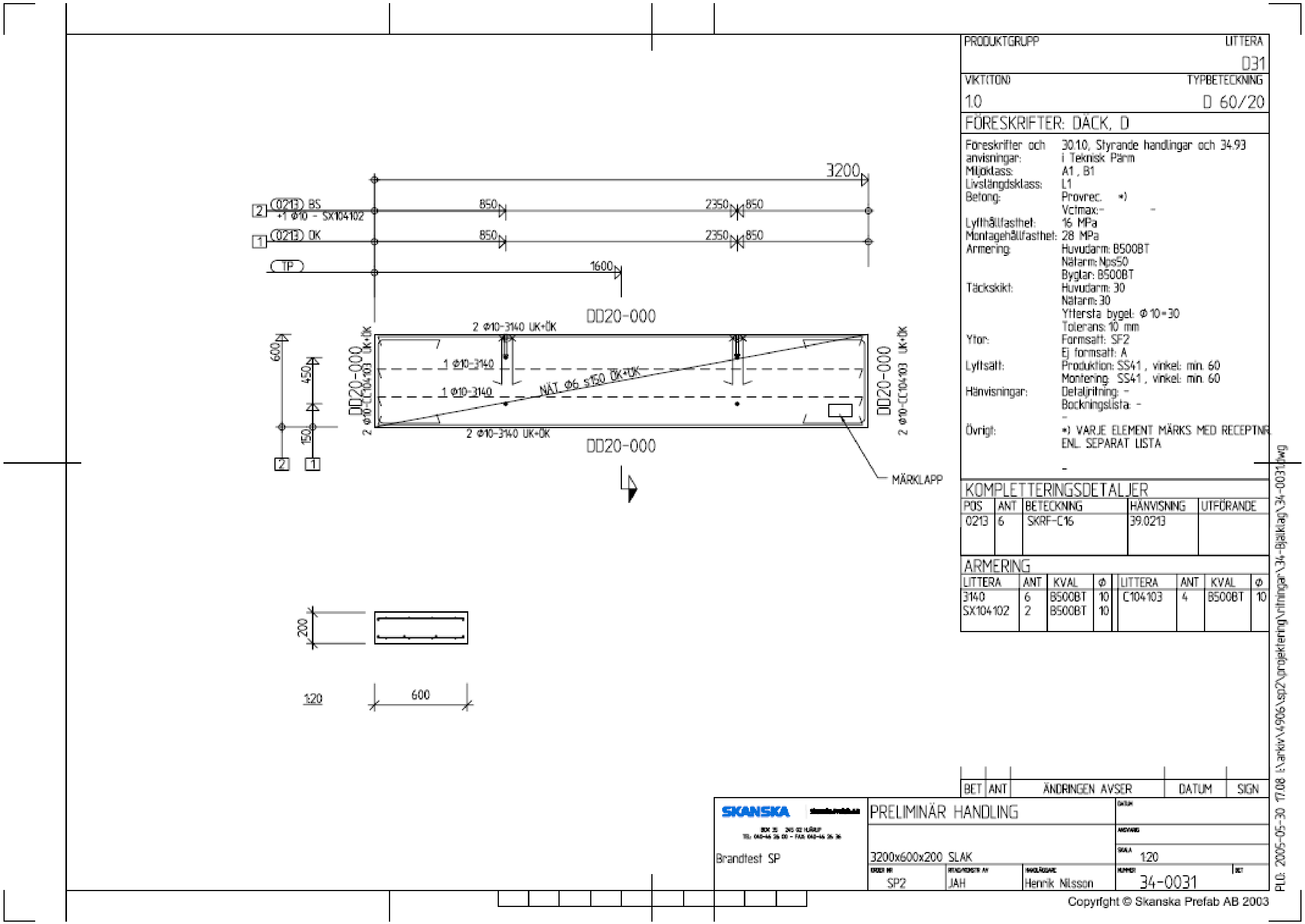
Brandtest SP

PRELIMINÄR HANDLING

1700x1200x200 SLAK

ORDER NR	RITAD/KONSTR AV	HANDLÄGGARE	SKALA	NUMMER	BET
SP2	JAH	Henrik Nilsson	1:20	34-0021	

PLO: 2005-05-30 17.08 I:\arkiv\4906\sp2\projektering\ritningar\34-Bjälklag\34-0021.dwg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LITTERA
D31
VIKT(TON)
1.0
TYPBETECKNING
D 60/20
FÖRESKRIFTER: DÄCK, D
Föreskrifter och anvisningar: 30.10, Styrande handlingar och 34.93 i Teknisk Pärm
Miljöklass: A1 , B1
Livslängdsklass: L1
Betong: Provrec. *)
Vctmax:-
Lyfthållfasthet: 16 MPa
Montagehållfasthet: 28 MPa
Armering: Huvudarm: B500BT
Nätarm: Nps50
Byglar: B500BT
Täckskikt: Huvudarm: 30
Nätarm: 30
Yttersta bygel: Φ 10=30
Tolerans: 10 mm
Ytor: Formsatt: SF2
Ej formsatt: A
Lyftsätt: Produktion: SS41 , vinkel: min. 60
Montering: SS41 , vinkel: min. 60
Hänvisningar: Detaljritning: -
Bockningslista: -
Övrigt: *) VARJE ELEMENT MÄRKS MED RECEPTNR ENL. SEPARAT LISTA
KOMPLETTERINGSDETALJER
POS | ANT | BETECKNING | HÄNVISNING | UTFÖRANDE
0213 | 6 | SKRF-C16 | 39.0213 |
ARMERING
LITTERA | ANT | KVAL | Φ | LITTERA | ANT | KVAL | Φ
3140 | 6 | B500BT | 10 | C104103 | 4 | B500BT | 10
SX104102 | 2 | B500BT | 10
BET | ANT | ÄNDRINGEN AVSER | DATUM | SIGN
SKANSKA
Brandtest SP
PRELIMINÄR HANDLING
3200x600x200 SLAK
SP2
JAH
Henrik Nilsson
1:20
34-0031
Copyright © Skanska Prefab AB 2003
PLO: 2005-05-30 17.08 I:\arkiv\4906\sp2\projektering\ritningar\34-Bjälklag\34-0031.dwg
3200
850
2350
1600
0213 BS
+1 Φ10 - SX104102
0213 ÖK
TP
DD20-000
2 Φ10-3140 UK+ÖK
1 Φ10-3140
NÄT Φ6 s150 ÖK+UK
2 Φ10-CC104103 UK+ÖK
MÄRKLAPP
600
450
150
200
1:20

Self-Compacting Concrete Exposed to Fire

Lars Boström, Robert Jansson

SP Technical Research Institute of Sweden

Fire Technology

SP Report 2008:53

Self-Compacting Concrete Exposed to Fire

Lars Boström, Robert Jansson

Photo first page: Per Aronsson

Abstract

Self-Compacting Concrete Exposed to Fire

An extensive experimental study on the behaviour of self-compacting concrete when exposed to fire has been carried out. Approximately 200 fire tests have been made on more than 50 different types of self-compacting concrete. The general conclusion from the study is that self-compacting concrete have a very high probability of spalling when exposed to fire if no precaution is made such as adding polypropylene fibres to the concrete. The probability of spalling is high even after one years drying. Different factors such as influence of compressive load, fire curve and concrete admixture have been examined. The load level did not affect the spalling as long as a compressive stress was applied. Unloaded specimens spalled slightly less compared to the loaded. The severity of the fire curve did not affect the probability of spalling. Although the time when the spalling starts is affected by the fire curve. In the tests made the spalling started when the furnace temperature reached 500-700 °C. No significant effect of the concrete admixture (water-cement ratio, water-powder ratio, amount of limestone filler) could be determined. An addition of 1.0-1.5 kg/m^3 polypropylene fibres with a diameter of 18 μm or 32 μm gave a good protection regarding progressive spalling which would be acceptable in most applications. Also a filler of polypropylene was examined. The probability of spalling was not affected by the addition of polypropylene filler in the concrete.

Key words: self-compacting concrete, fire, spalling, experiment

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SP Technical Research Institute of Sweden

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Contents

Preface

This project was financial supported by several organisations which all are gratefully acknowledged:

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- Brandforsk (The Swedish Fire Research Board)
- The Norwegian Public Roads Administration
- The Swedish Road Administration
- The Swedish Rail Administration
- CBI Betonginstitutet AB
- Cementa
- Skanska Asfalt och Betong
- Skanska Prefab
- Nordkalk
- Sika

The project would not have been possible to carry out without the project group. It has been a long and sometimes tough journey, but with the enthusiastic help of the project group have we finally reached the end. Furthermore have we had help from Bijan Adl-Zarrabi and Ulf Wickström from SP Fire Technology in the discussions regarding the project. The practical work with testing has been carried out by Simon Fitz, who made his practical part of his studies at SP, as well as Bengt Bogren, Patrik Nilsson, Martin Rylander, Peter Lindqvist and Kent Pettersson from SP Fire Technology. They are all gratefully acknowledged.

Borås, December 2008
Lars Boström and Robert Jansson

Summary

An extensive experimental study has been carried out with the objective to examine different qualities of self-compacting concretes and their behaviour when exposed to different fire scenarios. Over 50 concrete qualities have been examined, most with an addition of polypropylene fibres as a fire protection. The experiments showed clearly that self-compacting concrete without a fire protection will most probable spall severely when exposed to fire. An addition of 1.0-1.5 kg/m^3 of polypropylene fibres with a diameter between 15 and 40 μm will prevent or decrease the amount of spalling to an acceptable level in most cases. There are, however, cases where no or very limited spalling can be accepted and in these cases more fibres or other types of protection can be needed.

An intention with the project was to determine how different aspects regarding the concrete composition affected the spalling. Hence parameters such as water-powder ratio, water-cement ratio, type of cement, amount of limestone filler and air content was altered. The experimental results did not show any significant effect on the spalling behaviour of the examined parameters.

The moisture within the concrete is one of the driving forces of spalling when it is heated. Tests were carried out on specimens of different age in order to determine the effect of the moisture content. Within this project no effect of age could be observed, and some of the specimens were two years old when tested. An explanation could be that self-compacting concrete is very dense with a low permeability and thus it takes a very long time for the concrete to dry out.

Some concrete qualities were exposed to different fire curves ranging from slow heating (10 K/minute) up to rapid heating with the hydrocarbone curve (HC). The experiments showed no difference regarding spalling more than that with the slower heating the spalling started later. Generally the spalling started when the temperature in the furnace was 500-700 °C.

1 Introduction

1.1 Background

Despite the long tradition of using concrete, knowledge on performance of concrete structures when exposed to fire is still not satisfactory. There are several problems which are still not sufficiently recognized and investigated.

Reinforced structural concrete exposed to fire may be damaged because of:

- decrease of strength and stiffness of reinforcement bars when obtaining temperatures above 400-500^{o}C
- decrease of strength of concrete when obtaining temperatures above 400-500^{o}C
- explosive spalling
- loss of bonding between concrete and reinforcement
- damage of joints and connections due to high thermal elongation and thermal gradients, large deflections of concrete elements
- loss of separating function caused by improper location and size of gaps and dilatation joints

There are, as shown above, several ways concrete may be damaged when exposed to fire. In the following only spalling will be considered. A difference between conventional vibrated concrete and self-compacting concrete is the use of fine filler. The filler could be glass or limestone powder. By adding filler, the concrete will be much denser and thus the permeability will be lower. Earlier studies made on high performance concrete as well as self-compacting concrete, showed that spalling occurred to a considerably higher degree than for conventional concrete, see Oredsson (1997) and Boström (2002).

There are today no standardized methods for the determination of spalling and its effect on the structural behaviour of the concrete element/structure. When tests presently are carried out the responsible fire laboratory, or the client, defines how to test the concrete. Since tests of full scale specimens generally are very expensive, small specimens are often chosen in order to keep the costs down. When comparing results on spalling of self-compacting concrete made at different laboratories the results are contradictory in the sense that some resulted in extensive spalling while other almost no spalling at all, see for example Boström (2002). It is likely that the geometry of the test specimen and the load level and configuration have a great effect on the spalling. This assumption is based on the available test results where loaded medium and full scale tests have resulted in severe spalling while unloaded small scale tests have not spalled more than conventional concrete.

In the present European standards on fire resistance, very little is said about spalling. It is only in the general test standard EN 1363-1 that spalling is mentioned and here very vague. Quoting the standard it says:

> “Observations shall be made of the general behaviour of the test specimen during the course of the test and notes concerning phenomena such as smoke emission, cracking, melting, softening, spalling or charring etc. of materials of the test specimen shall be made.”

Thus only the spalling that takes place during the test shall be observed and noted. The standard does not say anything about measurements of the amount of spalling, only that it shall be observed. In all other fire resistance standards that can be used on concrete, i.e. the EN 1365 series on load-bearing structures and ENV 13381-3 on protection of concrete members, only reference to measurements in accordance with EN 1363-1 is given. It is therefore of great importance that a methodology is developed with which the spalling behaviour of all types of concrete can be determined.

Self-compacting concrete has been met with great attention. As an example a project on self-compacting concrete has been nominated as one of the finalists to the European Descartes prize for 2002. Self-compacting concrete is gaining more of the market, and is now widely used for different constructions. It is therefore of great importance that guidance on how to produce self-compacting concrete with good fire spalling properties is worked out and presented to industry and other stakeholders.

A state-of-the-art report was published by Rilem, De Schutter and Audenaert (2007), which gives a good overview of the current knowledge regarding the durability of self-compacting concrete including its fire resistance. In the references of this report is also a list on publications made within this project presented.

1.2 Objectives

The project had the following objectives;

1. To develop a guideline on how to produce self-compacting concrete including fibres of polypropylene
2. To prepare a methodology for determination of spalling of concrete. This includes:
   - comparative study of different test methods and test results
   - develop a small scale or intermediate test procedure
   - verification of the developed test procedure
3. To determine experimentally the effect of different factors, such as moisture content, geometry etc, on the fire spalling.
4. To develop a guidance on how to produce fire spalling resistant self-compacting concrete.
5. To determine the durability of self-compacting concrete including fibres of polypropylene

1.3 Limitations

The development of test methods for measurement of spalling has been reported in Boström (2004), and those results will not be repeated in this report.

This report will only cover the fire tests made within the project. Hence results on manufacturing, production and durability will be published in other reports.

The project has only included self-compacting concrete, i.e. no comparison has been made with similar conventional vibrated concretes.

Since the main objective with the study was to find self-compacting concretes with good fire resisting properties, i.e. concretes that do not spall when exposed to fire, the analysis made is mainly focused on the spalling measurements made. A much deeper analysis of the data from the measurements is of course possible, but that will be presented in other papers.

1.4 Research team and reference group

Henrik Nilsson, Skanska Sweden AB, has been the project leader for the whole project. The main research work on the fire tests has been carried out by Robert Jansson and Lars Boström from SP Fire Technology. They have had help from Bijan Adl-Zarrabi and Ulf Wickström from SP Fire Technology in the discussions regarding the project. The practical work with testing has been carried out by Simon Fitz, who made his practical part of his studies at SP, Bengt Bogren, Patrik Nilsson, Martin Rylander, Peter Lindqvist and Kent Pettersson from SP Fire Technology.

A reference group has been coupled to the project. The following persons have been engaged in the reference group:

Samir Redha, Swedish Road Administration
Iad Saleh, Sika Sweden AB
Hans-Erik Gram, Cementa
Jan Trägårdh, CBI
Claus K. Larsen, Norwegian Road Administration
Lars-Olof Nilsson, Lund Institute of Technology
Henrik Nilsson, Skanska Sweden AB
Lars Boström, SP Fire Technology
Robert Jansson, SP Fire Technology

2 Materials

2.1 Concrete mixes

2.1.1 General

All test specimens were manufactured at Skanska Prefab in Strängnäs, Sweden, with aggregates from the same source. A petrographic analysis of the aggregates used is presented in the report on manufacturing which will be published separately. The products used in the concrete mixes are shown in table 2.1. The complete recipes of each concrete is presented in Appendix A.

Table 2.1. Products used in the concrete mixes.

Cement	CEM I 42,5N BV/LA/SR CEM II 42,5R A-LL Norsk ANL
Superplasticizer	Sikament 20HE Glenum
Air entrainment	Sika Aer-S
Polypropylene fibers	Sika Crackstop, ϕ18 μm, length 6 mm Sika Crackstop, ϕ18 μm, length 12 mm Sika Crackstop, ϕ32 μm, length 6 mm
Polypropylene filler	Sika IgniFill
Limestone filler	Limus 25
Silica fume	-

2.1.2 Building concrete

A total of 27 different concretes were manufactured using cement for house building applications, i.e. CEM II cement. The cement type was for all mixes CEM II 42,5R A-LL. A summary of the tested house building concretes is shown in table 2.2. The complete mixes are presented in the appendices for each concrete type. In all concretes, except series 19, have a superplasticizer designated Sikament 20HE 50 been used. In series 19 was a Glenum superplasticizer used.

Table 2.2 House building concretes.

Series	w/p	w/c	Filler	Fibre type	Fibre amount
1	0.43	0.52	80	-	-
2	0.37	0.52	160	-	-
3	0.40	0.40	0	-	-
4	0.40	0.52	110	ϕ18 µm, l=6 mm	0.5
5	0.40	0.52	124	ϕ18 µm, l=12 mm	1.0
6	0.50	0.65	105	Filler	5.0
7	0.40	0.52	122	ϕ18 µm, l=6 mm	1.0
8	0.40	0.52	124	ϕ18 µm, l=12 mm	1.5
9	0.51	0.65	96	Filler	10.0
10	0.50	0.65	105	-	-
11	0.50	0.65	109	ϕ18 µm, l=6 mm	0.5
12	0.55	0.71	87	-	-
13	0.50	0.65	105	Filler	0.5
14	0.50	0.65	109	ϕ18 µm, l=12 mm	1.0
15	0.36	0.40	50	-	-
16	0.45	0.52	60	-	-
17	0.45	0.52	60	ϕ18 µm, l=6 mm	0.5
18	0.50	0.65	105	ϕ18 µm, l=6 mm	1.0
19 [1)]	0.50	0.65	109	ϕ18 µm, l=6 mm	1.0
25	0.45	0.52	60	ϕ32 µm, l=6 mm	1.0
26	0.40	0.52	124	ϕ18 µm, l=6 mm	1.5
27	0.45	0.52	60	ϕ32 µm, l=6 mm	1.5
46	0.40	0.52	120	-	-
50	0.45	0.52	60	ϕ18 µm, l=6 mm	1.5
55	0.40	0.52	124	ϕ32 µm, l=6 mm	2.0
56	0.40	0.52	124	ϕ32 µm, l=6 mm	1.0
57	0.50	0.65	109	ϕ32 µm, l=6 mm	2.0

[1)] Glenum superplasticizer

2.1.3 Civil engineering concrete

A total of 20 different concretes were manufactured using cement for civil engineering applications, i.e. CEM I cement. The cement type was for all mixes CEM I 42,5N BV/LA/SR. A summary of the tested civil engineering concretes is shown in table 2.3. The complete mixes are presented in the appendices for each concrete type.

Table 2.3 Civil engineering concretes.

Series	w/p	w/c	Filler	Fibre type	Fibre amount
28	0.30	0.40	140	ϕ18 μm, l=6 mm	0.5
30	0.30	0.30	-	-	-
31	0.35	0.40	60	-	-
32	0.30	0.40	143	ϕ32 μm, l=6 mm	1.0
33	0.30	0.40	143	ϕ32 μm, l=6 mm	2.0
34	0.25	0.40	252	-	-
35	0.25	0.40	252	ϕ18 μm, l=6 mm	0.5
38	0.30	0.40	140	ϕ18 μm, l=6 mm	1.0
39	0.30	0.40	140	-	-
40	0.25	0.40	252	ϕ18 μm, l=6 mm	1.5
41	0.25	0.40	252	ϕ32 μm, l=6 mm	1.0
42 [1)]	0.30	0.40	145	ϕ18 μm, l=6 mm	1.5
43	0.30	0.40	140	ϕ32 μm, l=6 mm	1.5
44	0.40	0.40	-	ϕ18 μm, l=6 mm	0.5
45	0.40	0.40	-	-	-
47	0.30	0.40	140	ϕ18 μm, l=12 mm	1.0
51	0.40	0.40	-	ϕ32 μm, l=6 mm	1.35
52	0.40	0.40	-	ϕ32 μm, l=6 mm	3.0
53 [1)]	0.30	0.40	140	-	-
54 [1)]	0.30	0.40	140	ϕ32 μm, l=6 mm	1.0

[1)] Contain Sika Aer-S

2.1.4 Norwegian concrete for tunnel applications

A total of 5 different concretes were manufactured using cement from Norway for civil engineering applications. The cement was designated Norsk ANL. A summary of the tested Norwegian civil engineering concretes is shown in table 2.4. The complete mixes are presented in the appendices for each concrete type. In all concretes, except series 62, have an air entrainment designated Sika Aer-S been used.

Table 2.4 Norwegian civil engineering concretes.

Series	w/p	w/c	Silica fume	Fibre type	Fibre amount
58	0.41	0.45	32	-	-
59	0.41	0.45	32	ϕ18 μm, l=6 mm	0.5
60	0.41	0.45	32	ϕ18 μm, l=6 mm	1.0
61	0.41	0.45	32	ϕ18 μm, l=6 mm	2.0
62 [1)]	0.41	0.45	33	-	-

1) No air entrainment

2.2 Manufacturing

The manufacturing of all test specimens was made at Skanska Prefab in Strängnäs. All details about the manufacturing will be published in a separate report.

2.3 Conditioning

Most specimens used in the fire tests were stored indoors in the laboratory from delivery to SP until testing. Some were stored outdoors under roof. The climate in the laboratory was approximately 20 °C and relative humidity 50 % on average during this time. Between manufacturing and transport to SP the specimens were stored under roof.

3 Specimens

3.1 General

In a previous project reported by Boström (2004) different test methods and especially specimen shapes were investigated. The study showed that a small scale slab specimen gave similar results as a large size slab specimen. There were some differences in behaviour and in spalling depth, but the small slab was the specimen giving the most comparable results with the large specimens. It was therefore decided to use the small scale slab test in the main study, and add some large scale tests for verification. Drawings of the test specimens are shown in Appendices B-D.

3.2 Small slab specimens

The small slabs had the dimensions 600 x 500 x 200 mm^3. There was no reinforcement in the small slabs, except the post-stress bars used for applying the external compressive load. The design of the small slabs is presented in figure 3.1. In each specimen were three aluminium pipes placed in the specimens into which post-stress bars could be placed after the casting. In all specimens thermocouples were placed centrally as shown in figure 3.1. One 10 mm and one 40 mm from the fire exposed surface.

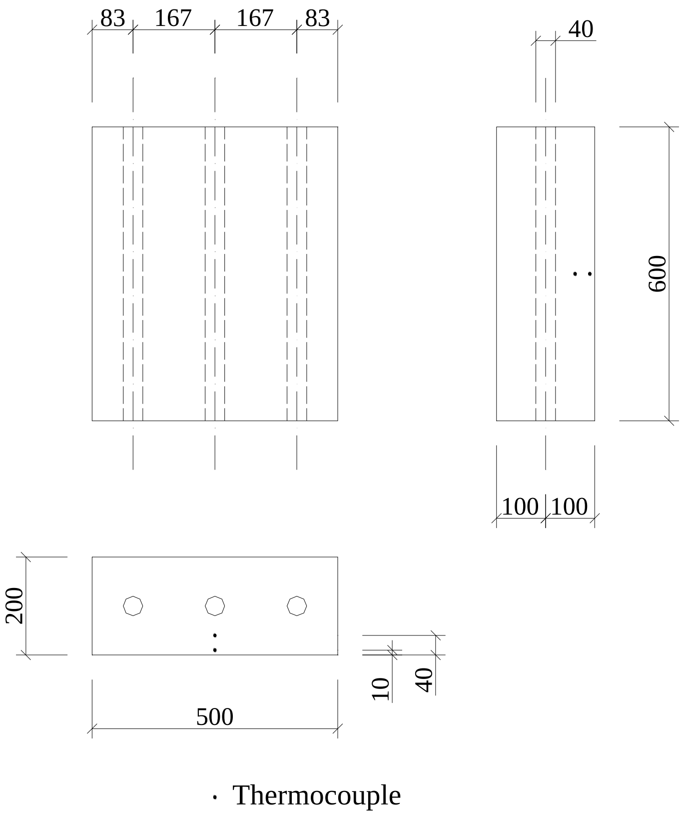

Figure 3.1 Drawing of the small slab specimens.

The photos in figures 3.2-3.3 show the moulds used. In figure 3.3 can the aluminium tubes for the post-stressing bars be seen, as well as the wooden stick on which the thermocouples had been mounted. Figure 3.4 shows the casting of small slabs. After the forms had been removed the specimens were transported to SP in Borås. The specimens were there stored indoors as shown in figure 3.5.

Figure 3.2 Moulds for small slab specimens.

Figure 3.3 Mould with pipes for post-stress bars and installed thermocouples.

Figure 3.4 Casting of small slabs.

Figure 3.5 Storage of specimens.

3.3 Large slab specimens

Slabs with the dimensions 1800 x 1200 x 200 mm^3 were manufactured. Drawings of the slabs are shown in figure 3.6. Six aluminium tubes were placed in each specimen through whom post-stress bars could be inserted. In figure 3.7 is a photo showing the mould.

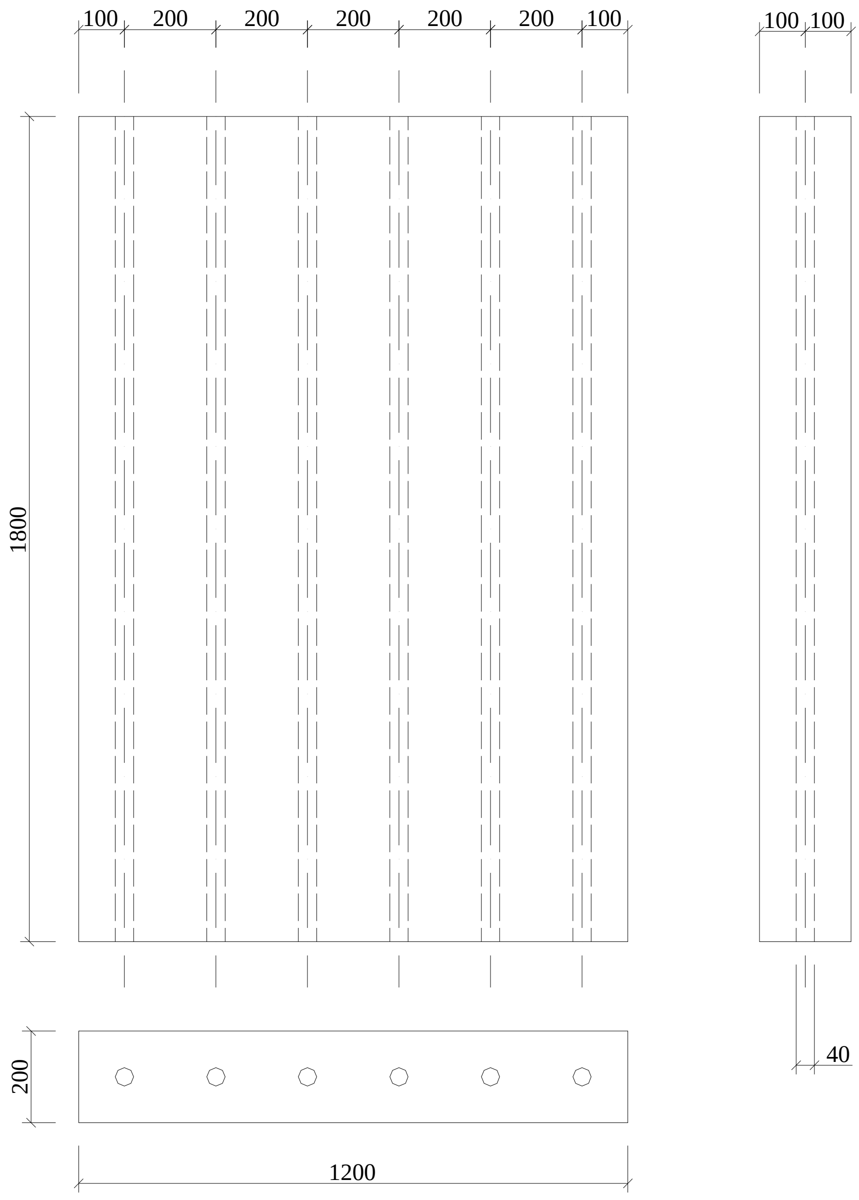

Figure 3.6 Principle drawing of the large slab specimens.

Figure 3.7 Mould for large slab specimens.

In all large slab specimens were 20 thermocouples mounted. The mounting was made at four locations and at five depths. The location of the thermocouples is presented in figure 3.8. In the photo in figure 3.9 one wooden stick is shown which composes a measuring station with five thermocouples.

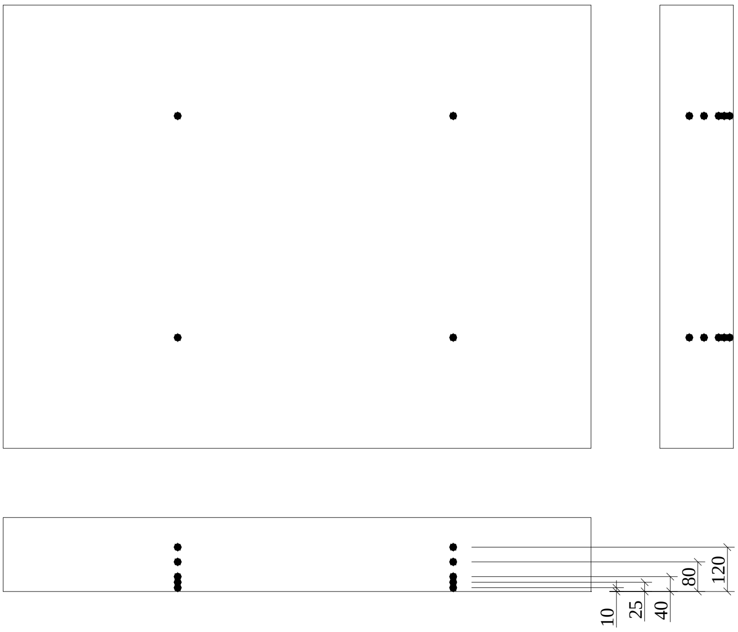

Figure 3.8 Placement of thermocouples in the large slab specimens.

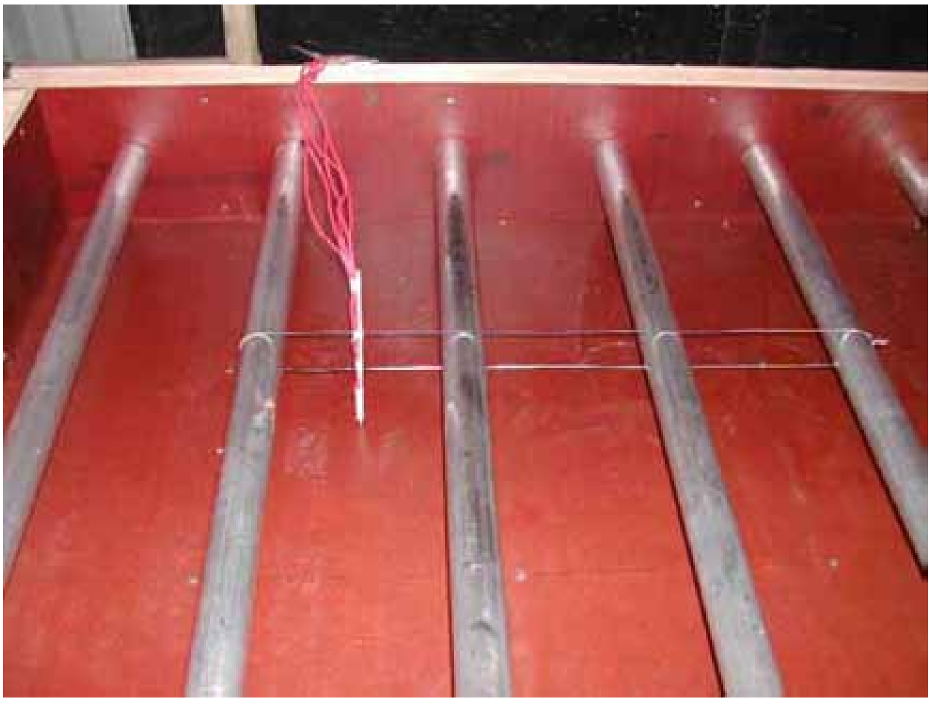

Figure 3.9 Aluminium tubes mounted in the mould as well as a wooden stick with thermocouples.

In addition to temperature measurements was the vapour pressure measured at different depths in some of the specimens. A measuring cradle with pipes for the pressure measurements is shown in figure 3.10.

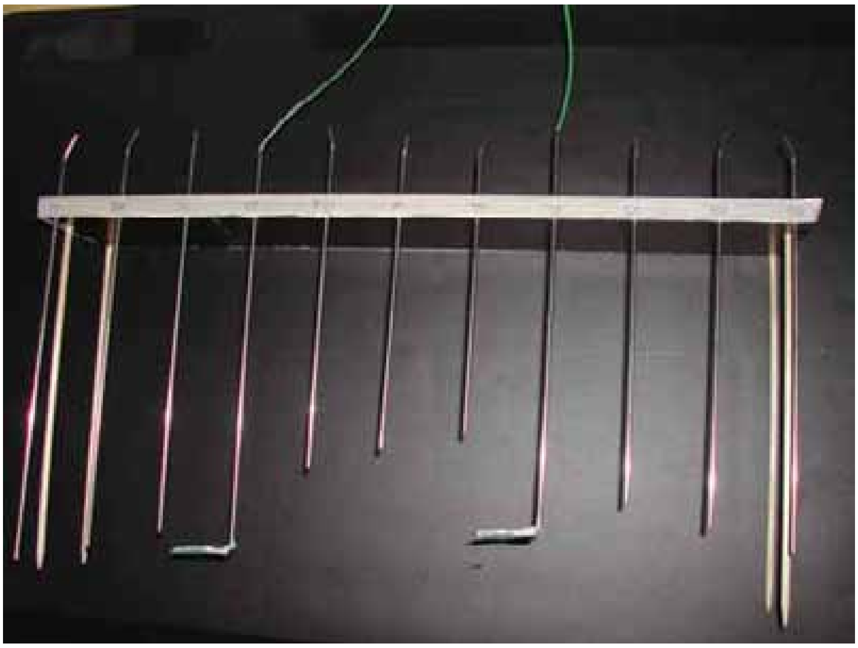

Figure 3.10 Cradle with pipes for pressure measurements and thermocouples.

3.4 Beam specimens

Beam specimens were manufactured with the dimensions 3200 x 600 x 200 mm^3. The objective with the beam specimens was to examine the case when the fire exposed concrete is loaded in tension. The design of the beams is shown in figure 3.11. Thermocouples were placed at six different locations and at each place at five depths.

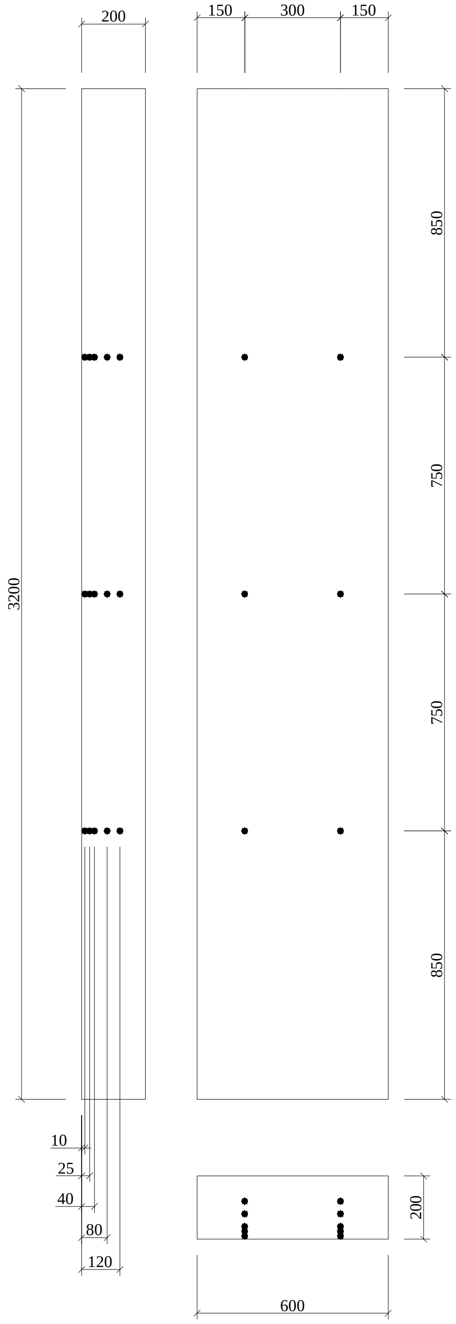

Figure 3.11 Drawing of the beam specimens and the location of thermocouples.

4 Test methods

4.1 Fire exposure

There are many different fire scenarios, or fire curves, to be chosen from. The most frequently used fire curve, often called the standard fire curve, is the ISO 834 fire curve. This scenario represents a room fire, i.e. a time-temperature relation that can be expected in a room, an underventilated fire. It can be argued whether the ISO 834 fire curve really represents a room fire and in many cases it is probably too severe. Nevertheless, by using a standardized fire curve it is possible to compare different materials, and in some situations the fire curve is realistic.

In other constructions such as tunnels a fire can become very severe. When designing tunnels many different fire curves are used around the world. One of the most severe curves is the so called RWS-curve. There are also other curves and a frequent used curve is the hydro carbon curve, the HC-curve. In figure 4.1 some different fire curves are shown.

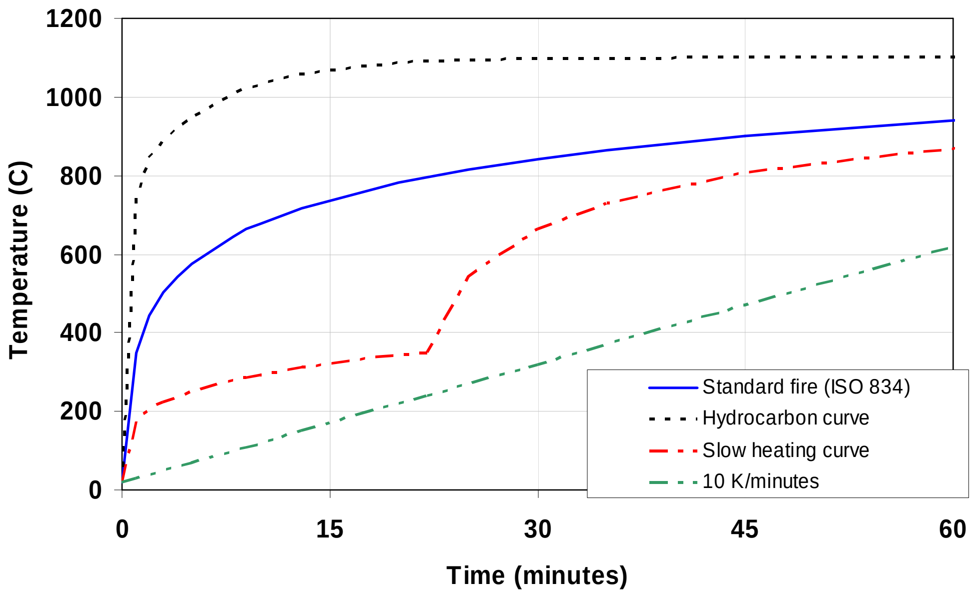

Figure 4.1 Different fire curves.

In the present project the standard fire curve in accordance with EN 1363-1 and the HC-curve in accordance with EN 1363-2 were used. In addition to these standardized fire curves also a slow heating exposure in accordance with EN 1363-2 and a very slow heating with 10 K/minute have been used.

The fire tests have in all cases been run for 60 minutes, and thereafter have the burners been shut down. Hence have the effect of the cooling phase, or fire-extinction not been examined.

4.2 Small furnace tests

4.2.1 Test set-up

The tests were performed on a small furnace. The clear opening of the furnace, i.e. the dimensions of the fire exposed surface of the specimens, had the dimensions 500 x 400 mm^2. The specimens were always placed horizontally on the furnace and the fire exposure was always one-sided. The furnace with a specimen is shown in figure 4.2 and a principle drawing in figure 4.3.

Figure 4.2 Small slab placed on the furnace.

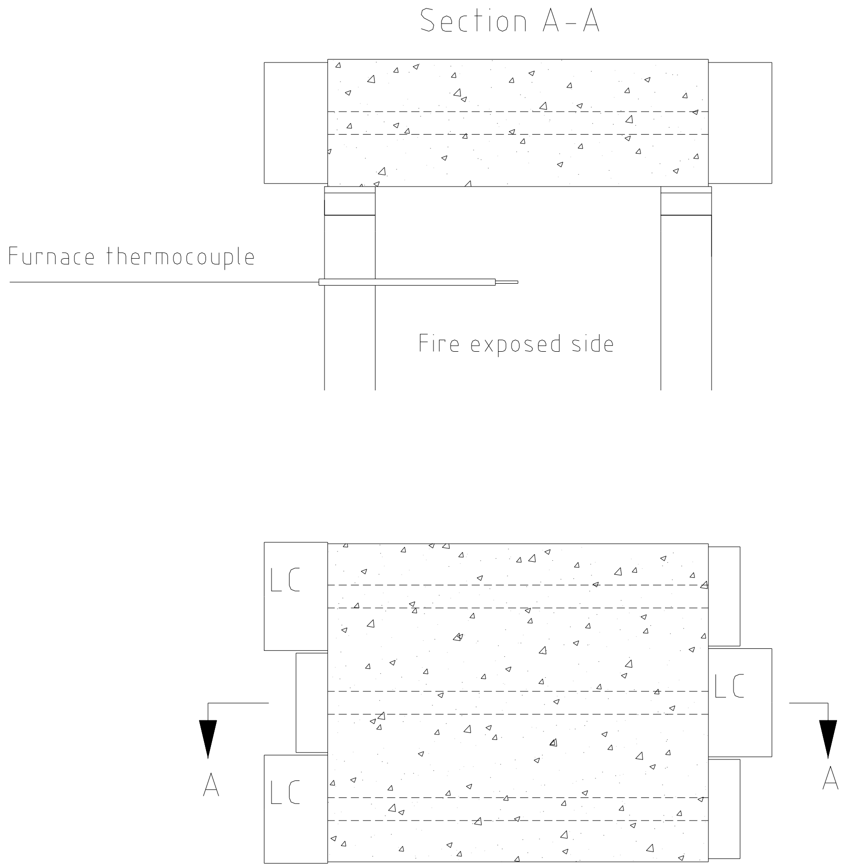

Figure 4.3 Principle drawing of small slab test set-up.

4.2.2 Temperature measurements

The temperature in the furnace was measured with one 1 mm type K thermocouple. The temperature was recorded with a frequency of 0.2 Hz, i.e. a measurement every 5 seconds.

The temperature was also measured within the concrete specimens. Thermo wire of type K with a quick tip was used. The wires were insulated with shrinking tubes before they were casted into the specimens. Two wires were casted into each specimen, one at a depth 10 mm from the fire exposed surface and one on the depth 40 mm. The thermocouples were centred on the specimen.

4.2.3 Load measurements

Most tests were performed on loaded specimens. The load was applied through post-stressing by Dywidag bars with a diameter of 36 mm. Three bars were used in each specimen. A loaded specimen is shown in figure 4.2 above. Between the nut and the specimen a steel plate with thickness 50 mm was mounted in order to transfer the load to the surface of the specimen.

A load cell was mounted on each bar. Hence the load was monitored and recorded during the fire test. The load cell was placed between the nut and the steel plate on one side of the specimen.

4.2.4 Vapour pressure measurements

During casting of the concrete test specimens, thin steel pipes with an inner diameter of 2 mm and wall thickness of 0.2 mm were inserted into the concrete, see figure 4.3. One end of each steel pipe was placed near the surface to be fire tested. The pipe extended from the measurement point through the test specimen, exiting on the cold side. To ensure that no concrete, i.e. cement paste, would fill the pipes, thin welding bars were inserted into the pipes during casting. Figure 4.4 shows a pressure measurement station with three steel pipes and one thermocouple. The struts placed at each of the four corners of the measurement station are used to position the whole apparatus correctly in the concrete specimen. The steel pipes are (from left to right) 10, 20 and 30 mm shorter than the four struts. This setup is then placed in the casting mould with the struts placed on the surface which is to be exposed to the fire, ensuring that each pressure measurement is made 10, 20 and 30 mm from the surface exposed to fire.

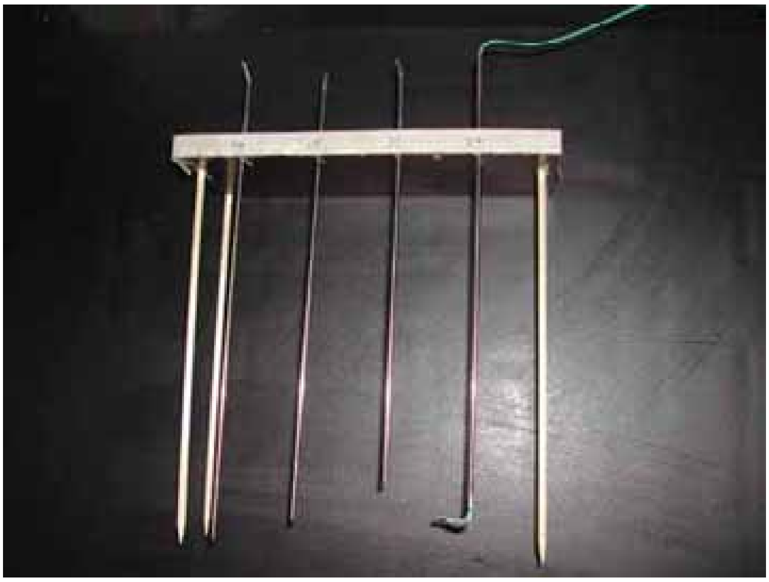

Figure 4.4 The oil pipes and one thermocouple.

When the fire tests were conducted the welding bars inside the steel pipes were removed and the pipes were filled with high temperature silicone oil, Sil 300, produced by Haake. Filling of the pipes was conducted by inserting a thin injection needle and carefully injecting oil from the bottom of the pipe to ensure that no air was trapped. Outside the concrete the steel pipes were connected to a pressure gauge using a T-junction (see figure 4.5). The pressure gauges that were used were of the type P8AP/100bar from Hottinger Baldwin Messtechnik GmbH.

Figure 4.5 The pressure gauges connected to the small pipes with angle tees.

4.2.5 Spalling measurements

The spalling depth was measured in a grid with a mesh-size of 100 x 100 mm^2. Accordingly a total of 7 x 6 measurements were made on each specimen. It was thus possible to produce a map on the spalling depth over the fire exposed surface of the specimens. Due to boundary effects the amount of spalling is always less at the boundaries. Therefore measurements on spalling depth close to the boundary are uncertain and should not be considered in an analysis of the results. When presenting the results on spalling depth it is the value obtained when the boundary measurements are omitted.

In addition to the spalling depth also the weight loss has been determined. It shall, however, be noted that the weight loss is not a good measure on spalling since other effects such as loss of water due to evaporation is included in the measure.

4.3 Large slab tests

4.3.1 Test set-up

The large slab specimens were always tested on a large horizontal furnace (a floor furnace) with a clear opening of 5000 x 3000 mm^2. The large slab specimens were coupled two and two in order to cover the width of the furnace. The total length of the coupled specimen is thus 3200 mm. A principle drawing of the coupling is shown in figure 4.6. The specimens then formed a roof on the furnace.

At each furnace test, 6 or 8 slab specimens were tested. A total of three furnace tests were carried out and during the first two tests 6 slab specimens were tested. At the last test the furnace was covered with 8 slab specimens. Figure 4.7 shows the set-up from the last furnace test, i.e. the test with 8 slab specimens on the furnace.

The two firs tests were carried with a standard fire scenario in accordance with the European standard EN 1363-1, similar to ISO 834. The last test was made with the HC-curve, i.e. a more severe fire, in accordance with EN 1363-2. The furnace temperature was measured with plate thermometers.

The pressure in the furnace was controlled to be 20 Pa higher compared to the laboratory, i.e. an overpressure in the furnace. The measuring point was 100 mm below the fire exposed surface of the specimens.

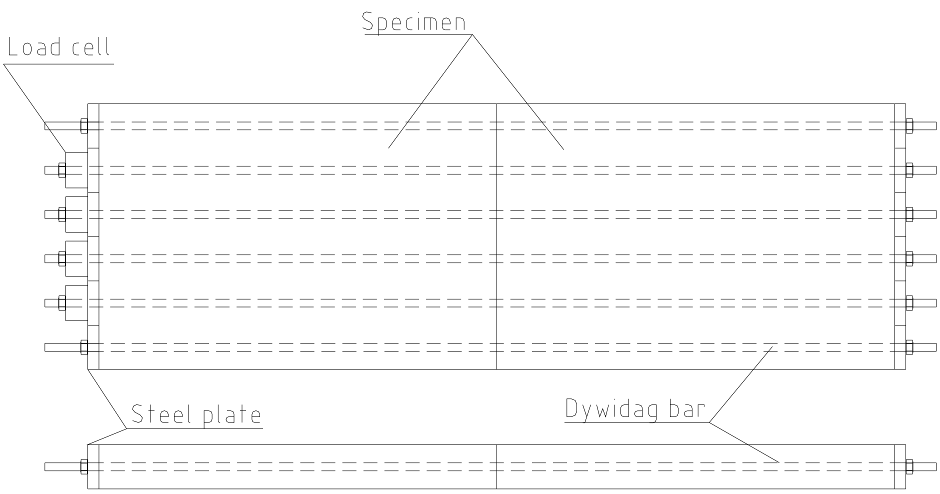

Figure 4.6 Coupling of two specimens with post-stressing bars.

Figure 4.7 Slab specimens on the horizontal furnace.

In the first furnace test three different concretes were tested, concrete 7 (one specimen), concrete 8 (one specimen) and concrete 10 (four specimens). The test was carried out on February 2, 2006. The specimen configuration is shown in figure 4.8.

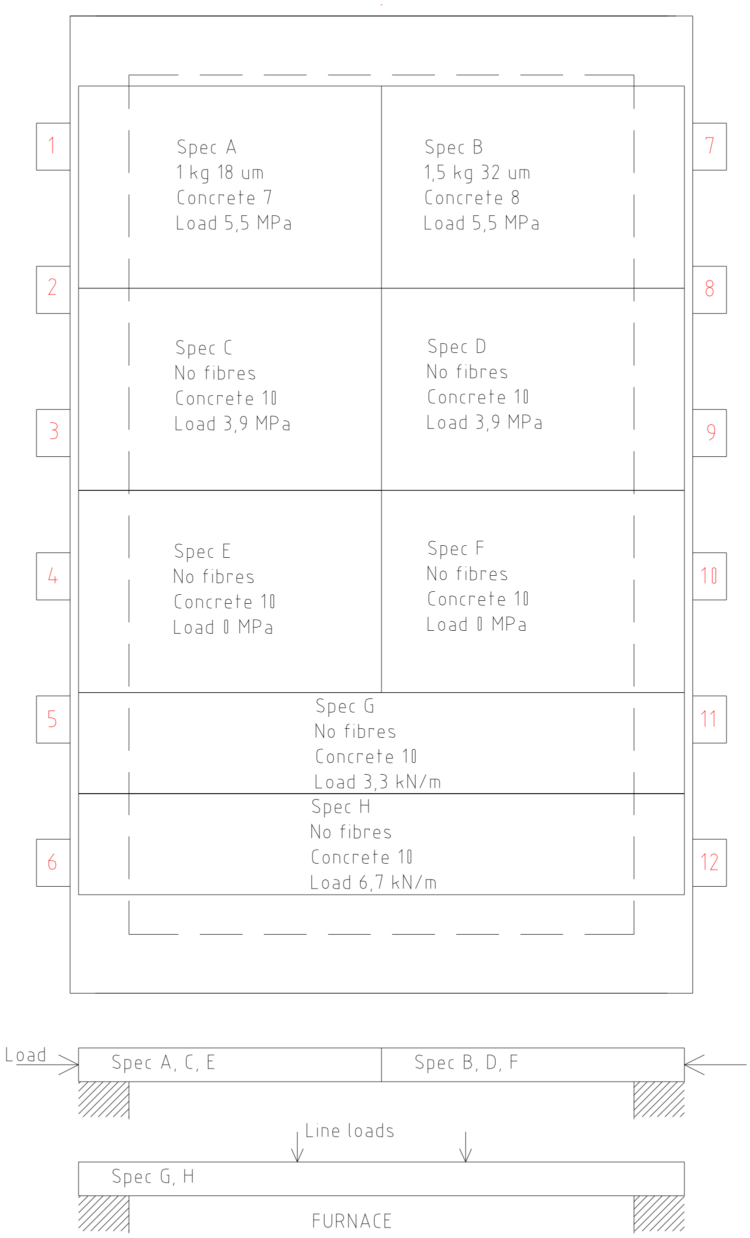

Figure 4.8 Specimen configuration of the fire test on February 2, 2006.

The second furnace test was carried out on May 31, 2007. In this test six different concretes were examined, one specimen each of concretes 10, 38, 39, 43, 45 and 46. The specimen configuration is shown in figure 4.9.

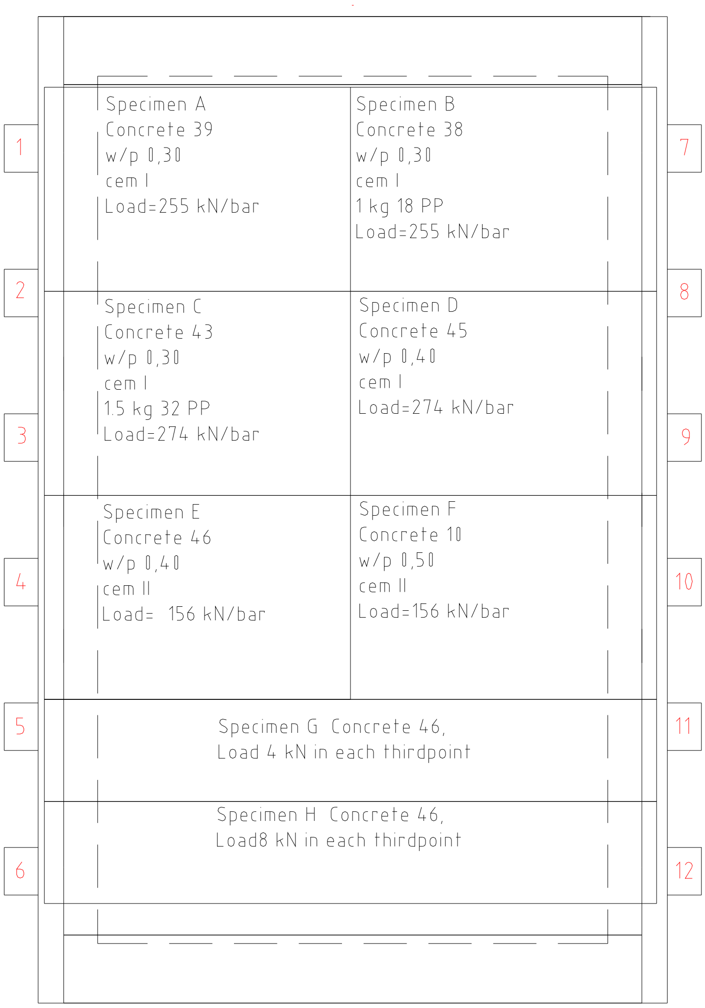

Figure 4.9 Specimen configuration of the fire test on May 31, 2007.

The third and last furnace test was carried out on June 5, 2007. In this test six different concretes were examined, one specimen each of concretes 10 and 46, and two specimens of concretes 38, 39 and 45. The specimen configuration is shown in figure 4.10.

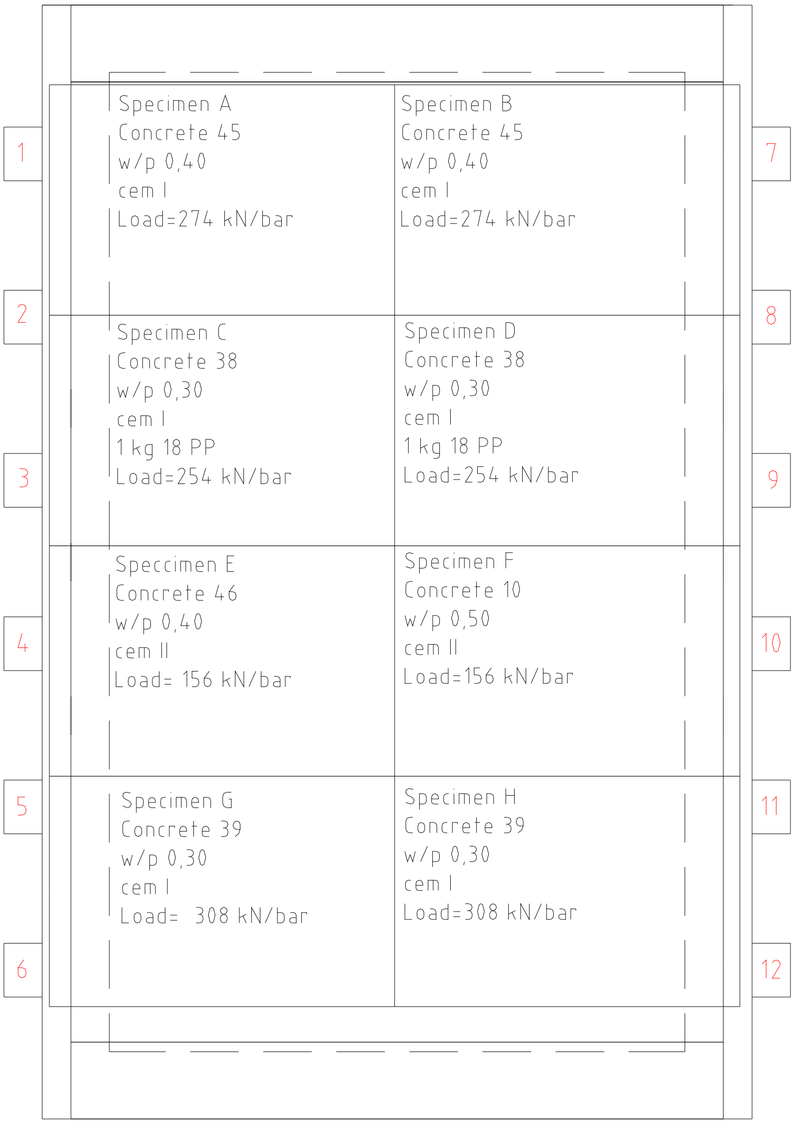

Figure 4.10 Specimen configuration of the fire test on June 5, 2007.

4.3.2 Temperature measurements

The furnace temperature was measured with plate thermometers in accordance with EN 1363-1. In each test six plate thermometers were mounted in the furnace, 100 mm below the fire exposed surface of the specimens. In figure 4.11 are plate thermometers shown during a fire test.

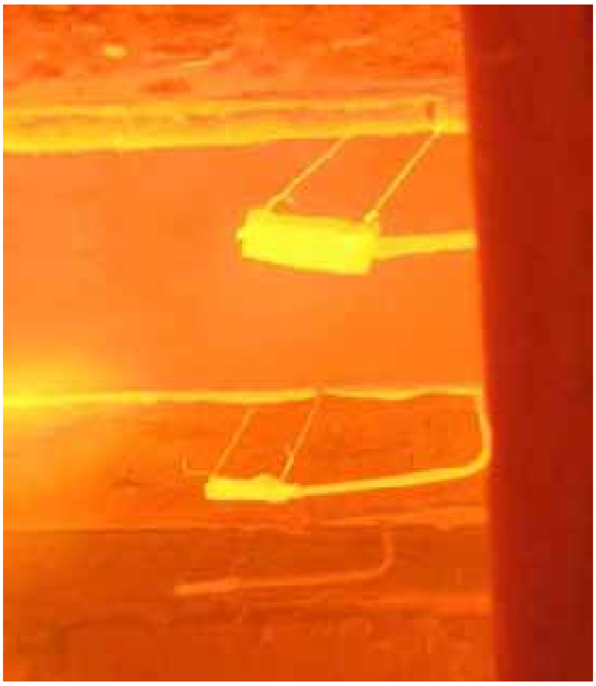

Figure 4.11 Plate thermometers in the furnace during a fire test.

The temperature was measured within the concrete specimens. In each specimen a total of 20 thermocouples, 1 mm type K, were mounted before the concrete was casted. The thermocouples were positioned at four different locations, in the quarter points of the fire exposed area, and at each position at five depths from the fire exposed surface, 10, 25, 40, 80 and 120 mm. The positions of the thermocouples are shown in figure 4.12. The thermocouples were connected to a data acquisition system as shown in figure 4.13.

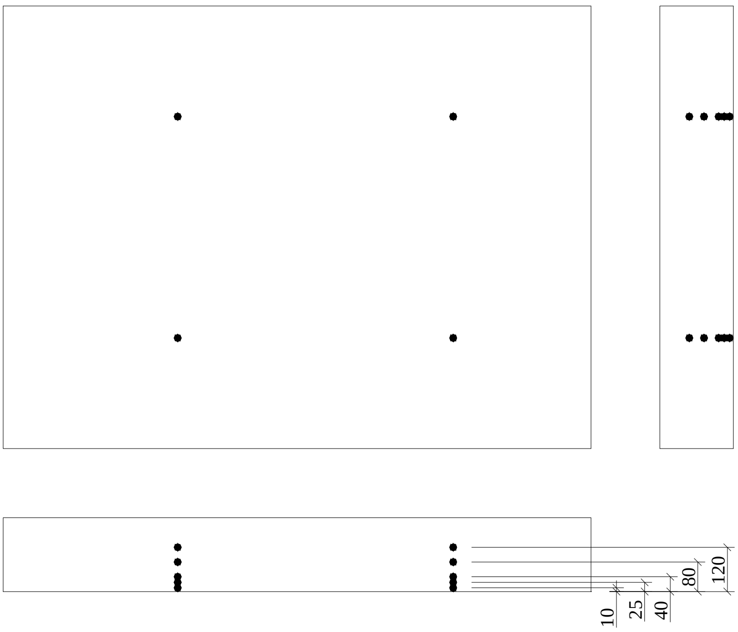

Figure 4.12 Measuring positions of temperature in the large slabs.

Figure 4.13 Temperature measurements in a concrete slab.

4.3.3 Load measurements

All large slab specimens were loaded in compression. In order to apply load a post-stressing system was used, i.e. the load was applied through threaded bars mounted in the aluminium pipes going through the specimens. Six bars were used in each specimen. The bars, designated Dywidag, had a diameter of 36 mm. The load was applied by using special pump equipment as shown in figure 4.14.

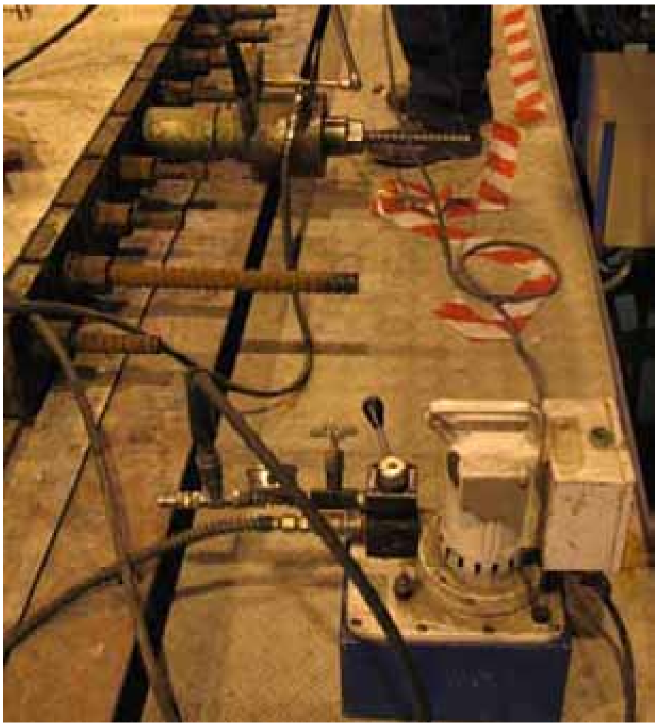

Figure 4.14 Equipment for post-stressing the Dywidag bars.

In order to ensure that a correct load level was applied, and to enable continuous measurement of the load level during the fire tests, load cells were mounted in the loading system. Specimens with load cells mounted are shown in figure 4.15. The load cells were coupled to a HBM data acquisition system.

Figure 4.15 Load cells mounted between steel plates.

4.3.4 Vapour pressure measurements

The same type of measuring system as used in the small slabs were employed on the large slabs, see figure 4.5. One end of each steel pipe was placed near the surface to be fire tested. The pipe extended from the measurement point through the test specimen, exiting on the cold side. To ensure that no concrete, i.e. cement paste, would fill the pipes, thin welding bars were inserted into the pipes during casting. Figure 4.16 shows a pressure measurement station with nine (9) steel pipes and two thermocouples. The struts placed at each of the four corners of the measurement station are used to position the whole apparatus correctly in the concrete specimen. The steel pipes are 10, 20, 30, 40, 50, 60, 70, 80 and 90 mm shorter than the four struts. This setup is then placed in the casting mould with the struts placed on the surface which is to be exposed to the fire, ensuring that each pressure measurement is made at the expected distance from the surface exposed to fire.

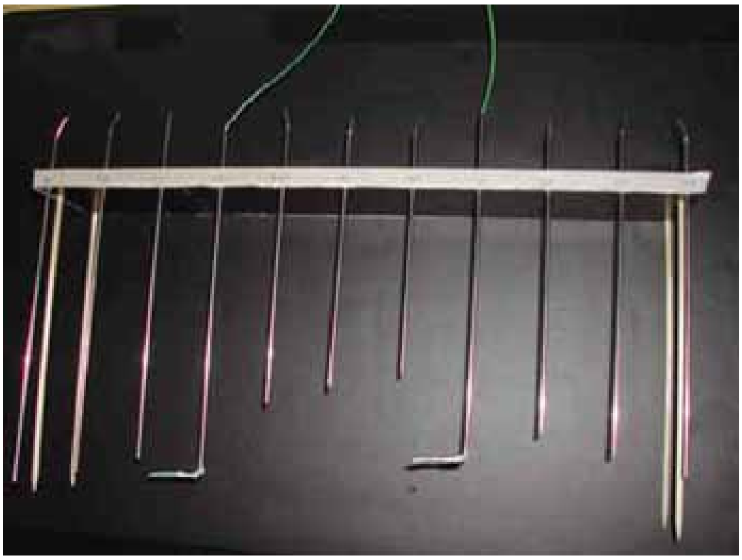

Figure 4.16 A measurement station used in some large slab specimens.

When the fire tests were conducted the welding bars inside the steel pipes were removed and the pipes were filled with high temperature silicone oil, Sil 300, produced by Haake. Filling of the pipes was conducted by inserting a thin injection needle and carefully injecting oil from the bottom of the pipe to ensure that no air was trapped. Outside the concrete the steel pipes were connected to a pressure gauge using a T-junction (see figure 4.17). The pressure gauges that were used were of the type P8AP/100bar from Hottinger Baldwin Messtechnik GmbH.

Figure 4.17 Pipes connected to pressure gauges.

4.3.5 Spalling measurements

The spalling depth was measured in a mesh with a grid size of 50 x 50 mm^2. The measurements were made using a calliper. A steel net with grid size 50 x 50 mm^2 was placed on the fire exposed surface of the specimen and used as a reference when measuring the spalling depth. A specimen with the steel grid mounted is shown in figure 4.18.

Figure 4.18 Specimen with a grid for spalling measurement mounted.

4.4 Beam tests

4.4.1 Test set-up

The beam specimens were always tested on a large horizontal furnace (a floor furnace) with a clear opening of 5000 x 3000 mm^2. The beams were placed on the walls of the furnace. Two beams were tested each time, together with a number of slab specimens. In figure 4.19 is the test set-up shown for testing of beams. The closest beam is loaded with one actuator at each third-point, and the other beam with two actuators, i.e. twice the load.

Two furnace tests were performed with beam specimens. Both tests were carried out with a standard fire scenario in accordance with the European standard EN 1363-1, similar to ISO 834. The furnace temperature was measured with plate thermometers. The measuring point was 100 mm below the fire exposed surface of the specimens.

The pressure in the furnace was controlled to be 20 Pa higher compared to the laboratory, i.e. an overpressure in the furnace.

Figure 4.19 Beam specimens placed on the horizontal furnace.

4.4.2 Temperature measurements

The temperature was measured within the beam specimens. In each specimen a total of 30 thermocouples, 1 mm type K, were mounted before the concrete was casted. The thermocouples were positioned at six different locations, in the quarter points of the fire exposed area, and at the centre of the beam length, and at each position at five depths from the fire exposed surface, 10, 25, 40, 80 and 120 mm. The positions of the thermocouples are shown in figure 4.20. The thermocouples were connected to a data acquisition system.

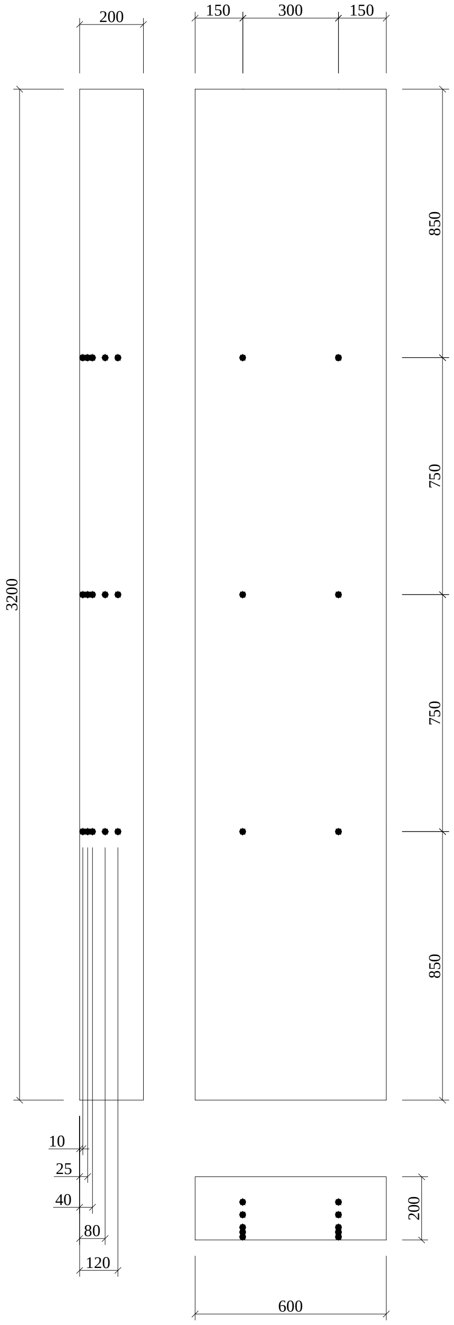

Figure 4.20 Position of temperature measurements within the beam specimens.

4.4.3 Load measurements

The load was not measured with external load cells on the beams. The load was applied through hydraulic pistons, and the load was controlled through the oil pressure. The load level had been calibrated before the tests were carried out. The load was applied at the third-points, i.e. 1.0 m from the supporting furnace walls on both sides. Figure 4.19 above show the load arrangement. The two beams of concrete recipe 10 were loaded with 3.3 kN and 6.7 kN respectively. The two beams of concrete recipe 46 were loaded with 4 kN and 8 kN respectively at each load point.

4.4.4 Spalling measurements

The spalling depth was measured in a mesh with a grid size of 50 x 50 mm^2. The measurements were made using a calliper. A steel net with grid size 50 x 50 mm^2 was placed on the fire exposed surface of the specimen and used as a reference when measuring the spalling depth. A specimen with the steel grid mounted is shown in figure 4.21.

Figure 4.21 Grid for spalling measurement mounted on a beam specimen.

4.5 Other tests performed

4.5.1 Compressive strength

The compressive strength was measured on 150 x 150 x 150 mm^3 cubes. The strength was determined at 28 days age and at the time of fire testing. The tests were made in accordance with EN 12390-3.

4.5.2 Moisture content

The moisture content was measured on the cubes used for measurement of compressive strength. After the strength test the material was weighted and thereafter placed in an oven and dried at 105 °C. The specimens were kept in the oven until the weight had stabilized. The moisture content was then calculated as the difference between the initial weight and the weight after drying, divided with the dry weight.

5 Results

5.1 House building concrete

5.1.1 Small slab specimens

The results from the tests on the small slab specimens are presented in appendix A. A summary of the test results is given in table 5.1 below.

Table 5.1 Test results from small slab tests.

Specimen	Max spalling (mm)	Mean spalling (mm)	Spalling time (min)	Weight loss (%)	Fire curve (-)	Appl. load (kN)	Appl. stress (MPa)	Age (days)	Moisture content (%)	Compr. strength (MPa)
1-1	43	20	14,8	8,0	std	624	6,2	176	4,5	63
1-4	40	21	14,8	9,0	std	617	6,2	177	4,5	63
1-5	29	17	12,7	3,0	std	634	6,3	400	4,5	63
2-1	62	32	9,0	13,0	std	622	6,2	180	4,1	61
2-4	36	19	12,8	10,0	std	616	6,2	180	4,1	61
3-3	51	33	19,4	17,4	std	601	6,0	183	5,1	60
3-5	46	33	14,0	17,5	std	609	6,1	183	5,1	60
4-1	0	0	-	2,2	std	588	5,9	183	4,3	58
4-3	0	0	-	-	std	0	0,0	99	-	-
4-4	0	0	-	1,4	std	575	5,8	183	4,3	58
5-2	0	0	-	3,3	std	585	5,8	181	4,9	58
5-6	0	0	-	1,3	std	583	5,8	181	4,9	58
6-2	35	28	15,4	11,0	std	456	4,6	181	4,6	46
6-4	45	20	14,6	11,4	std	458	4,6	182	4,6	46
6-6	0	0	-	-v	std	0	0,0	94	-	-
7-3	0	0	-	4,7	std	530	5,3	182	4,8	53
7-5	0	0	-	0,4	std	530	5,3	182	4,8	53
8-13	0	0	-	3,4	std	588	5,9	181	5,7	58
8-15	0	0	-	2,6	std	576	5,8	181	5,7	58
9-3	43	26	13,8	12,0	std	414	4,1	181	5,0	42
9-6	55	27	17,0	15,0	std	427	4,3	181	5,0	42
10-1	66	26	21,6	15,0	std	391	3,9	272	4,6	47
10-2	38	24	17,2	12,3	std	394	3,9	272	4,6	47
10-3	34	18	19,9	7,8	std	191	1,9	273	4,6	47
10-4	36	17	18,3	8,3	std	228	2,3	273	4,6	47
10-5	40	19	22,0	9,7	std	194	1,9	371	4,2	48
10-6	0	0	-	2,4	std	195	1,9	367	4,2	48
10-12	56	15	15,4	-	std	198	2,0	107	5,3	39
10-14	0	0	-	-	std	386	3,9	101	5,3	39
10-16	29	11	23,1	6,8	std	400	4,0	286	4,6	47
10-17	43	25	15,7	-	std	195	2,0	104	5,3	39
10-18	30	21	14,9	-	std	372	3,7	99	5,3	39
10-21	38	19	17,7	10,0	std	386	3,9	184	5,0	46
10-22	24	3	15,4	7,4	std	0	0,0	182	5,0	46
10-23	0	0	-	2,2	std	392	3,9	372	4,2	48

Table 5.1 Cont.

Specimen	Max spalling (mm)	Mean spalling (mm)	Spalling time (min)	Weight loss (%)	Fire curve (-)	Appl. load (kN)	Appl. stress (MPa)	Age (days)	Moisture content (%)	Compr. strength (MPa)
10-24	0	0	-	6,0	std	0	0,0	183	5,0	46
10-25	0	0	-	1,9	std	395	3,9	372	4,2	48
10-26	43	19	13,4	11,9	std	398	4,0	185	5,0	46
11-5	0	0	-	1,8	std	466	4,7	197	6,0	48
11-7	33	14	17,7	8,0	std	472	4,7	198	6,0	48
12-1	43	20	10,0	11,1	std	417	4,2	194	5,7	41
12-2	54	29	13,4	14,8	std	413	4,1	195	5,7	41
12-3	37	14	16,8	8,3	std	0	0,0	183	5,7	41
12-8	28	13	15,5	7,3	std	0	0,0	182	5,7	41
13-6	41	22	17,8	9,8	std	443	4,4	184	5,7	45
13-7	44	21	20,4	14,2	std	465	4,6	184	5,7	45
14-3	0	0	-	2,4	std	475	4,8	191	5,7	48
14-8	0	0	-	2,0	std	476	4,8	196	5,7	48
15-5	50	26	10,2	13,4	std	701	7,0	351	6,0	70
15-6	49	26	10,0	13,8	std	703	7,0	343	6,0	70
16-10	24	8	17,8	5,6	std	0	0,0	337	6,6	56
16-4	40	22	12,7	12,2	std	552	5,5	337	6,6	56
16-6	44	25	13,0	11,6	std	548	5,5	338	6,6	56
16-9	25	8	18,3	5,6	std	0	0,0	336	6,6	56
17-3	0	0	-	2,1	std	505	5,1	344	4,7	51
17-9	0	0	-	2,0	std	507	5,1	342	4,7	51
18-5	36	10	17,7	6,3	std	422	4,2	182	4,4	43
18-6	0	0	-	5,1	std	430	4,3	182	4,4	43
19-5	0	0	-	1,7	std	433	4,3	186	5,0	44
19-6	0	0	-	1,5	std	427	4,3	187	5,0	44
25-5	0	0	-	1,7	std	542	5,4	192	4,2	55
25-6	0	0	-	1,8	std	544	5,4	192	4,2	55
26-3	0	0	-	1,7	std	447	4,5	190	6,2	46
26-8	0	0	-	1,4	std	462	4,6	194	6,2	46
27-1	0	0	-	1,7	std	513	5,1	195	5,5	51
27-2	0	0	-	2,0	std	502	5,0	196	5,5	51
46-9	58	29	4,0	16,5	hc	567	5,7	208	5,2	58
46-10	67	42	9,5	19,2	std	575	5,8	190	5,2	58
46-11	46	26	11,3	13,3	std	572	5,7	194	5,2	58
46-12	43	25	3,0	12,0	hc	574	5,7	204	5,2	58
46-13A	77	48	28,8	22,6	slow	600	6,0	203	5,2	58
46-13B	30	11	10,2	6,1	std	0	0,0	187	5,2	58
46-14A	58	36	3,4	16,1	hc	571	5,7	205	5,2	58
46-14B	39	20	14,9	11,7	std	0	0,0	188	5,2	58
46-16A	84	44	28,5	20,3	slow	565	5,6	195	5,2	58
46-16B	56	31	10,3	18,1	std	621	6,2	314	5,2	62
46-17	75	38	10,1	21,9	std	608	6,1	320	5,2	62
46-18	52	25	12,2	14,4	std	607	6,1	357	4,7	62
46-19	49	21	11,3	12,4	std	275	2,8	189	5,2	58
46-20A	68	35	11,7	20,2	std	312	3,1	365	4,7	62

Table 5.1 Cont.

Specimen	Max spalling (mm)	Mean spalling (mm)	Spalling time (min)	Weight loss (%)	Fire curve (-)	Appl. load (kN)	Appl. stress (MPa)	Age (days)	Moisture content (%)	Compr. strength (MPa)
46-20B	76	42	9,9	22,8	std	294	2,9	189	5,2	58
46-21	49	25	14,9	11,4	std	311	3,1	356	4,7	62
46-22	51	27	13,0	13,4	std	299	3,0	308	5,2	62
46-23	65	36	14,0	21,3	std	644	6,4	352	4,7	62
46-24	72	41	13,1	20,3	std	298	3,0	309	5,2	62
46-25	70	45	10,8	20,0	std	277	2,8	101	5,2	56
46-26	80	44	11,0	21,7	std	312	3,1	101	5,2	56
46-27	61	39	11,2	16,7	std	556	5,6	102	5,2	56
46-28	76	53	10,2	24,8	std	585	5,8	105	5,2	56
50-1	0	0	-	-	std	413	4,1	176	-	43
50-2	0	0	-	1,3	std	433	4,3	176	-	43
55-1	0	0	-	2,0	std	605	6,0	195	6,8	58
55-2	0	0	-	2,0	std	590	5,9	196	6,8	58
56-3	0	0	-	1,9	std	667	6,7	196	6,1	63
56-4	0	0	-	3,1	std	628	6,3	197	6,1	63
57-1	0	0	-	2,1	std	398	4,0	221	4,6	40
57-2	0	0	-	3,2	std	467	4,7	221	4,6	40

5.1.2 Large specimens

The furnace temperature was measured with six plate thermometers in each test. Three furnace tests were carried out and the tested specimens and characteristics for each test are given in table 5.2. The measured furnace temperature is shown in figures 5.1-5.3.

Table 5.2 Large furnace tests

Test date	Fire curve	Test time (minutes)	Slab specimens	Beam specimens
2006-02-10	Standard	67	7-1, 8-1, 10-1, 10-2, 10-3, 10-4	10-3, 10-4
2007-05-31	Standard	45	10-8, 46-1	46-1, 46-2
2007-06-05	HC	41	10-5, 46-2	-

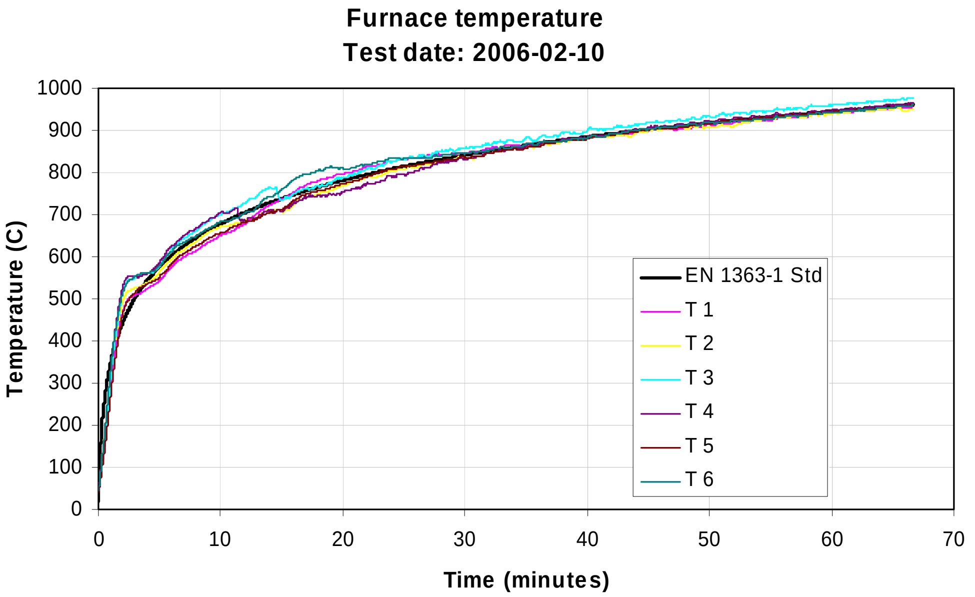

Figure 5.1 Furnace temperatures in the test on November 10, 2006.

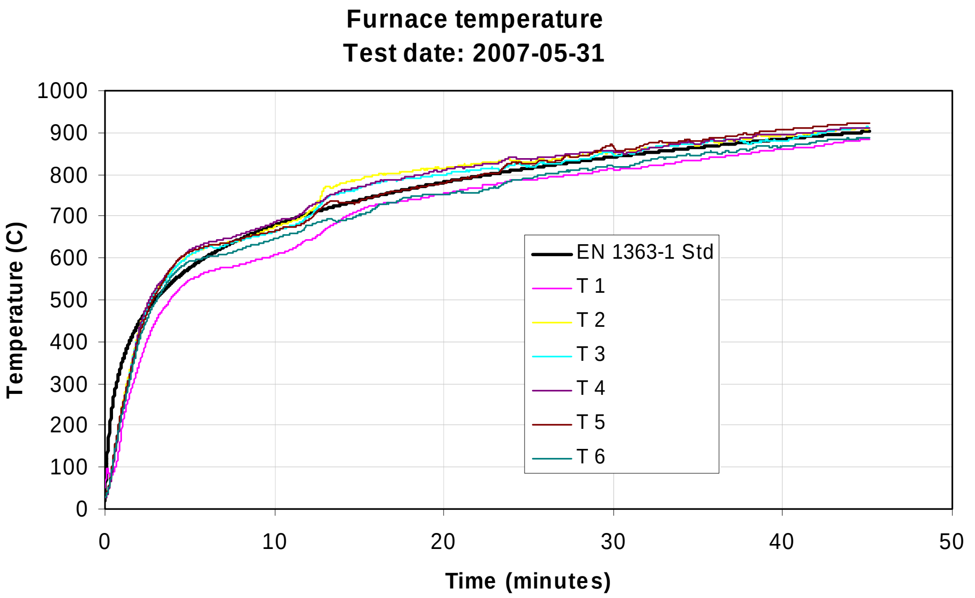

Figure 5.2 Furnace temperatures in the test on May 31, 2007.

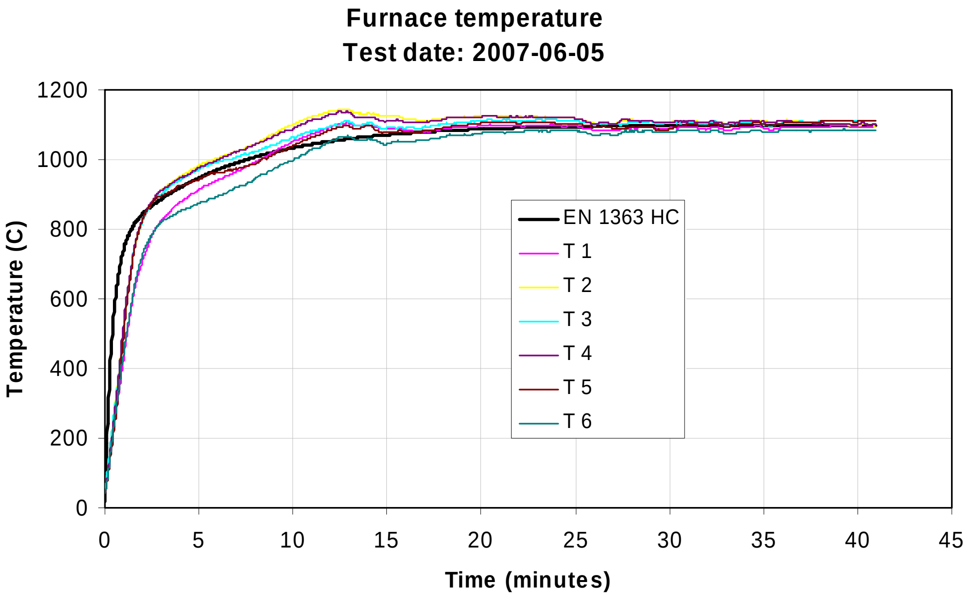

Figure 5.3 Furnace temperatures in the test on June 5, 2007.

The visual observations made during the test are presented in Tables 5.3-5.5.

Table 5.3 Observations made during the test made on February 10, 2006.

Time (min:sec)	**Observation**
00:00	Start of test
09:30	Slab 10-1: Spalling start Slab 10-3: Spalling start
10:10	Slab 10-2: Spalling start, large flakes. Slab 10-4: Spalling start, large flakes.
10:30	Beam 10-3: Spalling start.
15:30	Slab 10-1: The whole surface has spalled off. Slab 10-2: The whole surface has spalled off.
18:00	Slab 10-3: Reinforcement visible.
19:00	Slab 10-2: Reinforcement visible.
21:00	Slab 10-1: Reinforcement visible. Slab 10-4: Reinforcement visible.
24:00	Slab 10-3: Decreased intensity of spalling. Slab 10-4: Decreased intensity of spalling.
25:00	Slab 10-1: Decreased intensity of spalling. Slab 10-2: Decreased intensity of spalling.
64:00	Test is terminated

Table 5.4 Observations made during the test made on May 31, 2007.

Time (min:sec)	Observation
00:00	Start of test
06:10	Slab 46-1: Spalling start
08:50	Slab 10-8: Spalling start
09:45	Slab 10-8: Heavy spalling
10:00	Slab 46-1: 75 % of surface spalled to depth 4-5 cm
12:30	Beam 46-1: Spalling start
14:10	Beam 46-2: Spalling start
15:00	Slab 46-1: Reinforcement visible
18:30	Slab 10-8: Reinforcement visible
42:00	Slab 46-1: Still spalling
45:00	Test is terminated

Table 5.5 Observations made during the test made on June 5, 2007.

Time (min:sec)	Observation
00:00	Start of test
01:20	Slab 10-5: Spalling start
02:30	Slab 46-2: Spalling start
06:00	Slab 46-2: Reinforcement visible
41:00	Test is terminated

5.1.2.1 Temperature measurements

The temperature was measured at different locations on both the slab and the beam specimens. The presented results are mean values on each specimen at different depths, i.e. a mean value of three or four measurements at different locations. The measured values for each individual thermocouple are presented in the appendices.

Temperature measurements in the specimens tested on February 10, 2006, are presented in figures 5.4-5.11.

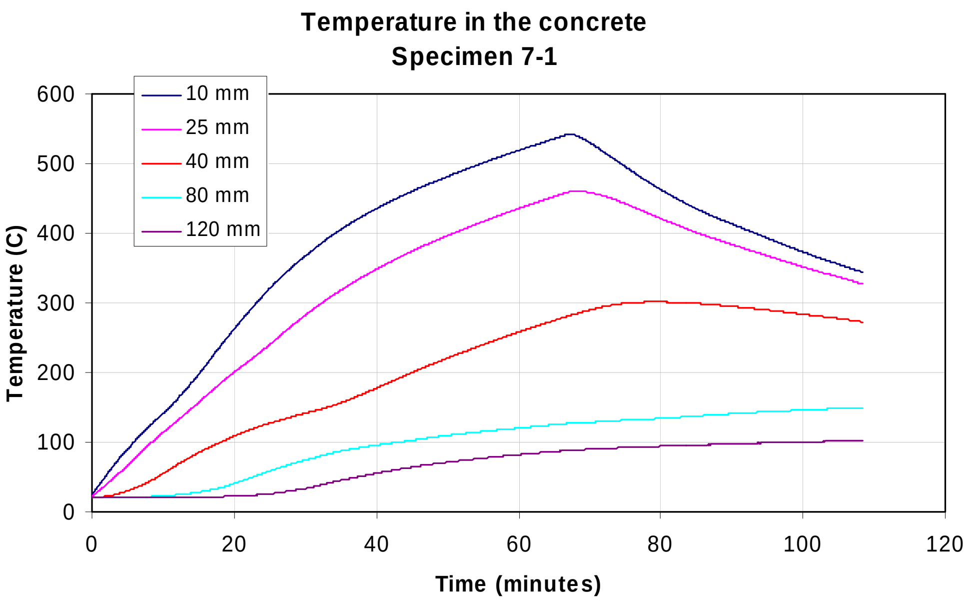

Figure 5.4 Temperatures in slab specimen 7-1 during the test made on February 10, 2006.

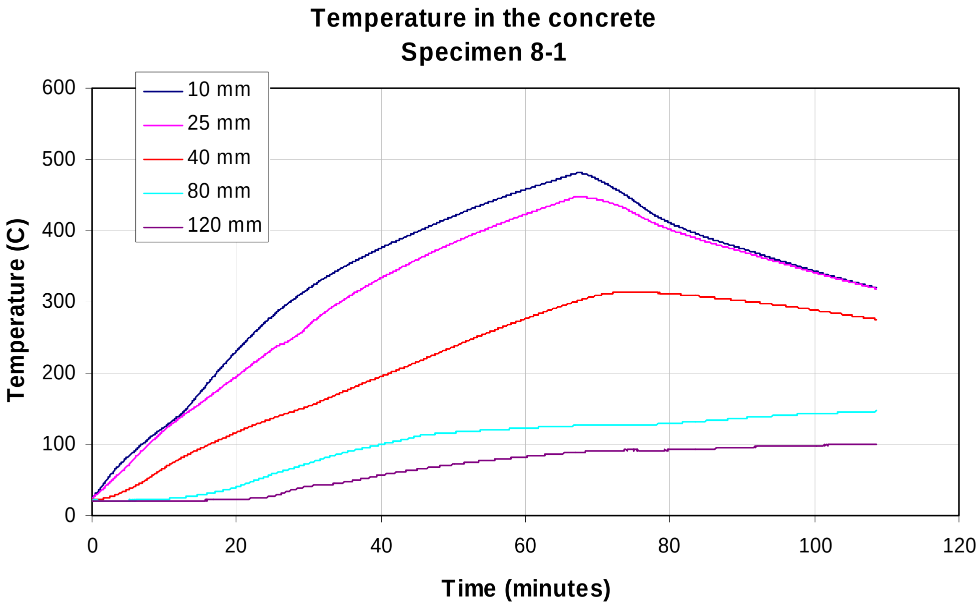

Figure 5.5 Temperatures in slab specimen 8-1 during the test made on February 10, 2006.

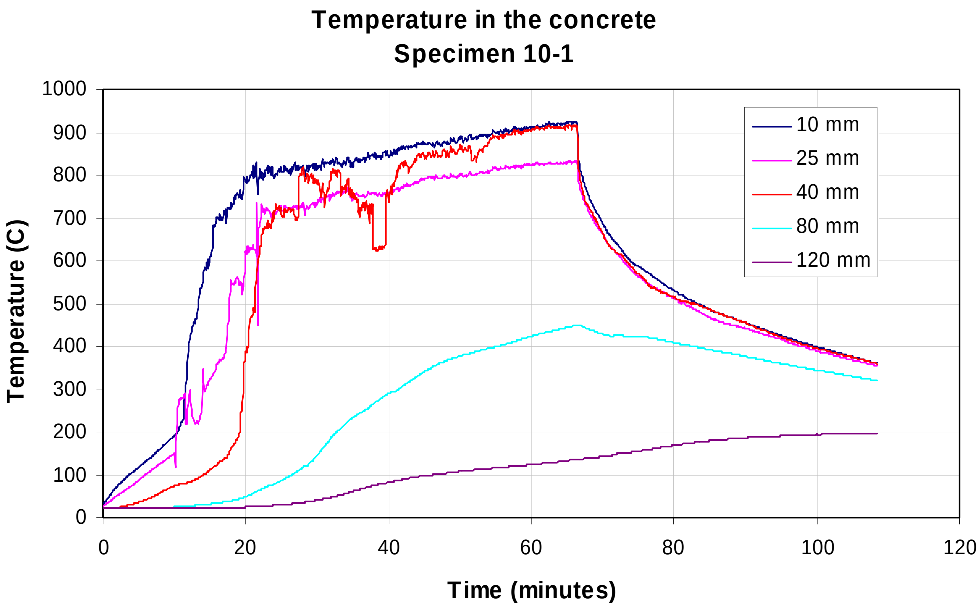

Figure 5.6 Temperatures in slab specimen 10-1 during the test made on February 10, 2006.

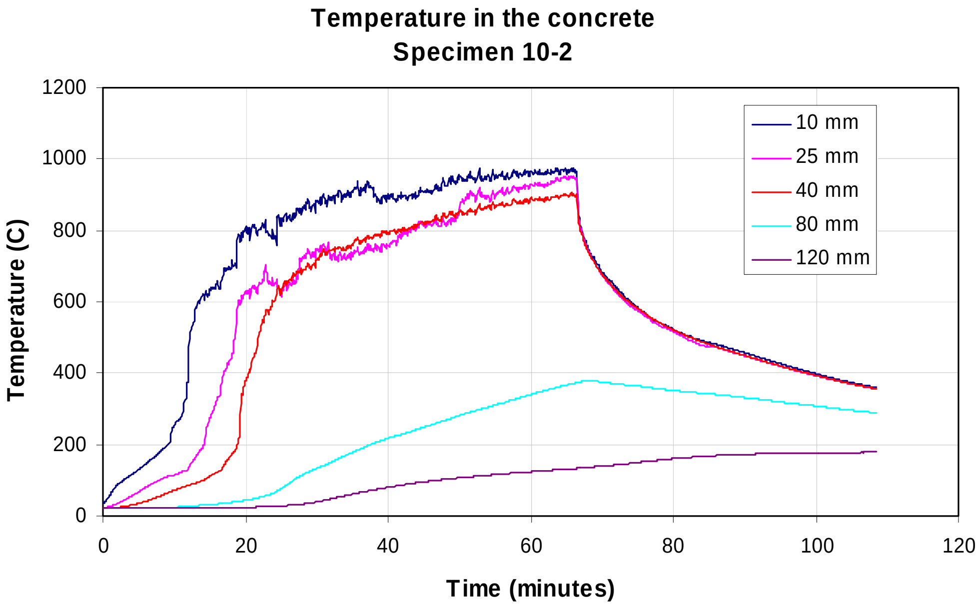

Figure 5.7 Temperatures in slab specimen 10-2 during the test made on February 10, 2006.

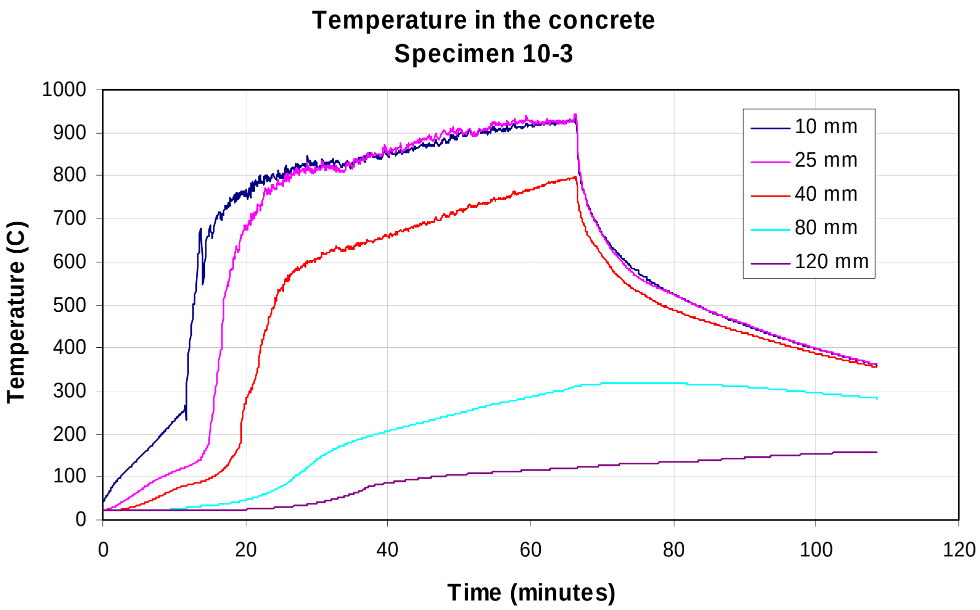

Figure 5.8 Temperatures in slab specimen 10-3 during the test made on February 10, 2006.

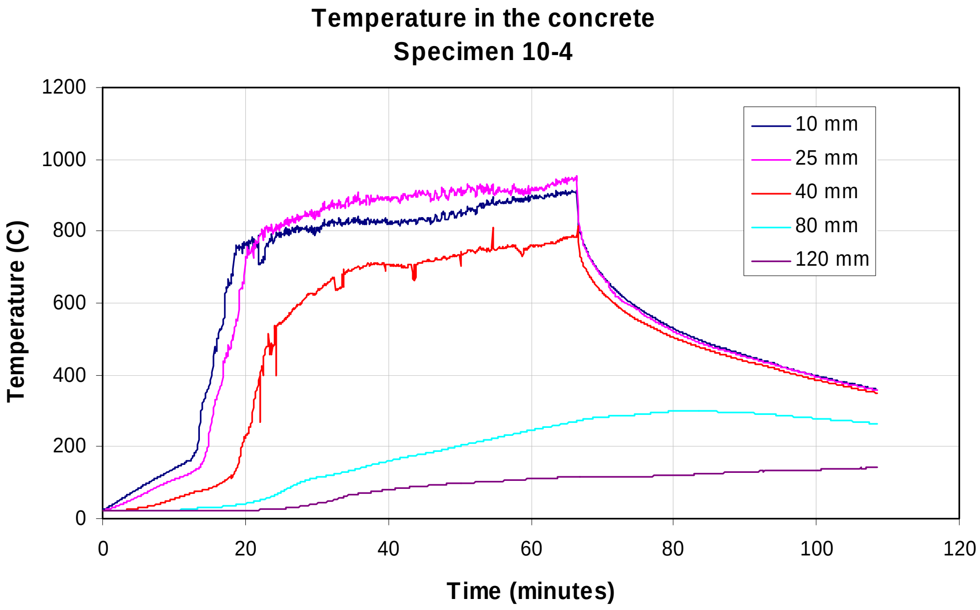

Figure 5.9 Temperatures in slab specimen 10-4 during the test made on February 10, 2006.

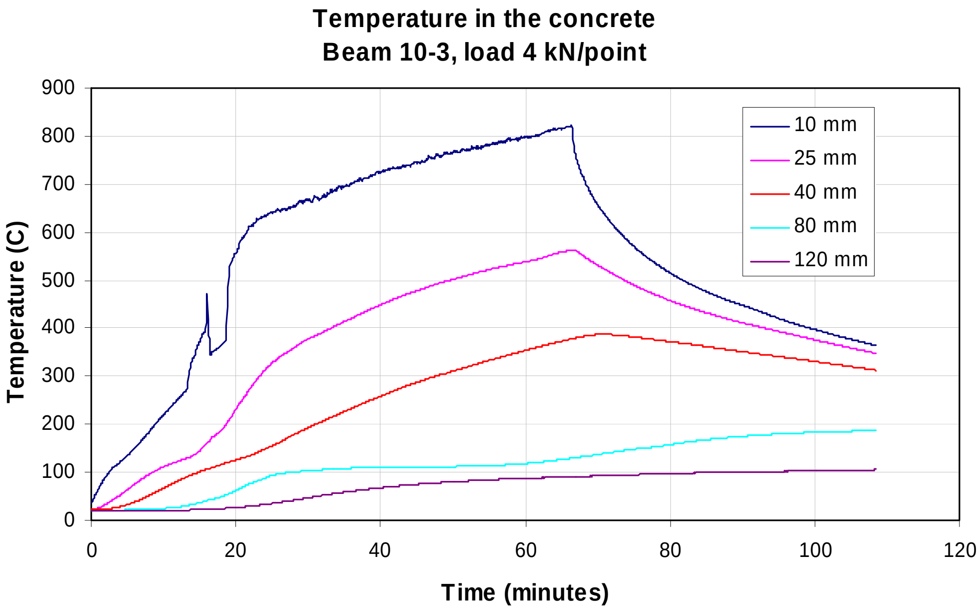

Figure 5.10 Temperatures in beam specimen 10-3 during the test made on February 10, 2006.

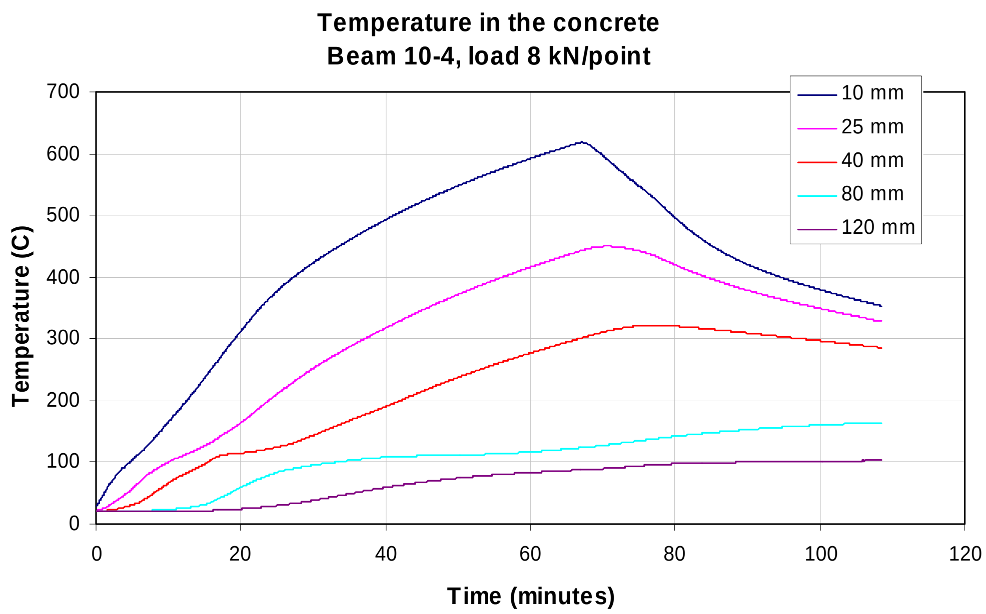

Figure 5.11 Temperatures in beam specimen 10-4 during the test made on February 10, 2006.

Temperature measurements in the specimens tested on May 31, 2007, are presented in figures 5.12-5.15.

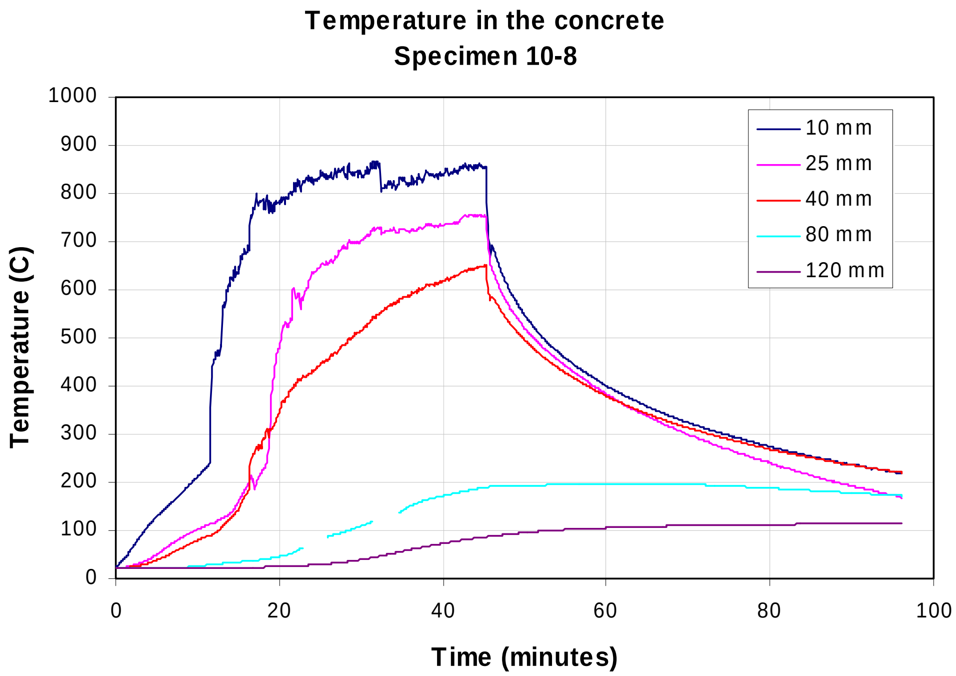

Figure 5.12 Temperatures in slab specimen 10-8 during the test made on May 31, 2007.

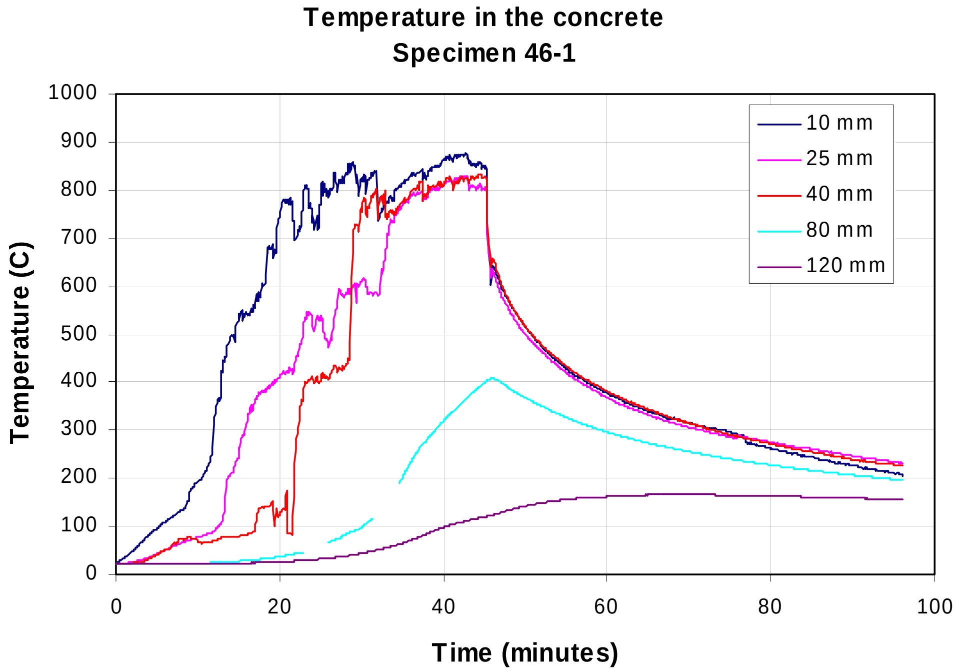

Figure 5.13 Temperatures in slab specimen 46-1 during the test made on May 31, 2007.

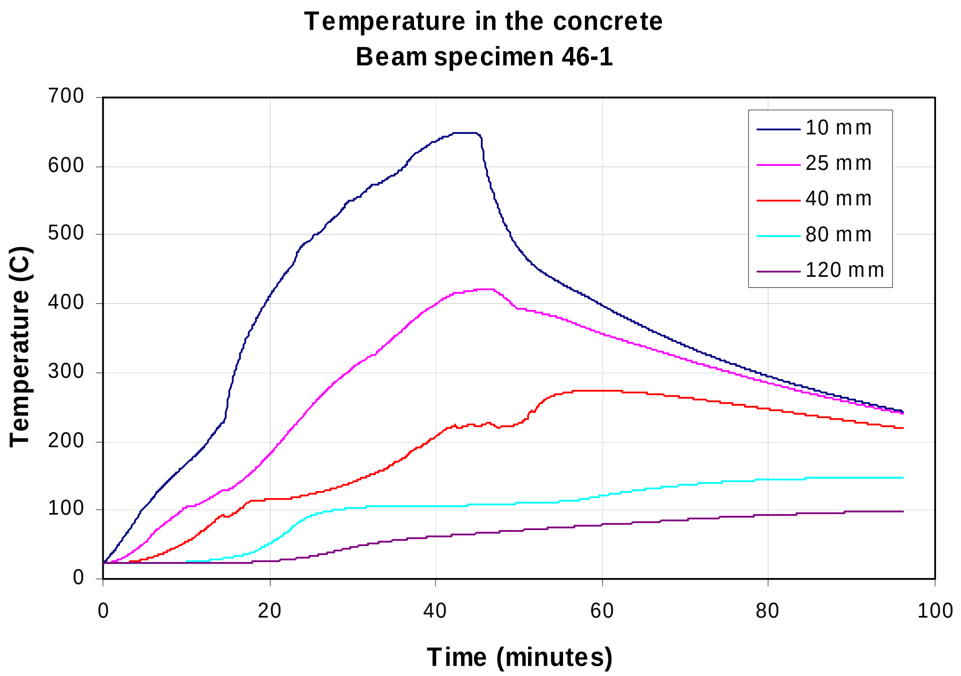

Figure 5.14 Temperatures in beam specimen 46-1 during the test made on May 31, 2007.

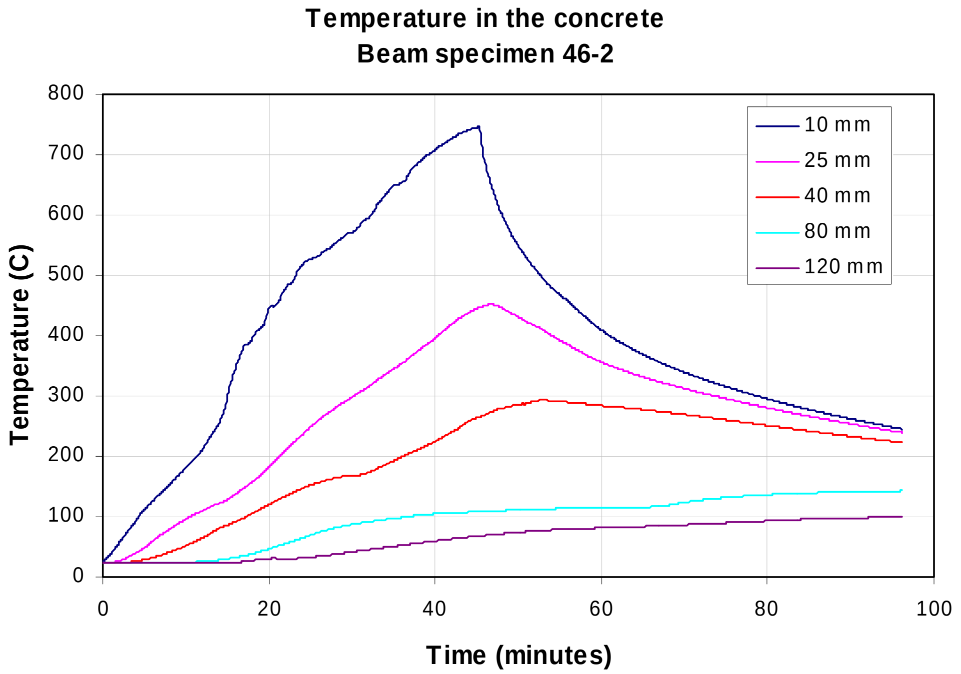

Figure 5.15 Temperatures in beam specimen 46-2 during the test made on May 31, 2007.

Temperature measurements in the specimens tested on June 5, 2007, are presented in figures 5.16-5.17.

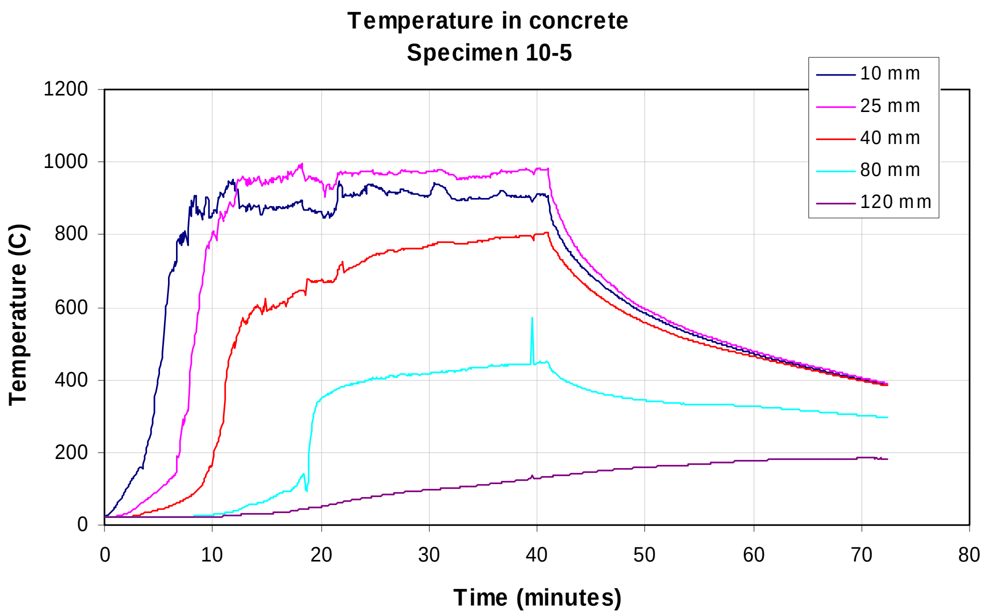

Figure 5.16 Temperatures in slab specimen 10-5 during the test made on June 5, 2007.

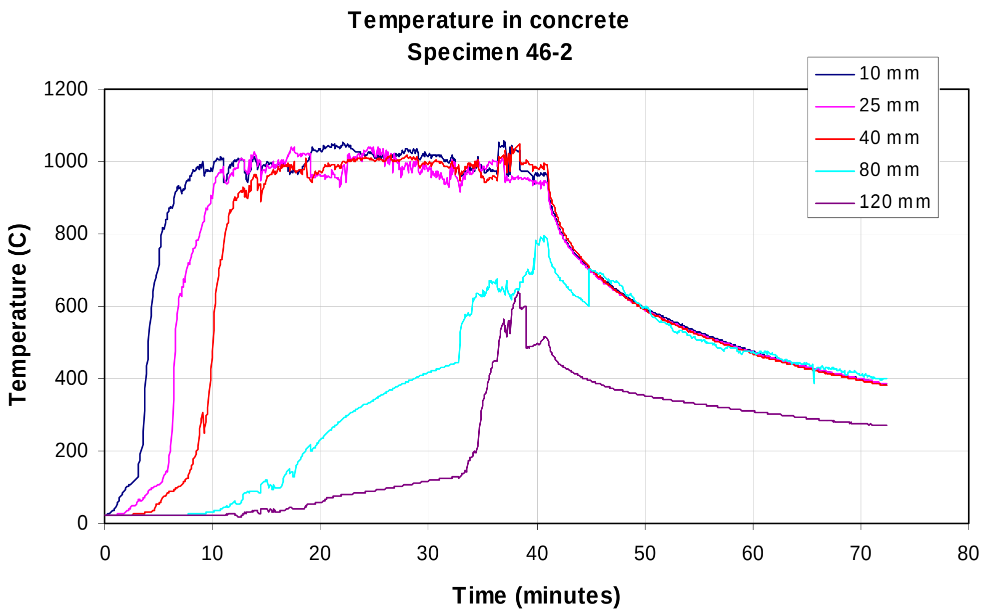

Figure 5.17 Temperatures in slab specimen 46-2 during the test made on June 5, 2007.

5.1.2.2 Load measurements

The specimen pair consisting of specimens 7-1 and 8-1 was loaded initially to 220 kN per bar giving a compressive stress of 5.5 MPa. The load was measured in all bars, and the results are presented in figure 5.18. The specimen pair consisting of specimens 10-1 and 10-2 was loaded to 156 kN per bar giving a compressive stress of 3.9 MPa. Also in this specimen pair the load was continuously measured in all bars and the results are presented in figure 5.19. The third specimen pair consisting of specimens 10-3 and 10-4 was unloaded during the test and no load measurements were made.

Two beams were tested. The beam named 10-3 was loaded with 4 kN in each third point giving a tensile stress of 1 MPa between the loading points on the fire exposed surface. The beam named 10-4 was loaded with 8 kN in each third point giving a tensile stress of 2 MPa between the loading points on the fire exposed surface.

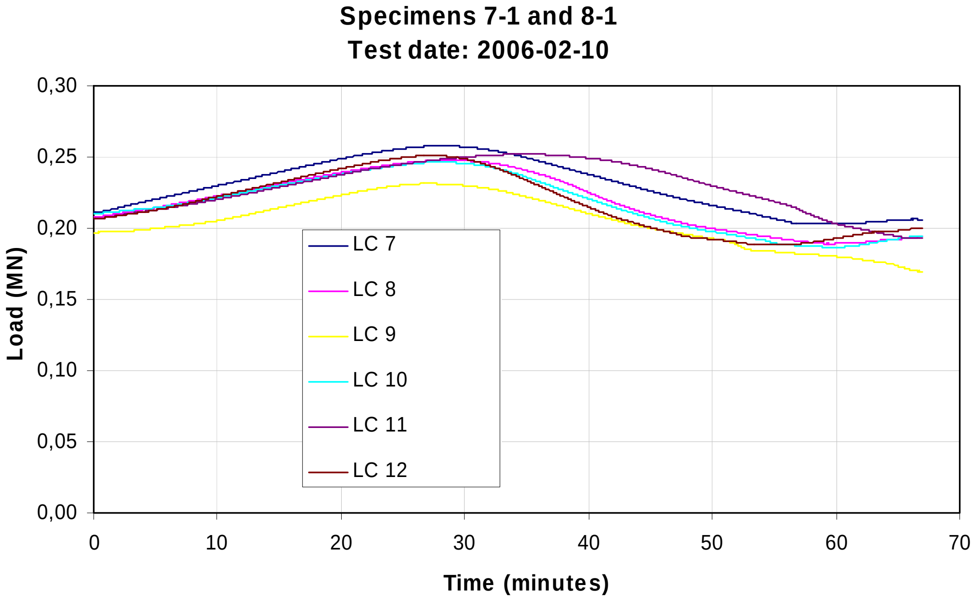

Figure 5.18 Load measurements on specimen pair 7-1 and 8-1.

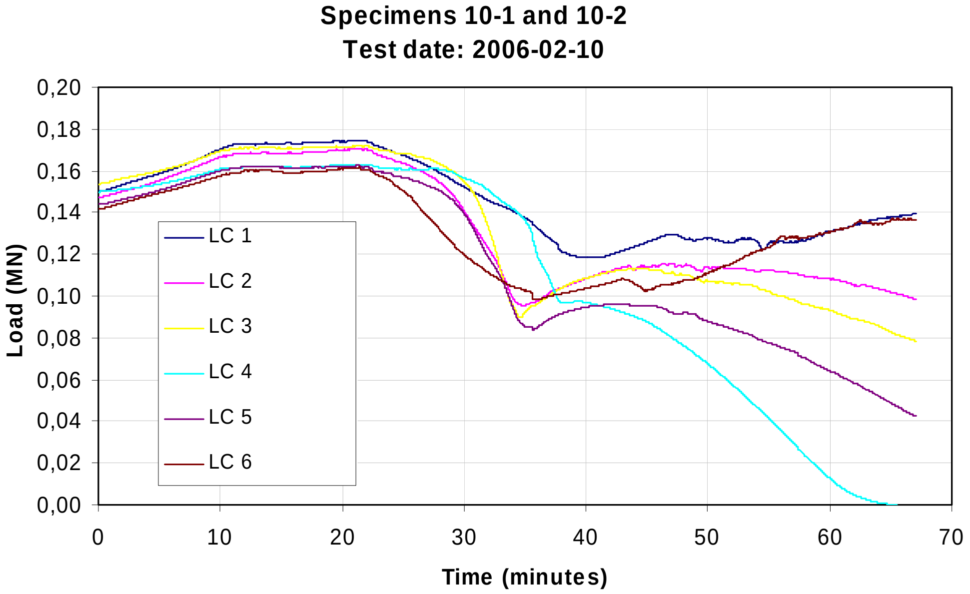

Figure 5.19 Load measurements on specimen pair 10-1 and 10-2.

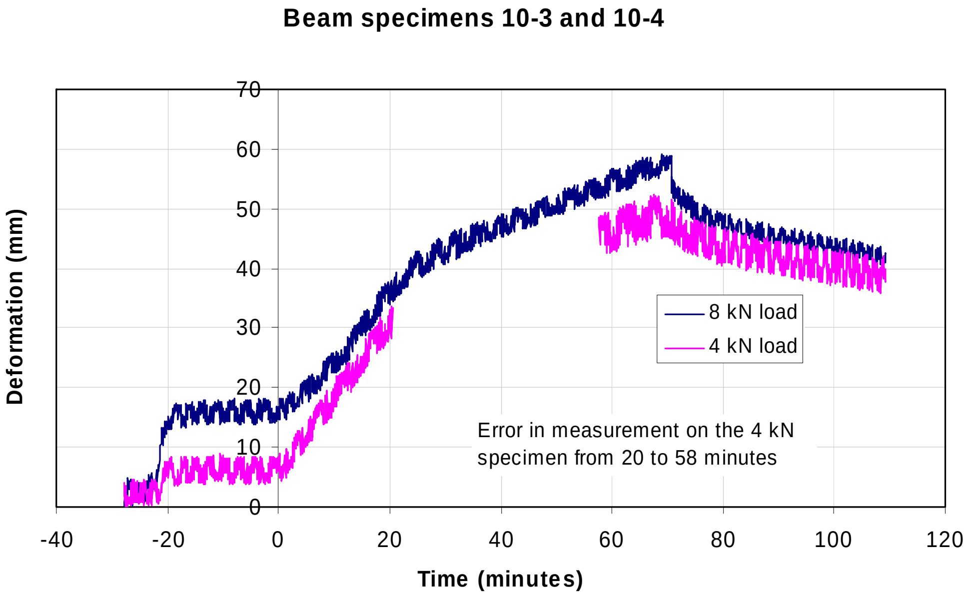

Figure 5.20 Deformation on beam specimens 10-3 and 10-4. Fire test start at time 0.

The specimen pair consisting of specimens 10-8 and 46-1 was loaded initially to 150 kN per bar giving a compressive stress of 3.8 MPa. The load was measured in two bars, and the results are presented in figure 5.21.

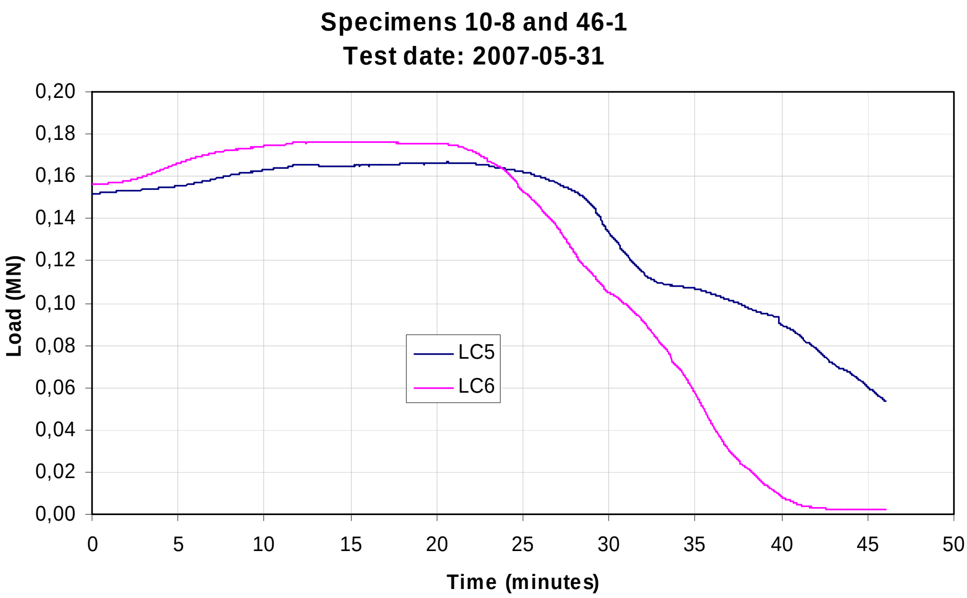

Figure 5.21 Load measurements on specimen pair 10-8 and 46-1.

The specimen pair consisting of specimens 10-5 and 46-2 was loaded initially to 150 kN per bar giving a compressive stress of 3.8 MPa. The load was measured in two bars, and the results are presented in figure 5.22.

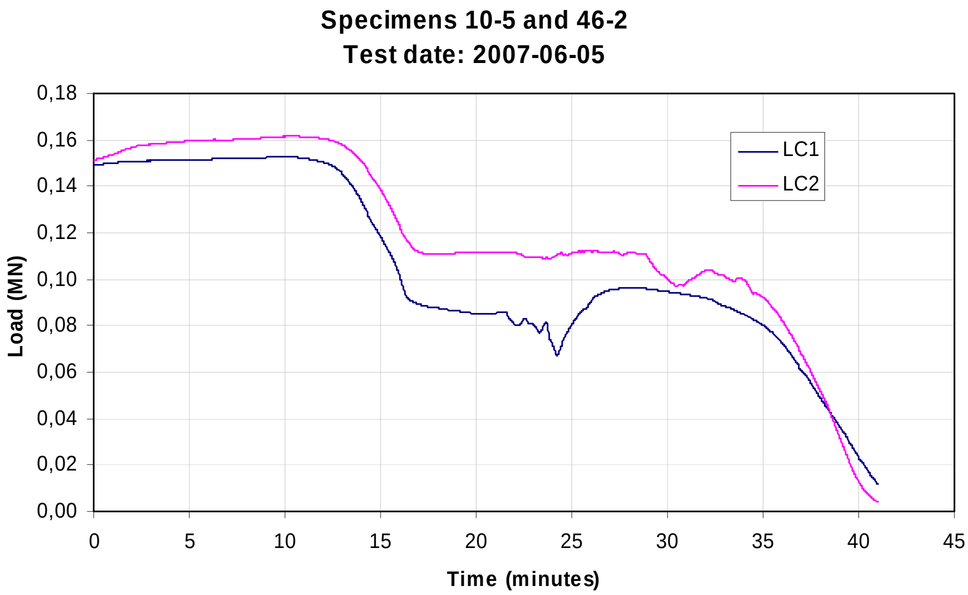

Figure 5.22 Load measurements on specimen pair 10-5 and 46-2.

5.1.2.3 Spalling measurements

5.1.2.3.1 Test on February 10, 2006

The measured spalling depth of the fire exposed surface was measured with a grid size of 100 x 100 mm. The measured spalling depths on specimen 7-1 are presented in table 5.6. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.7. A graph showing the spalling depth is presented in figure 5.23.

Table 5.6 Measured spalling depths on slab specimen 7-1.

Position	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
0,0	0	0	0	0	0	0	0	0	0	0	0	0	0
0,1	0	0	0	0	0	0	0	0	0	0	0	0	0
0,2	0	0	0	0	0	0	0	0	0	0	0	0	0
0,3	0	0	0	0	0	0	0	0	0	0	0	0	0
0,4	0	0	0	0	0	0	0	0	0	0	0	0	0
0,5	0	0	0	0	0	0	0	0	0	0	0	0	0
0,6	0	0	0	0	0	0	0	0	0	0	0	0	0
0,7	0	0	0	0	0	0	0	0	0	0	0	0	0
0,8	0	0	0	0	0	0	0	0	0	0	0	0	0
0,9	0	0	0	0	0	0	0	0	0	0	0	0	0
1,0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,1	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.7 Spalling of slab specimen 7-1.

Mean all	0
Mean inner	0
Max measured	0

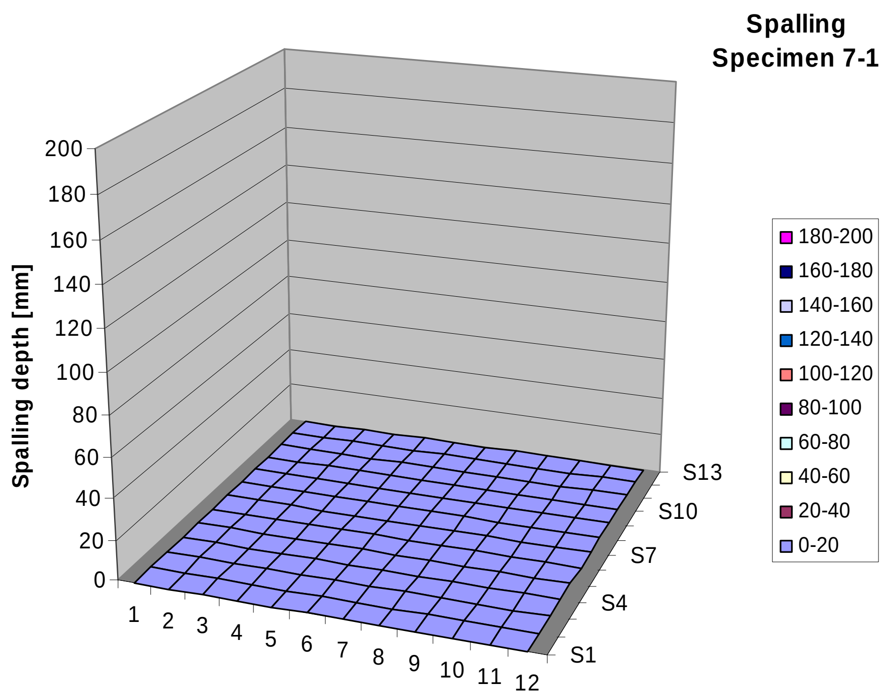

Figure 5.23 Map of spalling depth of slab specimen 7-1.

The measured spalling depths on specimen 8-1 are presented in table 5.8. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.9. A graph showing the spalling depth is presented in figure 5.24.

Table 5.8 Measured spalling depths on slab specimen 8-1.

Position	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
0,0	0	0	0	0	0	0	0	0	0	0	0	0	0
0,1	0	0	0	0	0	0	0	0	0	0	0	0	0
0,2	0	0	0	0	0	0	0	0	0	0	0	0	0
0,3	0	0	0	0	0	0	0	0	0	0	0	0	0
0,4	0	0	0	0	0	0	0	0	0	0	0	0	0
0,5	0	0	0	0	0	0	0	0	0	0	0	0	0
0,6	0	0	0	0	0	0	0	0	0	0	0	0	0
0,7	0	0	0	0	0	0	0	0	0	0	0	0	0
0,8	0	0	0	0	0	0	0	0	0	0	0	0	0
0,9	0	0	0	0	0	0	0	0	0	0	0	0	0
1,0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,1	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.9 Spalling of slab specimen 8-1.

Mean all	0
Mean inner	0
Max measured	0

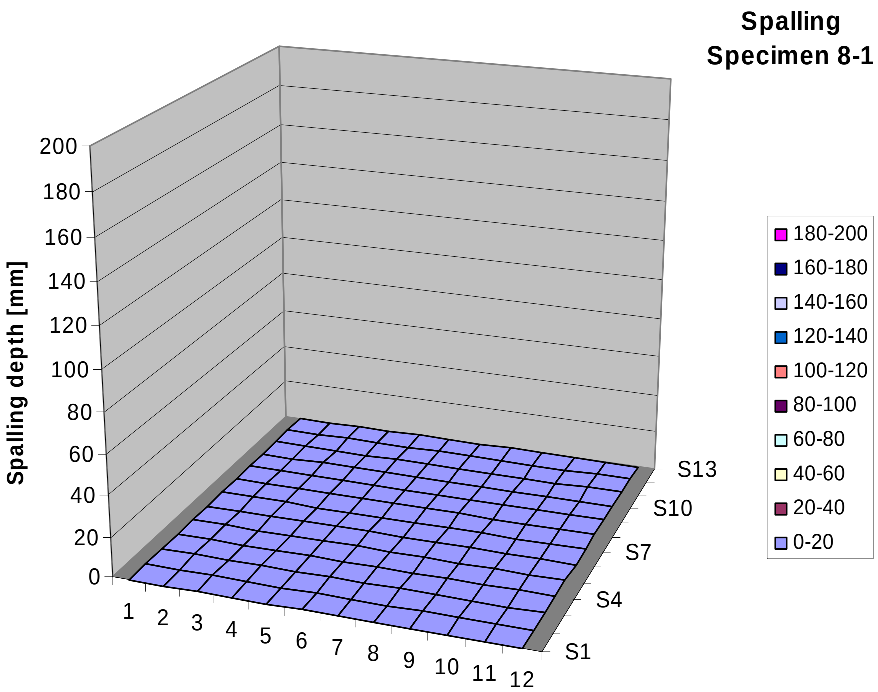

Figure 5.24 Map of spalling depth of slab specimen 8-1.

The measured spalling depths on specimen 10-1 are presented in table 5.10. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.11. A graph showing the spalling depth is presented in figure 5.25.

Table 5.10 Measured spalling depths on slab specimen 10-1.

Position	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
0,0	0	8	22	19	29	34	32	37	25	41	22	20	20
0,1	0	0	18	27	25	30	33	40	42	49	22	25	25
0,2	0	4	32	44	39	39	77	54	54	52	28	23	23
0,3	0	9	47	62	46	47	57	59	47	44	34	27	27
0,4	0	2	62	62	50	46	40	62	42	47	22	42	42
0,5	0	4	65	57	64	48	72	72	57	50	43	32	32
0,6	0	17	72	117	78	84	64	68	44	50	52	33	33
0,7	0	12	74	102	89	88	79	71	51	56	52	34	34
0,8	0	12	65	72	78	89	80	62	46	50	47	33	33
0,9	0	4	70	44	98	92	87	68	57	49	56	47	33
1,0	0	2	44	42	49	82	82	82	82	49	56	47	33
1,1	0	17	32	49	57	102	107	97	87	49	56	47	33

Table 5.11 Spalling of slab specimen 10-1.

Mean all	45
Mean inner	55
Max measured	117

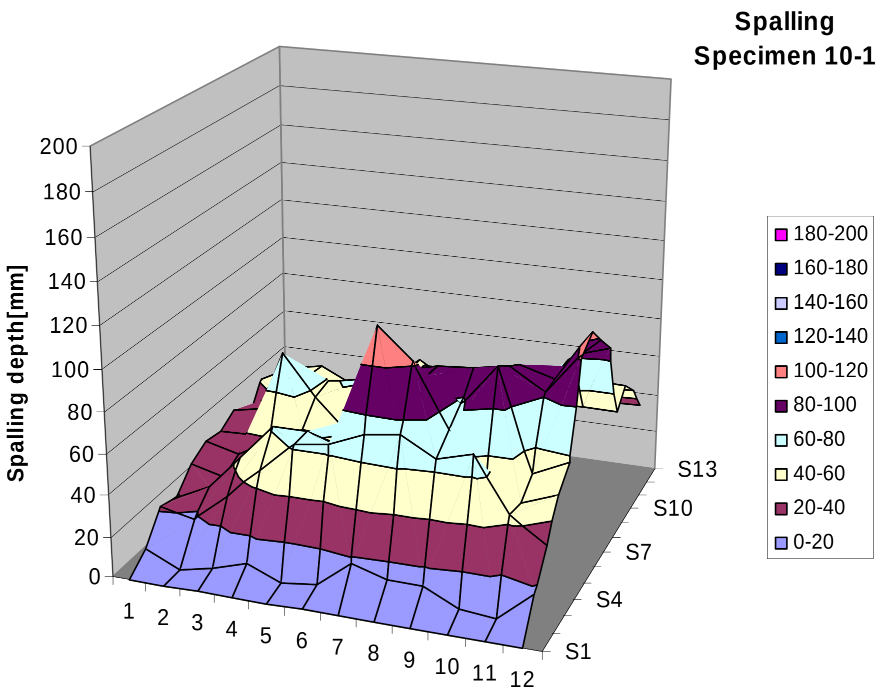

Figure 5.25 Map of spalling depth of slab specimen 10-1.

The measured spalling depths on specimen 10-2 are presented in table 5.12. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.13. A graph showing the spalling depth is presented in figure 5.26.

Table 5.12 Measured spalling depths on slab specimen 10-2.

Position	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
0,0	0	0	0	26	27	20	32	12	18	12	17	6	0
0,1	17	12	9	25	30	28	25	20	22	17	20	0	0
0,2	30	24	35	36	47	37	37	20	32	44	24	0	0
0,3	32	49	42	39	47	37	61	57	57	64	40	0	0
0,4	39	39	39	40	50	57	67	64	55	62	46	0	0
0,5	37	45	30	35	40	47	50	47	47	60	37	0	0
0,6	42	42	36	27	27	25	62	54	58	72	50	0	0
0,7	40	34	36	42	19	35	55	52	62	72	62	0	0
0,8	37	32	21	42	45	60	67	62	55	87	62	0	0
0,9	20	24	20	25	43	47	62	62	50	45	64	0	0
1,0	8	7	7	19	28	47	52	37	22	27	35	0	0
1,1	10	21	30	19	25	25	34	17	12	32	30	0	0

Table 5.13 Spalling of slab specimen 10-2.

Mean all	31
Mean inner	41
Max measured	87

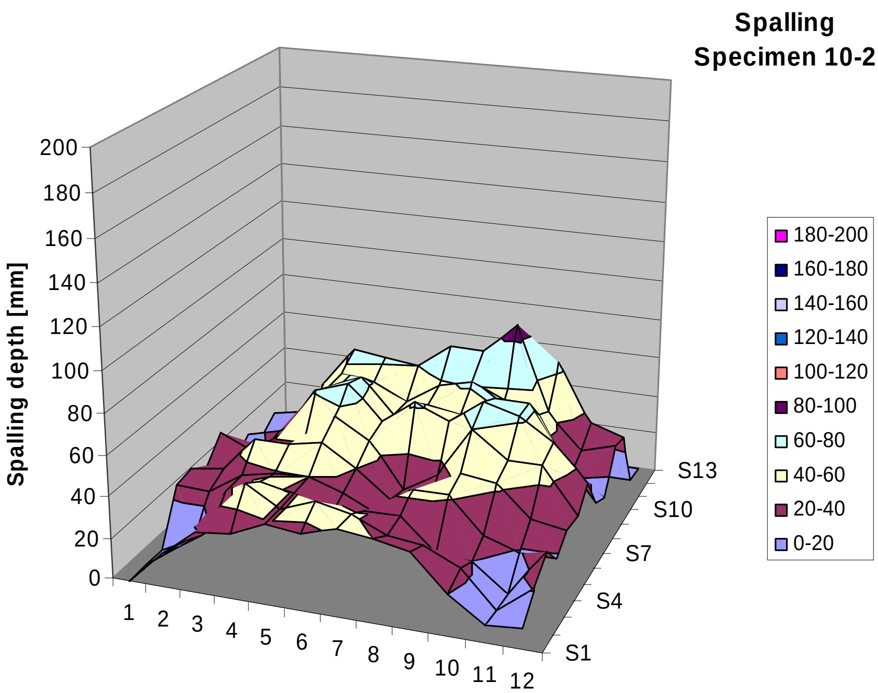

Figure 5.26 Map of spalling depth of slab specimen 10-2.

The measured spalling depths on specimen 10-3 are presented in table 5.14. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.15. A graph showing the spalling depth is presented in figure 5.27.

Table 5.14 Measured spalling depths on slab specimen 10-3.

Position	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
0,0	22	7	0	0	0	0	0	0	0	0	0	0	0
0,1	19	16	26	23	12	11	12	5	7	5	-3	2	0
0,2	32	22	24	16	37	32	29	7	12	32	35	2	0
0,3	32	22	27	22	38	34	28	9	15	29	35	4	-1
0,4	43	26	12	16	32	22	38	38	34	35	42	7	-1
0,5	32	40	37	37	32	49	62	34	69	77	55	14	-1
0,6	32	35	36	14	40	57	46	56	72	78	52	2	-1
0,7	27	34	32	30	33	54	55	62	57	56	47	21	-1
0,8	17	22	32	25	44	54	79	73	71	61	55	13	-1
0,9	17	24	34	39	54	56	92	95	104	87	80	16	0
1,0	17	12	32	42	52	57	74	70	92	57	39	22	0
1,1	29	17	45	62	46	44	64	62	47	26	29	0	0

Table 5.15 Spalling of slab specimen 10-3.

Mean all	32
Mean inner	40
Max measured	104

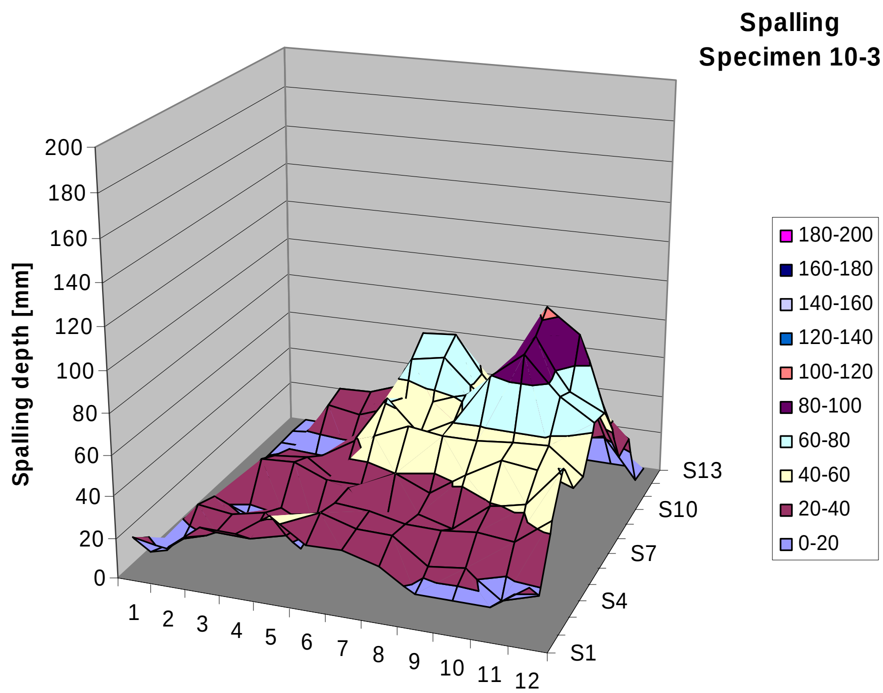

Figure 5.27 Map of spalling depth of slab specimen 10-3.

The measured spalling depths on specimen 10-4 are presented in table 5.16. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.17. A graph showing the spalling depth is presented in figure 5.28.

Table 5.16 Measured spalling depths on slab specimen 10-4.

Position	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
0,0	0	0	17	20	12	27	12	0	0	0	0	0	0
0,1	0	0	30	39	34	29	17	2	3	14	7	0	0
0,2	0	0	41	49	40	22	25	29	9	28	24	2	7
0,3	0	0	44	57	42	34	37	34	27	37	42	26	19
0,4	0	0	42	69	43	30	34	25	22	36	42	27	27
0,5	0	0	27	55	49	30	49	17	17	42	45	32	22
0,6	0	0	31	47	50	17	25	20	5	27	37	29	24
0,7	0	0	26	46	41	43	45	38	27	45	44	45	35
0,8	0	0	25	31	49	53	44	50	50	52	42	29	25
0,9	0	0	26	43	40	47	52	47	44	40	40	29	12
1,0	0	0	24	22	30	42	55	45	47	27	42	29	12
1,1	0	0	15	20	30	38	52	42	30	22	29	26	14

Table 5.17 Spalling of slab specimen 10-4.

Mean all	26
Mean inner	35
Max measured	69

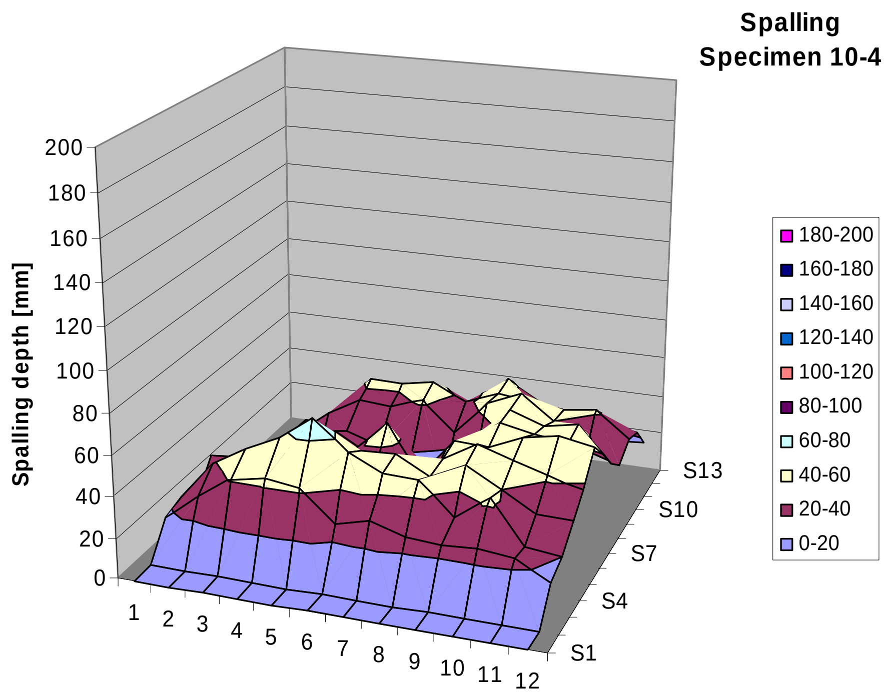

Figure 5.28 Map of spalling depth of slab specimen 10-4.

The measured spalling depths on beam specimen 10-3 are presented in table 5.18. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.19. A graph showing the spalling depth is presented in figure 5.29.

Table 5.18 Measured spalling depths on beam specimen 10-3.

Position	0,0	0,1	0,3	0,4	0,6	0,7	0,8	1,0	1,1	1,3	1,4	1,5	1,7	1,8	2,0	2,1	2,2	2,4	2,5	2,7	2,8	2,9	3,1	3,2
0,0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	24	19	19	0
0,1	0	14	14	6	2	0	0	0	0	0	0	4	3	2	0	0	0	0	0	12	22	17	21	0
0,2	0	9	17	12	14	0	0	0	0	0	0	14	16	2	0	0	0	0	12	14	12	23	20	0
0,3	0	9	17	9	12	6	0	0	0	0	0	18	16	4	0	0	0	4	19	21	32	24	20	0
0,4	0	9	21	8	9	0	0	0	0	0	0	10	5	0	0	0	0	11	14	19	31	28	16	0
0,5	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	13	7	0

Table 5.19 Spalling of beam specimen 10-3.

Mean all	5
Mean inner	8
Max measured	32

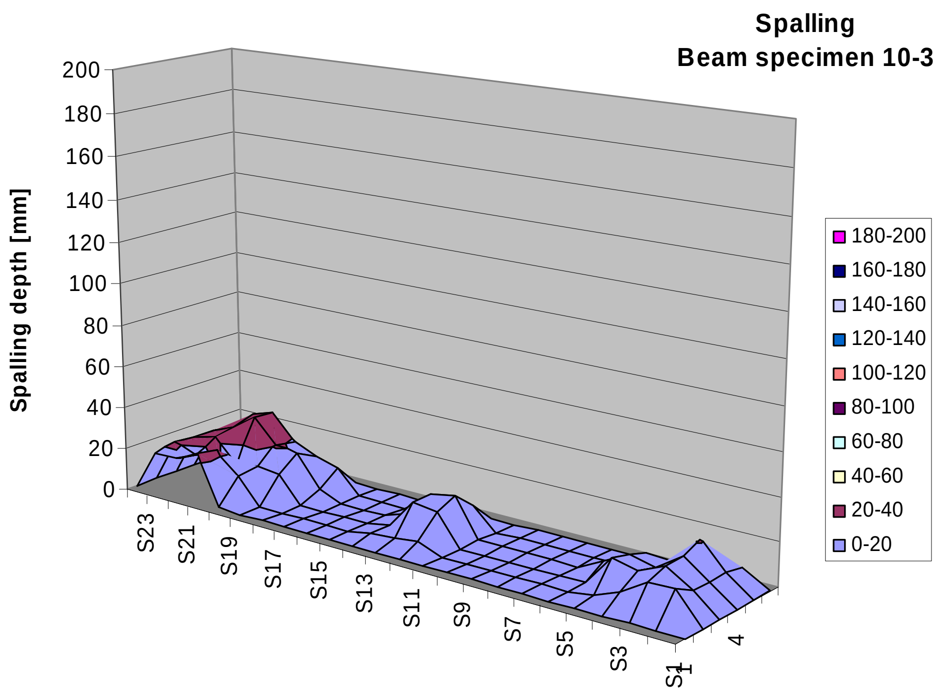

Figure 5.29 Map of spalling depth of beam specimen 10-3.

The measured spalling depths on beam specimen 10-4 are presented in table 5.20. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.21. A graph showing the spalling depth is presented in figure 5.30.

Table 5.20 Measured spalling depths on beam specimen 10-4.

Position	0,0	0,1	0,3	0,4	0,6	0,7	0,8	1,0	1,1	1,3	1,4	1,5	1,7	1,8	2,0	2,1	2,2	2,4	2,5	2,7	2,8	2,9	3,1	3,2
0,0	0	25	23	25	20	18	25	25	0	0	0	0	0	1	0	0	0	0	0	4	28	32	37	0
0,1	0	1	5	2	0	0	0	0	2	0	0	0	20	3	0	0	0	0	0	0	21	11	16	0
0,2	0	15	18	15	0	0	0	0	5	0	0	0	5	4	0	0	0	0	0	0	20	23	29	0
0,3	0	15	26	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	30	29	0
0,4	0	20	21	20	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	15	30	22	0
0,5	0	15	15	7	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	8	10	17	0

Table 5.21 Spalling of beam specimen 10-4.

Mean all	6
Mean inner	6
Max measured	37

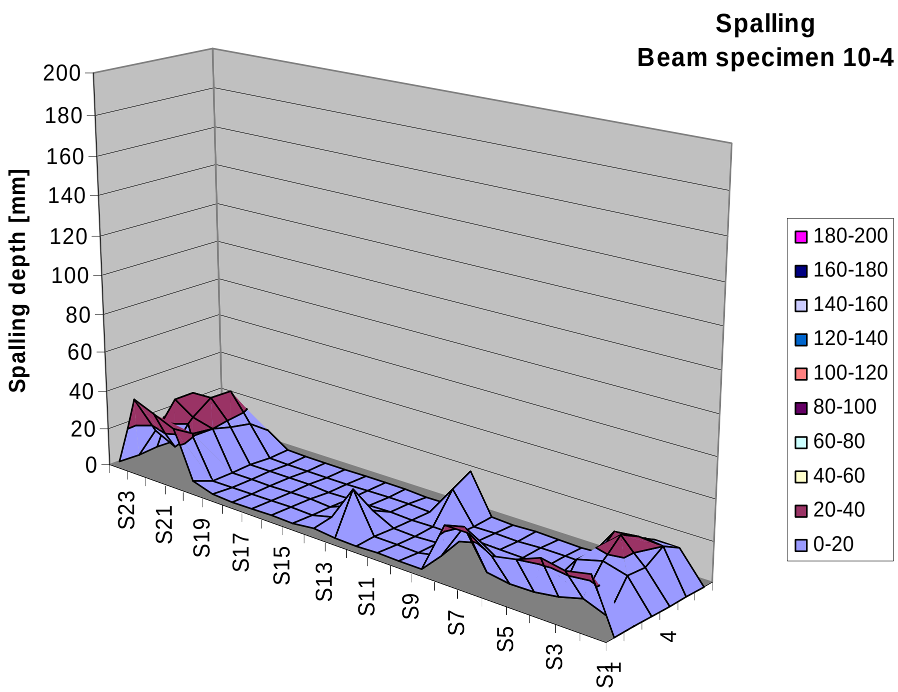

Figure 5.30 Map of spalling depth of beam specimen 10-4.

5.1.2.3.2 Test on May 31, 2007

The measured spalling depth of the fire exposed surface was measured with a grid size of 50 x 50 mm. The measured spalling depths on specimen 10-8 are presented in table 5.22. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.23. A graph showing the spalling depth is presented in figure 5.31.

Table 5.22 Measured spalling depths on slab specimen 10-8.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	12	22	29	19	13	22	25	30	26	23	16	18	19	19	15	24	21	19	0	0	0	0	0
2	0	10	26	28	28	-2	22	29	37	36	24	22	17	19	14	17	13	16	8	0	0	0	0	0
3	0	5	25	33	37	26	47	45	41	41	31	25	23	21	16	20	18	14	18	3	0	0	0	0
4	0	2	11	28	35	46	49	52	35	38	37	35	25	19	17	17	13	18	21	15	0	0	0	0
5	0	3	20	30	44	52	52	55	36	34	43	38	33	20	16	16	15	13	11	8	9	5	10	7
6	0	0	20	38	65	75	71	70	43	35	43	42	33	16	19	11	16	21	21	25	20	22	16	19
7	0	0	19	40	66	78	84	76	54	46	43	38	26	18	24	25	18	19	27	27	28	25	20	23
8	0	0	16	36	52	76	82	70	58	47	42	40	34	28	22	18	18	30	28	35	33	28	31	36
9	0	0	10	37	58	70	68	70	52	49	46	43	40	36	38	30	36	38	34	38	36	30	34	37
10	0	0	9	38	45	57	70	59	54	50	47	45	37	37	35	34	35	40	44	40	41	41	32	35
11	0	0	15	37	45	55	64	57	53	45	36	37	32	35	27	34	44	44	47	41	48	50	42	33
12	0	0	10	26	44	52	62	58	53	43	33	28	26	32	27	30	32	40	38	46	50	44	45	28
13	0	0	8	24	35	42	37	35	41	31	26	22	22	23	24	23	24	24	40	39	45	50	45	30
14	0	0	13	21	28	33	34	35	39	36	33	25	23	19	18	17	21	17	26	30	45	45	48	36
15	0	0	19	30	38	42	45	44	40	32	36	36	36	23	23	25	23	25	33	37	43	55	47	40
16	0	0	13	30	33	38	38	42	43	39	37	37	40	32	27	25	29	27	33	47	50	54	49	31
17	0	0	7	20	25	36	39	46	44	46	43	34	33	23	26	28	30	37	36	47	48	42	50	31
18	0	0	4	17	40	37	42	39	47	51	46	39	29	24	20	31	33	26	30	41	41	39	46	25
19	0	0	0	17	31	38	37	45	52	56	45	33	22	16	22	27	24	22	34	40	37	35	36	26
20	0	0	5	15	32	33	32	32	36	37	37	23	10	15	21	20	27	35	37	29	30	26	29	24
21	0	0	4	14	17	18	20	25	26	23	21	20	6	4	12	17	31	29	28	24	17	19	19	13
22	0	0	3	7	12	22	27	25	25	17	17	9	6	6	18	17	18	30	29	14	13	16	9	9

Table 5.23 Spalling of slab specimen 10-8.

Mean all	28
Mean inner	34
Max in diagram	84

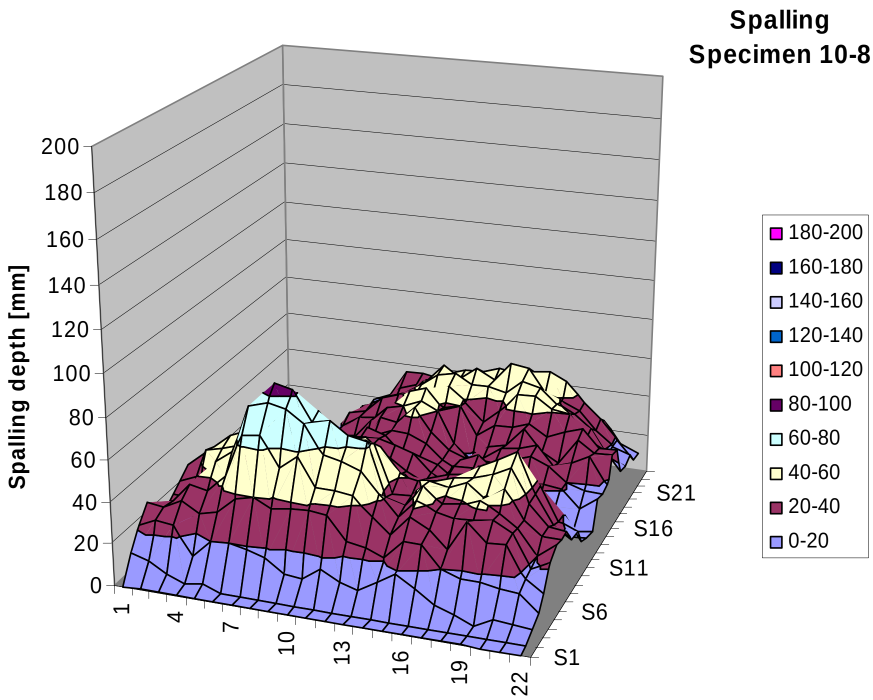

Figure 5.31 Map of spalling depth of slab specimen 10-8.

The measured spalling depths on specimen 46-1 are presented in table 5.24. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.25. A graph showing the spalling depth is presented in figure 5.32.

Table 5.24 Measured spalling depths on slab specimen 46-1.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	12	27	42	53	55	48	53	66	62	59	56	55	53	68	78	87	81	69	64	56	18	13	3	0
2	10	59	65	69	64	65	67	68	68	69	73	65	65	66	82	73	88	78	66	65	54	36	5	0
3	13	58	74	75	67	77	77	78	77	70	83	91	88	90	94	86	94	90	105	85	73	53	15	0
4	19	67	71	71	80	91	99	99	96	93	112	112	104	112	125	114	108	113	119	97	90	52	16	0
5	25	57	52	59	70	95	100	107	112	124	124	128	118	130	133	126	121	121	131	128	79	49	14	0
6	33	48	63	71	74	71	80	76	83	88	94	87	96	103	110	108	117	125	118	127	113	58	13	0
7	34	50	64	77	71	82	81	88	95	100	97	100	89	97	108	119	119	112	113	122	109	75	25	0
8	40	55	69	79	82	89	90	92	125	123	126	121	106	103	115	123	118	110	113	123	115	84	23	0
9	44	64	71	85	86	86	95	115	132	133	131	126	124	127	120	115	108	107	112	124	112	78	31	0
10	81	92	107	119	99	92	82	81	93	103	106	113	126	131	129	130	136	141	135	129	103	66	30	0
11	90	100	114	115	109	91	81	84	97	105	102	122	117	126	127	128	150	152	146	155	124	75	25	0
12	86	85	96	108	96	79	81	83	105	111	112	104	127	134	145	136	141	150	144	154	125	82	28	0
13	67	65	65	76	64	76	77	83	97	106	118	100	126	133	140	136	135	140	138	146	121	77	47	0
14	63	63	67	68	70	79	76	74	96	109	121	121	132	132	135	136	136	140	134	140	117	83	51	0
15	60	67	75	75	73	94	77	75	87	105	108	124	124	130	136	150	145	154	156	147	144	102	40	0
16	51	65	82	81	78	80	85	89	99	106	112	116	126	125	127	152	141	151	148	144	131	96	41	0
17	43	46	63	74	74	80	87	94	105	116	117	125	125	120	122	116	129	135	136	138	99	72	35	0
18	33	42	56	76	90	105	115	102	104	103	104	95	96	106	120	127	127	102	128	85	82	67	36	0
19	31	39	51	73	92	100	94	79	101	94	102	89	86	96	94	106	117	101	104	84	72	51	21	0
20	28	42	49	53	65	78	73	63	84	68	67	84	87	81	84	89	98	85	85	77	55	45	16	0
21	24	38	25	9	25	38	42	31	53	45	44	36	42	45	48	75	74	49	52	52	33	30	12	0
22	20	16	11	21	21	30	33	30	33	33	33	15	30	34	31	41	31	36	30	27	29	18	8	0

Table 5.25 Spalling of slab specimen 46-1.

Mean all	82
Mean inner	102
Max in diagram	156

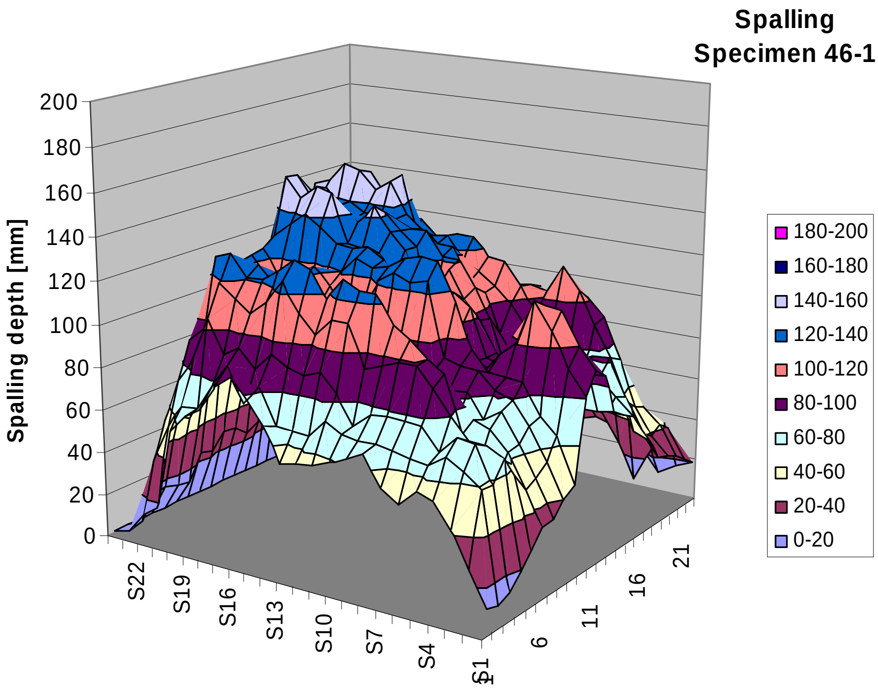

Figure 5.32 Map of spalling depth of slab specimen 46-1.

The measured spalling depths on beam specimen 46-1 are presented in table 5.26. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.27. A graph showing the spalling depth is presented in figure 5.33.

Table 5.26 Measured spalling depths on beam specimen 46-1.

Pos	1	2	3	4	5	6	7	8	9	10	11
AA	0	0	0	0	2	9	1	2	5	0	0
AB	0	5	6	15	30	37	36	30	32	22	8
AC	8	10	12	20	41	51	48	39	30	18	16
AD	6	14	20	28	32	39	46	39	40	28	19
AE	10	10	14	22	34	36	38	38	44	32	3
AF	7	9	14	19	26	29	37	37	33	24	21
AG	5	15	16	23	29	31	30	28	26	26	20
AH	4	6	10	18	23	31	26	24	29	22	22
AI	0	9	18	17	20	32	29	29	37	23	25
AJ	0	8	16	19	20	28	29	26	20	21	27
AK	0	12	19	21	22	22	31	31	29	23	26
AL	0	6	21	23	26	32	33	26	28	29	24
AM	0	0	9	20	26	28	30	29	27	26	26
AN	0	10	18	19	21	27	34	28	29	24	22
AO	4	13	20	28	26	33	26	22	28	26	19
AP	9	8	19	24	25	32	33	23	24	26	25
AQ	13	12	17	25	33	34	23	23	23	34	24
AR	6	8	22	25	31	31	38	26	25	29	21
AS	29	7	19	23	34	34	35	27	34	35	28
AT	25	16	23	21	32	32	32	16	29	31	26
AU	11	6	18	21	31	28	25	27	28	30	26
AV	8	10	12	13	30	23	26	25	32	33	28
AX	17	7	17	21	24	23	22	23	26	24	17
AY	9	8	6	13	21	27	23	22	23	27	18
AZ	16	8	18	19	23	33	26	24	25	16	18
BA	8	3	13	20	24	29	29	17	18	20	17
BB	8	14	20	21	20	23	19	17	13	15	20
BC	17	8	9	12	15	18	15	16	17	16	14
BD	6	7	10	14	13	19	18	17	17	15	20
BE	13	1	15	10	18	19	13	10	13	12	14
BF	9	1	6	9	20	26	24	24	18	14	11
BG	7	8	15	17	19	21	14	12	14	11	9
BH	14	7	17	15	25	31	28	25	11	14	8
BI	16	15	20	19	19	28	19	20	14	15	16
BJ	16	17	22	18	13	16	23	14	22	24	13
BK	0	2	18	14	17	29	30	20	20	16	17
BL	0	0	0	0	9	13	18	17	22	17	13
BM	0	2	4	4	16	18	18	13	16	13	13
BN	0	14	14	10	3	6	16	18	23	18	19
BO	9	14	12	13	5	15	25	26	23	17	14
BP	12	7	18	19	18	10	23	23	20	15	15
BQ	9	14	15	16	9	18	25	23	20	14	19
BR	9	11	13	19	18	19	18	18	17	13	17
BS	9	5	19	27	33	42	44	27	20	18	17
BT	6	3	16	12	34	40	42	31	23	18	16
BU	0	8	14	33	38	41	44	24	25	15	0
BV	0	1	5	10	12	18	19	13	0	0	0

Table 5.27 Spalling of beam specimen 46-1.

Mean all	19
Mean inner	23
Max in diagram	51

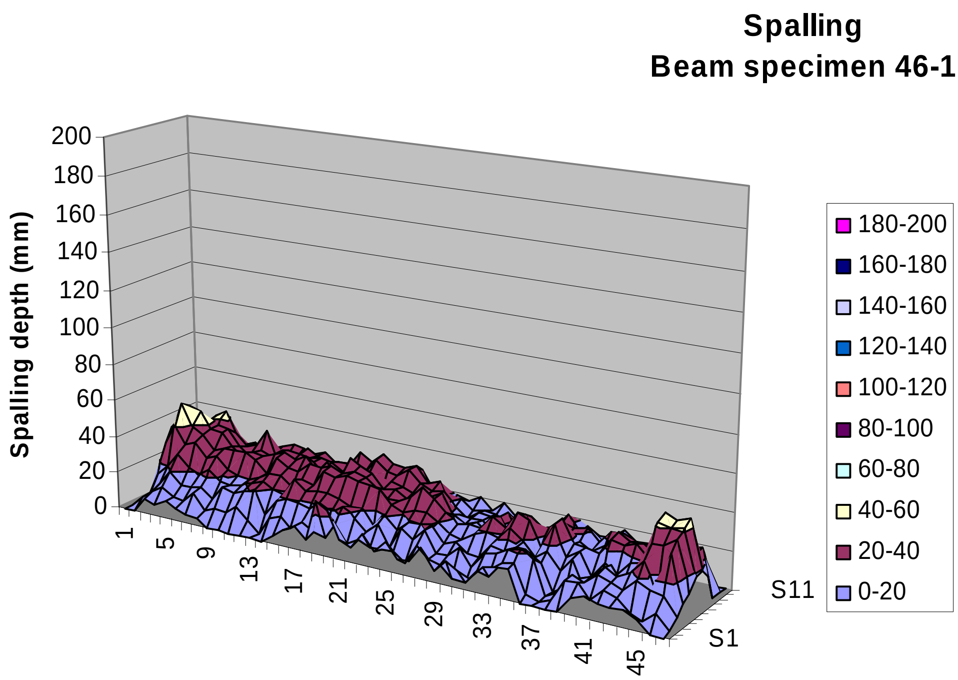

Figure 5.33 Map of spalling depth of beam specimen 46-1.

The measured spalling depths on beam specimen 46-2 are presented in table 5.28. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.29. A graph showing the spalling depth is presented in figure 5.34.

Table 5.28 Measured spalling depths on beam specimen 46-2.

Pos	1	2	3	4	5	6	7	8	9	10	11
AA	0	0	4	6	4	13	10	7	0	0	0
AB	10	12	18	30	29	27	18	14	8	1	5
AC	13	15	25	34	26	22	20	12	18	13	11
AD	17	18	28	29	30	27	24	20	18	14	10
AE	18	15	28	32	36	38	31	22	20	31	29
AF	18	17	22	28	36	33	34	18	25	31	33
AG	18	17	16	28	28	30	31	18	20	23	34
AH	0	3	15	15	18	18	17	18	13	18	17
AI	1	12	15	22	22	22	25	18	20	13	13
AJ	0	12	14	15	15	12	10	14	10	12	12
AK	8	9	8	12	14	18	13	10	11	14	15
AL	4	3	10	16	13	22	18	11	17	16	13
AM	4	1	8	10	8	12	8	4	8	13	13
AN	12	10	13	10	9	9	8	9	13	14	12
AO	8	7	5	4	12	4	6	9	6	8	8
AP	8	13	13	8	12	14	8	12	12	6	8
AQ	6	10	13	10	5	13	13	9	9	14	11
AR	13	9	7	9	6	8	7	8	6	7	11
AS	0	6	7	6	4	9	8	0	0	0	12
AT	6	0	0	0	2	4	8	3	15	4	8
AU	3	0	2	5	3	8	12	12	12	10	14
AV	6	4	6	8	6	4	10	13	13	12	9
AX	15	13	4	13	12	15	11	9	14	9	12
AY	8	7	7	11	1	1	4	9	5	12	7
AZ	8	8	15	16	18	11	14	17	10	10	12
BA	17	12	18	28	23	14	8	7	5	8	13
BB	20	12	17	23	21	19	19	3	1	8	13
BC	14	15	13	14	13	16	16	5	0	0	4
BD	10	8	4	11	12	9	12	13	0	0	0
BE	9	8	19	14	7	8	5	0	0	0	0
BF	8	7	11	5	12	8	9	9	8	0	0
BG	9	11	15	13	3	11	8	6	3	0	3
BH	5	12	12	8	13	15	19	18	5	9	13
BI	9	8	10	6	12	10	4	6	8	12	11
BJ	9	12	12	7	7	10	10	5	13	18	13
BK	18	13	21	21	12	21	23	13	12	18	18
BL	13	18	28	25	16	18	16	13	14	14	11
BM	11	12	24	29	29	32	28	18	18	17	14
BN	15	12	21	19	37	28	26	18	24	17	13
BO	32	20	13	19	19	22	18	10	13	17	16
BP	23	22	20	27	25	29	24	21	24	12	6
BQ	23	28	23	38	43	23	28	28	28	26	18
BR	23	21	28	40	36	33	30	32	28	26	13
BS	22	17	34	40	41	40	40	32	29	24	16
BT	16	20	24	37	38	36	36	28	23	14	12
BU	4	15	12	19	26	28	32	18	13	13	12
BV	0	0	0	1	3	1	0	0	0	0	0

Table 5.29 Spalling of beam specimen 46-2.

Mean all	14
Mean inner	16
Max in diagram	43

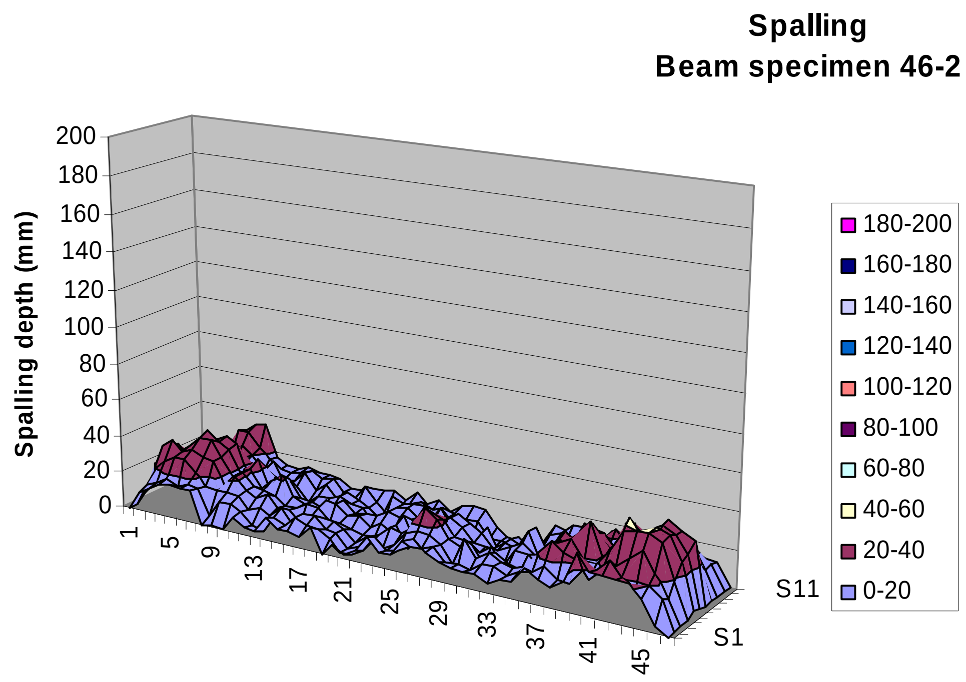

Figure 5.34 Map of spalling depth of slab specimen 46-2.

5.1.2.3.3 Test on June 5, 2007

The measured spalling depth of the fire exposed surface was measured with a grid size of 50 x 50 mm. The measured spalling depths on specimen 10-5 are presented in table 5.30. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.31. A graph showing the spalling depth is presented in figure 5.35.

Table 5.30 Measured spalling depths on slab specimen 10-5.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	2	4	11	5	12	21	21	15	5	4	4	2	0	0	7	1	1	1	8	14	15	3	0	0
2	9	9	13	9	29	30	30	23	19	23	17	13	8	11	10	9	13	23	23	22	21	4	0	0
3	11	18	14	14	26	31	33	26	21	29	28	21	9	15	12	13	22	30	24	22	23	8	0	0
4	15	19	17	30	30	30	40	33	30	32	37	35	21	14	13	16	18	30	22	33	28	6	0	0
5	12	22	30	40	39	39	40	39	35	33	43	36	31	23	25	28	15	25	28	32	35	1	0	0
6	19	22	31	34	39	39	34	42	43	35	39	40	40	33	34	35	26	33	32	34	29	3	0	0
7	34	35	38	45	51	39	36	41	50	50	46	51	59	42	45	46	43	46	49	43	30	0	0	0
8	45	44	41	55	54	48	37	41	49	53	48	56	65	56	50	51	58	53	50	39	33	6	0	0
9	42	45	47	47	47	42	33	35	35	57	58	46	49	48	56	57	61	62	57	37	29	5	0	0
10	33	47	48	51	49	42	39	40	26	67	66	29	45	45	55	65	82	66	64	36	28	8	0	0
11	44	49	54	58	55	57	60	42	40	51	37	40	42	47	72	91	91	93	75	48	32	8	0	0
12	43	43	52	53	50	49	55	51	60	66	47	61	51	48	72	88	87	88	80	46	38	5	0	0
13	45	54	50	55	48	40	43	44	47	57	59	50	42	44	75	79	88	87	86	66	36	3	0	0
14	47	53	40	31	33	28	35	41	43	50	51	50	42	45	74	83	82	84	66	55	35	1	0	0
15	31	29	26	33	31	25	28	36	34	37	51	50	38	36	72	86	83	87	74	56	37	9	0	0
16	23	35	36	35	33	27	25	25	37	41	30	45	38	29	40	65	75	88	66	62	29	9	0	0
17	19	32	37	30	24	26	19	25	23	30	25	24	25	26	38	41	48	54	59	53	29	10	0	0
18	8	31	32	25	15	20	27	37	33	23	21	30	30	18	25	40	51	39	48	33	32	10	0	0
19	6	18	28	22	27	26	27	46	30	31	28	30	24	20	12	25	37	33	45	32	21	0	0	0
20	1	8	14	22	27	29	24	27	26	25	19	19	5	15	13	12	20	27	36	15	18	0	0	0
21	1	1	11	15	18	10	9	19	15	15	13	5	4	10	10	12	15	12	10	16	10	0	0	0
22	4	11	5	10	9	16	7	9	5	10	3	7	7	4	4	13	16	9	10	9	8	0	0	0

Table 5.31 Spalling of slab specimen 10-5.

Mean all	31
Mean inner	39
Max in diagram	93

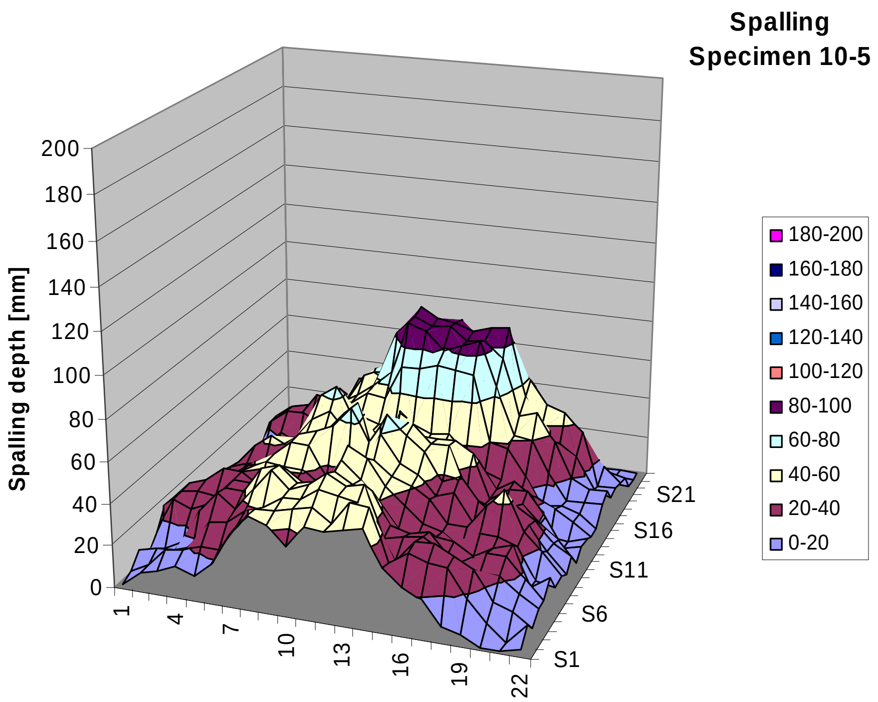

Figure 5.35 Map of spalling depth of slab specimen 10-5.

The measured spalling depths on specimen 46-2 are presented in table 5.32. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.33. A graph showing the spalling depth is presented in figure 5.36.

Table 5.32 Measured spalling depths on slab specimen 46-2.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	1	15	18	25	20	23	22	10	15	12	12	13	13	18	19	13	19	13	15	12	15	20	17
2	0	1	34	35	31	31	42	33	33	29	36	34	37	23	22	30	34	34	34	20	29	33	32	30
3	0	1	34	57	57	46	37	32	47	42	44	36	51	40	36	45	50	44	48	52	47	43	34	39
4	0	6	35	60	66	46	48	55	96	69	58	61	57	52	53	55	59	59	65	62	61	53	36	41
5	0	15	51	72	56	60	72	96	114	104	102	100	79	61	66	69	72	61	59	47	50	36	39	39
6	0	33	63	75	65	97	120	130	137	146	135	133	121	125	132	126	117	70	50	48	38	30	43	39
7	0	34	81	102	91	101	122	131	160	152	148	148	148	143	146	129	124	105	79	69	50	47	57	43
8	0	17	75	94	105	125	145	141	163	158	155	153	161	164	160	157	141	114	93	70	61	58	56	46
9	0	4	45	71	115	126	154	163	171	164	176	164	172	174	177	172	152	123	106	88	93	82	66	57
10	0	1	28	74	140	172	163	177	184	179	191	189	180	188	184	191	168	150	129	120	114	105	81	66
11	0	0	26	86	164	183	173	170	179	183	184	200	195	193	200	194	172	155	137	132	117	116	86	72
12	0	0	11	85	167	192	187	168	184	184	191	183	192	195	195	177	166	149	137	127	128	122	108	78
13	0	0	29	96	136	163	157	157	177	170	175	159	163	168	164	159	154	139	138	136	128	121	118	65
14	0	0	40	88	135	136	138	128	143	130	141	157	149	142	167	151	155	161	160	159	150	138	95	70
15	0	0	47	86	126	131	120	109	115	111	110	113	133	135	152	150	160	163	163	168	157	154	106	67
16	0	10	50	78	93	87	79	70	66	80	73	83	91	119	148	150	167	168	162	164	156	146	78	42
17	0	25	62	61	78	78	68	67	56	62	49	60	60	68	133	138	151	155	150	152	109	108	57	38
18	0	26	72	69	85	86	63	66	66	63	53	44	49	59	58	49	46	68	75	69	75	73	70	44
19	0	19	59	75	83	75	70	58	69	60	54	40	55	67	61	45	59	65	63	61	70	76	54	45
20	0	19	41	64	49	54	54	45	51	54	48	44	58	52	42	38	48	50	35	37	43	48	39	32
21	0	12	40	43	40	43	48	39	38	53	48	34	26	30	33	30	39	33	23	21	32	36	17	5
22	0	5	25	36	46	45	43	41	44	48	32	23	20	14	15	14	20	24	27	22	27	15	9	0

Table 5.33 Spalling of slab specimen 46-2.

Mean all	81
Mean inner	106
Max in diagram	200

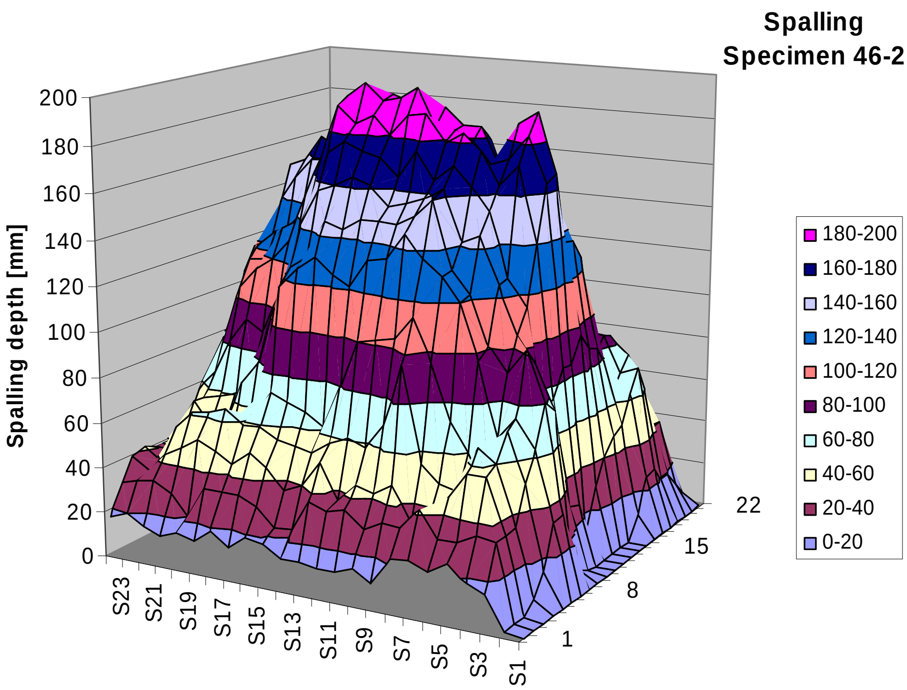

Figure 5.36 Map of spalling depth of slab specimen 46-2.

5.1.2.4 Pressure measurements

5.1.2.4.1 Test on February 10, 2006

The pressure within the concrete was measured at different depths. The measured pressures in the tested specimens are presented in figures 5.37-5.40.

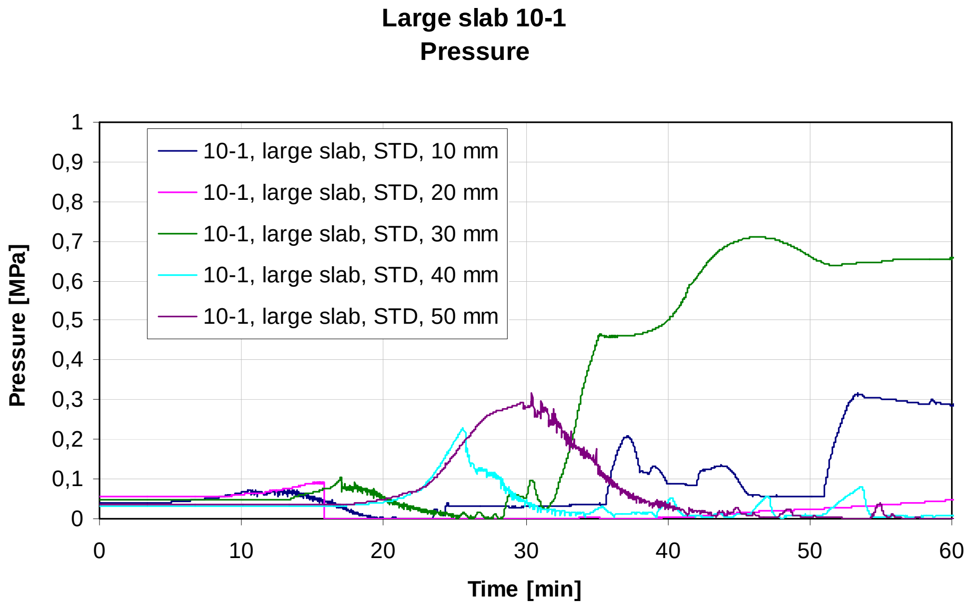

Figure 5.37 Measured pressure on different depths of slab specimen 10-1.

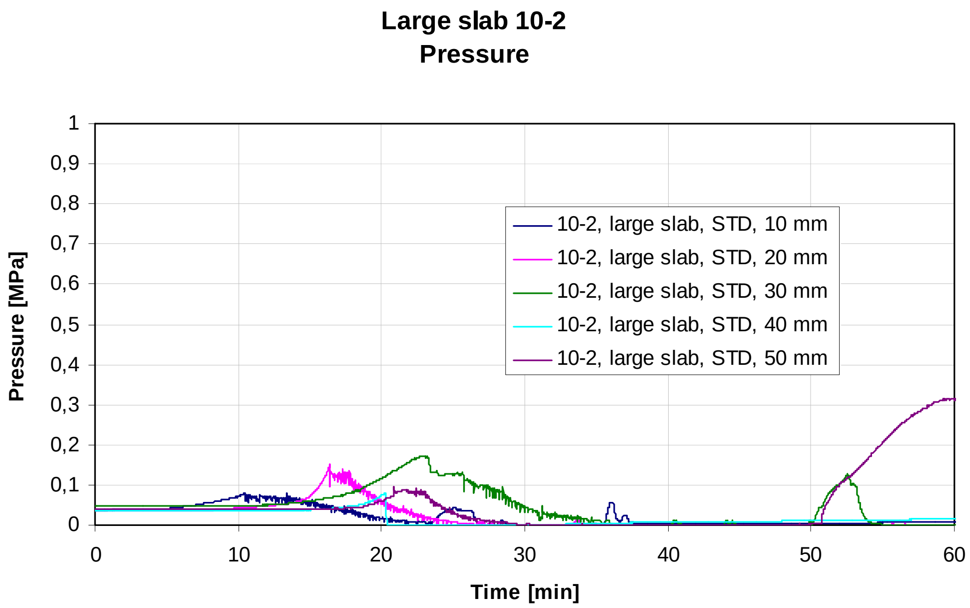

Figure 5.38 Measured pressure on different depths of slab specimen 10-2.

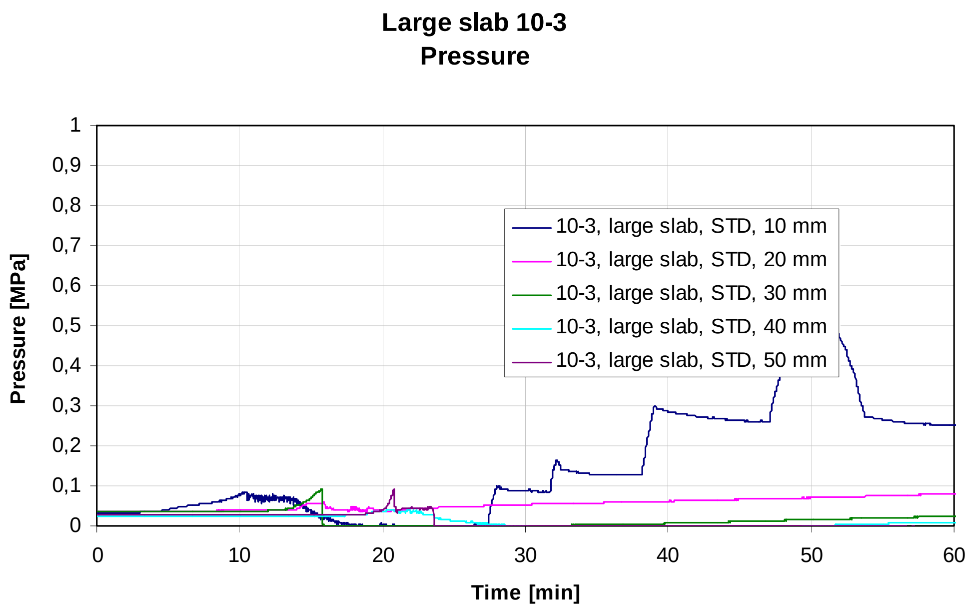

Figure 5.39 Measured pressure on different depths of slab specimen 10-3.

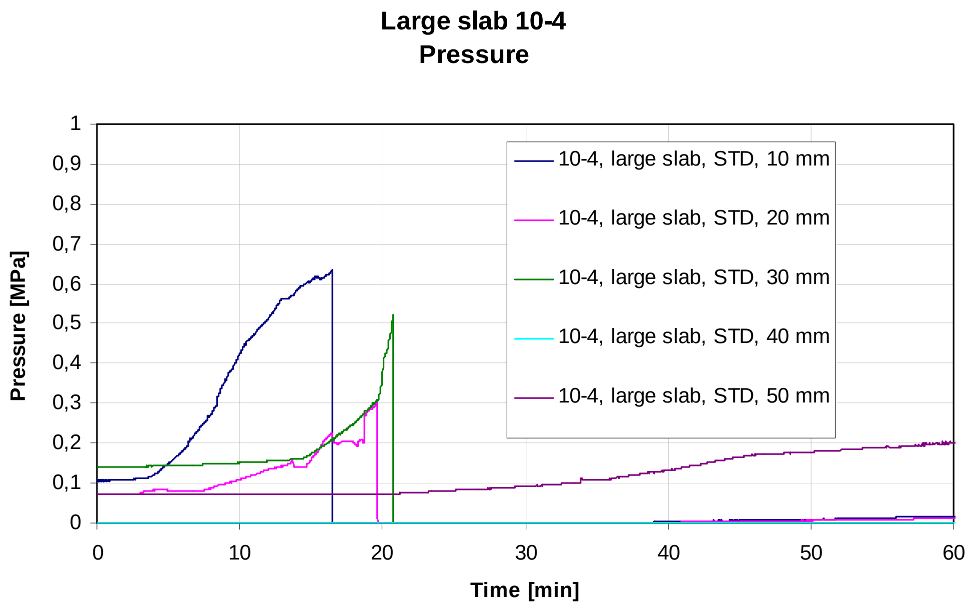

Figure 5.40 Measured pressure on different depths of slab specimen 10-4.

5.1.2.4.2 Test on May 31, 2007

The pressure within the concrete was measured at different depths. The measured pressures in the tested specimen are presented in figures 5.41.

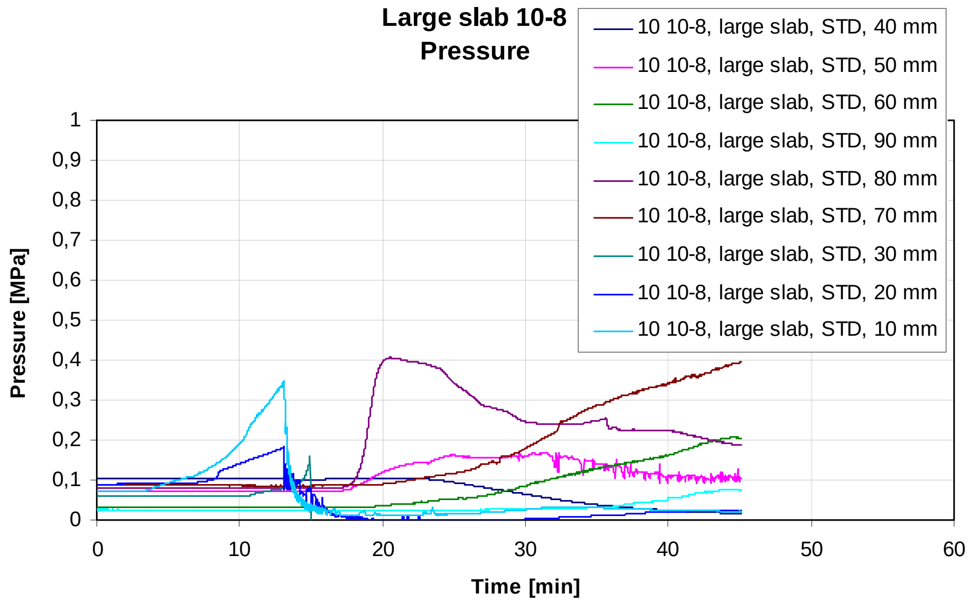

Figure 5.41 Measured pressure on different depths of slab specimen 10-8.

5.1.2.4.3 Test on June 05, 2007

The pressure within the concrete was measured at different depths. The measured pressures in the tested specimen are presented in figures 5.42.

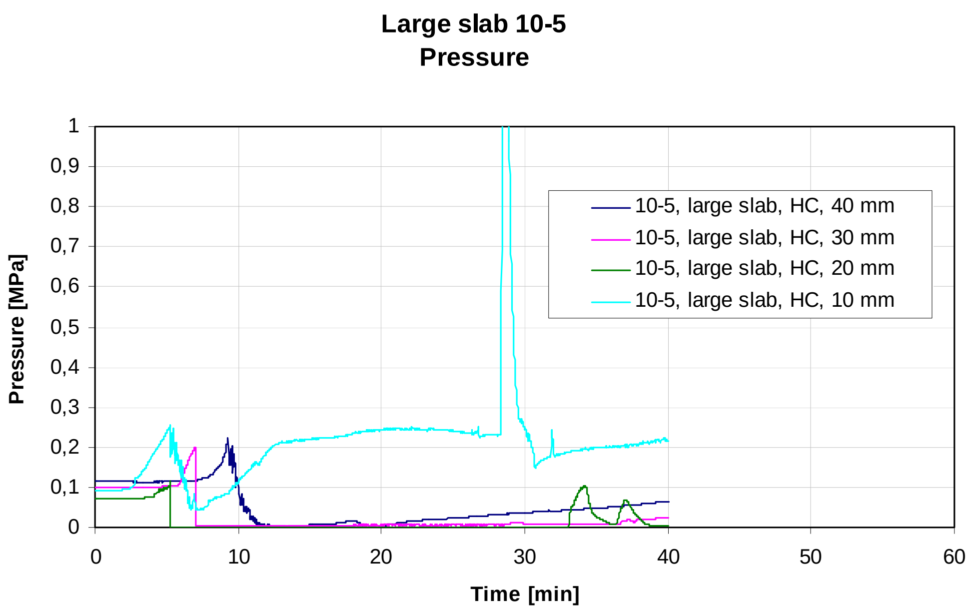

Figure 5.42 Measured pressure on different depths of slab specimen 10-5.

5.2 Civil engineering concrete

5.2.1 Small slab specimens

The results from the tests on the small slab specimens are presented in appendix A. A summary of the test results is given in Table 5.34 below.

Table 5.34 Summary of test results.

Specimen	Max spalling (mm)	Mean spalling (mm)	Spalling time (min)	Weight loss (%)	Fire curve (-)	Appl. load (kN)	Appl. stress (MPa)	Age (days)	Moisture content (%)	Comp. strength (MPa)
28-3	0	0	-	2,2	hc	760	7,6	187	4,1	77
28-8	0	0	-	2,0	hc	764	7,6	187	4,1	77
30-2	100	31	5,1	12,5	hc	1018	10,2	193	4,1	105
30-3	37	16	-	-	hc	1056	10,6	-	4,1	105
31-4	21	11	4,2	9,2	hc	748	7,5	186	4,1	75
31-5	28	14	4,1	8,2	hc	756	7,6	185	4,1	75
31-8	28	8	6,4	5,2	hc	0	0,0	184	4,1	75
31-9	13	4	5,5	8,4	hc	0	0,0	185	4,1	75
32-2	0	0	-	3,7	hc	760	7,6	196	4,1	78
32-3	0	0	-	1,9	hc	791	7,9	183	4,1	78
33-1	0	0	-	1,0	hc	797	8,0	207	4,0	81
33-4	0	0	-	2,7	hc	809	8,1	201	4,0	81
34-1	38	26	4,0	9,6	hc	764	7,6	174	-	77
34-2	43	25	3,3	10,8	hc	753	7,5	179	-	77
35-1	23	5	7,3	3,9	hc	783	7,8	180	4,9	79
35-2	0	0	-	2,7	hc	800	8,0	180	4,9	79
38-3	0	0	-	1,3	hc	753	7,5	188	4,8	77
38-4	0	0	-	1,3	hc	819	8,2	192	4,8	77
39-12	59	42	53,4	22,6	10 K/min	920	9,2	197	4,9	92
39-13	41	21	2,8	12,6	hc	1019	10,2	368	4,8	103
39-14	31	16	3,8	6,0	hc	734	7,3	92	5,5	74
39-15	35	14	3,7	3,7	hc	734	7,3	91	5,5	74
39-17	43	22	2,6	14,8	hc	1000	10,0	370	4,8	103
39-18	42	24	2,8	14,7	hc	360	3,6	91	5,5	74
39-19	64	29	3,3	18,1	hc	507	5,1	364	4,8	103
39-20	49	28	3,0	15,8	hc	362	3,6	88	5,5	74
39-23	63	26	3,2	14,3	hc	503	5,0	363	4,8	103
39-25	24	10	3,8	7,5	hc	0	0,0	173	4,9	92
39-27	53	28	2,0	15,5	hc	462	4,6	181	4,9	92
39-28	48	25	3,0	12,1	hc	953	9,5	169	4,9	92
39-29	64	29	3,0	15,2	hc	934	9,3	179	4,9	92
39-30	24	12	2,7	7,5	hc	0	0,0	172	4,9	92
39-31	66	33	3,0	16,9	hc	461	4,6	180	4,9	92
39-33	59	28	13,0	13,8	std	436	4,4	280	4,9	92
39-34	41	23	13,0	12,5	std	442	4,4	281	-	-
39-35	55	22	10,0	12,5	std	924	9,2	183	4,9	92
39-36	64	35	31,9	18,3	slow	884	8,8	190	4,9	92
39-37	71	38	30,0	17,3	slow	920	9,2	181	4,9	92

Table 5.34 Cont.

Specimen	Max spalling (mm)	Mean spalling (mm)	Spalling time (min)	Weight loss (%)	Fire curve (-)	Appl. load (kN)	Appl. stress (MPa)	Age (days)	Moisture content (%)	Comp. strength (MPa)
39-38	47	22	2,5	13,7	hc	910	9,1	275	-	-
39-39	64	34	2,7	19,4	hc	874	8,7	278	-	-
39-40	67	41	11,0	19,7	std	915	9,2	180	4,9	92
40-3	0	0	-	1,7	hc	811	8,1	166	4,3	82
40-4	0	0	-	4,8	hc	816	8,2	166	4,3	82
41-1	27	9	6,3	11,2	hc	975	9,8	167	4,8	97
41-2	0	0	-	3,0	hc	964	9,6	168	4,8	97
42-3	0	0	-	3,0	hc	911	9,1	194	-	85
42-4	0	0	-	0,9	hc	851	8,5	194	-	85
43-7	0	0	-	3,2	hc	860	8,6	190	4,9	87
43-8	0	0	-	2,8	hc	911	9,1	190	4,9	87
44-3	16	3	3,8	2,7	hc	820	8,2	191	-	84
44-4	26	6	9,3	4,0	hc	838	8,4	191	-	84
45-1	11	2	3,9	2,7	hc	0	0,0	192	4,8	82
45-11	10	2	4,2	2,2	hc	399	4,0	100	4,6	78
45-12	20	9	4,2	5,6	hc	773	7,7	102	4,6	78
45-15	18	4	4,6	2,2	hc	857	8,6	361	4,3	88
45-16	15	5	3,0	7,0	hc	476	4,8	360	4,3	88
45-17	11	2	3,4	5,5	hc	876	8,9	360	4,3	88
45-18	14	5	3,5	5,4	hc	445	4,4	359	4,3	88
45-2	13	2	3,3	2,1	hc	0	0,0	192	4,8	82
45-21	23	7	2,0	4,4	hc	917	9,2	274	4,3	85
45-22	16	3	3,0	4,3	hc	443	4,4	273	4,3	85
45-23	26	8	1,7	5,4	hc	864	8,6	274	4,3	85
45-24	19	5	2,1	4,1	hc	283	2,8	274	4,3	85
45-4	16	4	3,7	5,4	hc	821	8,2	193	4,8	82
45-6	20	6	3,0	4,1	hc	864	8,6	193	4,8	82
45-7	22	8	3,7	6,8	hc	786	7,9	102	4,6	78
45-8	20	5	5,3	5,1	hc	388	3,9	100	4,6	78
47-1	0	0	-	3,0	hc	952	9,5	185	4,5	97
47-2	0	0	-	3,1	hc	1020	10,2	185	4,5	97
51-3	0	0	-	2,9	hc	709	7,1	201	4,9	72
51-4	0	0	-	3,6	hc	715	7,2	202	4,9	72
52-3	0	0	-	-	hc	718	7,2	202	5,1	70
52-4	0	0	-	2,5	hc	697	7,0	203	5,1	70
53-1	4	0	-	2,7	hc	520	5,2	196	4,3	52
53-2	0	0	-	2,2	hc	532	5,3	196	4,3	52
54-3	0	0	-	1,7	hc	471	4,7	197	4,5	47
54-4	0	0	-	1,4	hc	487	4,9	200	4,5	47

5.2.2 Large slab specimens

The furnace temperature was measured with six plate thermometers in each test. Three furnace tests were carried out and the tested specimens and characteristics for each test are given in table 5.35. The measured furnace temperature is shown in figures 5.43-5.44.

Table 5.35 Large furnace tests

Test date	Fire curve	Test time (minutes)	Slab specimens
2007-05-31	Standard	45	38-2, 39-3, 43-2, 45-4
2007-06-05	HC	41	38-1, 38-4, 39-1, 39-2, 45-1, 45-2

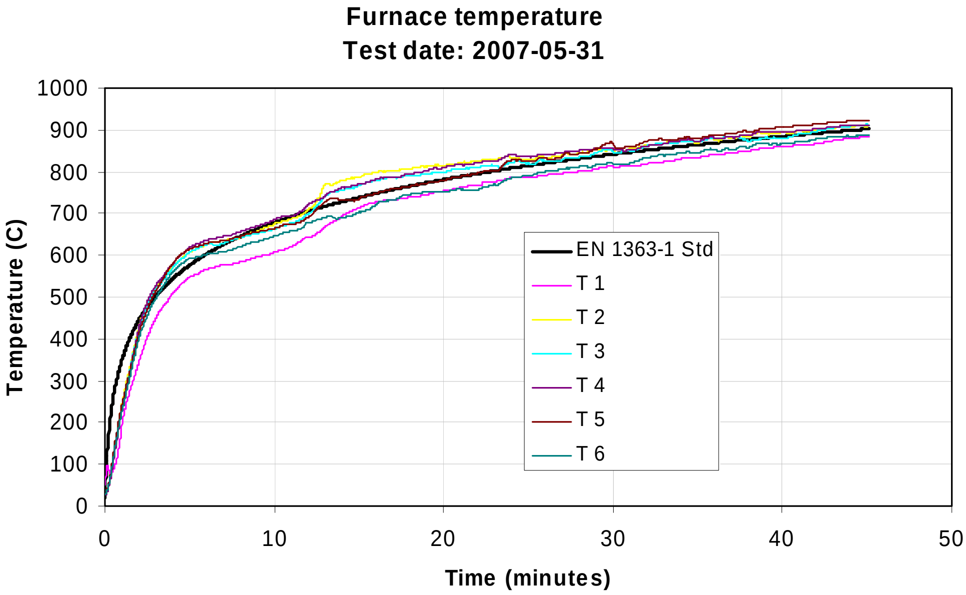

Figure 5.43 Furnace temperatures in the test on May 31, 2007.

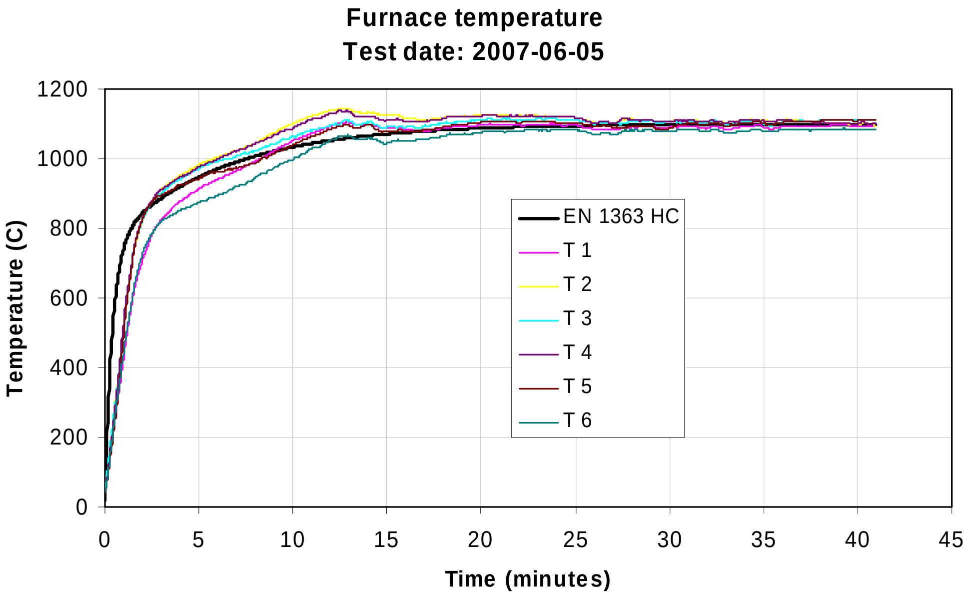

Figure 5.44 Furnace temperatures in the test on June 5, 2007.

5.2.2.1 Observations during the tests

The visual observations made during the test are presented in table 5.36-5.37.

Table 5.36 Visual observations made during the test on May 31, 2007.

Time (min:sec)	Observation
00:00	Start of test
08:15	Slab 38-3: Spalling start
10:00	Slab 45-4: 75 % of surface spalled to depth 1-3 cm
11:40	Slab 39-3: Spalling start
12:10	Slab 39-3: 50 % of surface spalled to depth 1 cm
15:00	Slab 45-4: Reinforcement visible
16:20	Slab 38-2: spalling start
18:30	Slab 39-3: Reinforcement visible
42:00	Slab 39-3: Still spalling
45:00	Test is terminated

Table 5.37 Visual observations made during the test on June 5, 2007.

Time (min:sec)	Observation
00:00	Start of test
01:20	Slabs 38-1, 39-1 and 39-2: Spalling start
02:00	Slab 45-1: Spalling start
02:20	Slab 38-4: Spalling start
06:30	Slabs 39-1 and 45-2: Reinforcement visible
07:30	Slab 39-2: Reinforcement visible
41:00	Test is terminated

5.2.2.2 Temperature measurements

The temperature was measured at different locations on the slab specimens. The presented results are mean values on each specimen at different depths, i.e. a mean value of four measurements at different locations. The measured values for each individual thermocouple are presented in the appendices.

Temperature measurements in the specimens tested on May 31, 2007, are presented in figures 5.45-5.48.

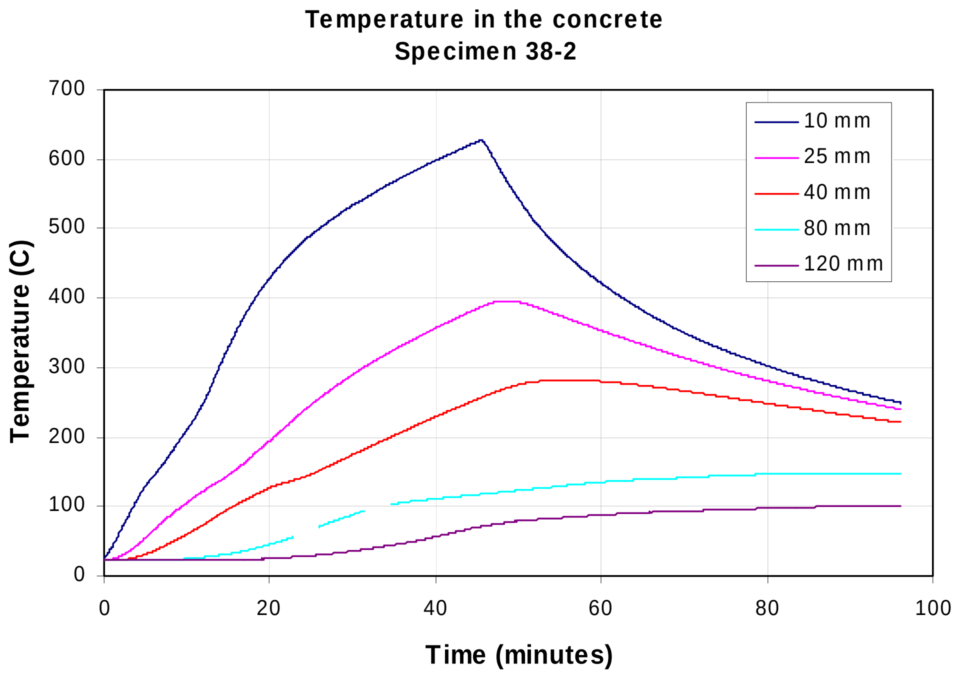

Figure 5.45 Temperatures in slab specimen 38-2 tested on May 31, 2007.

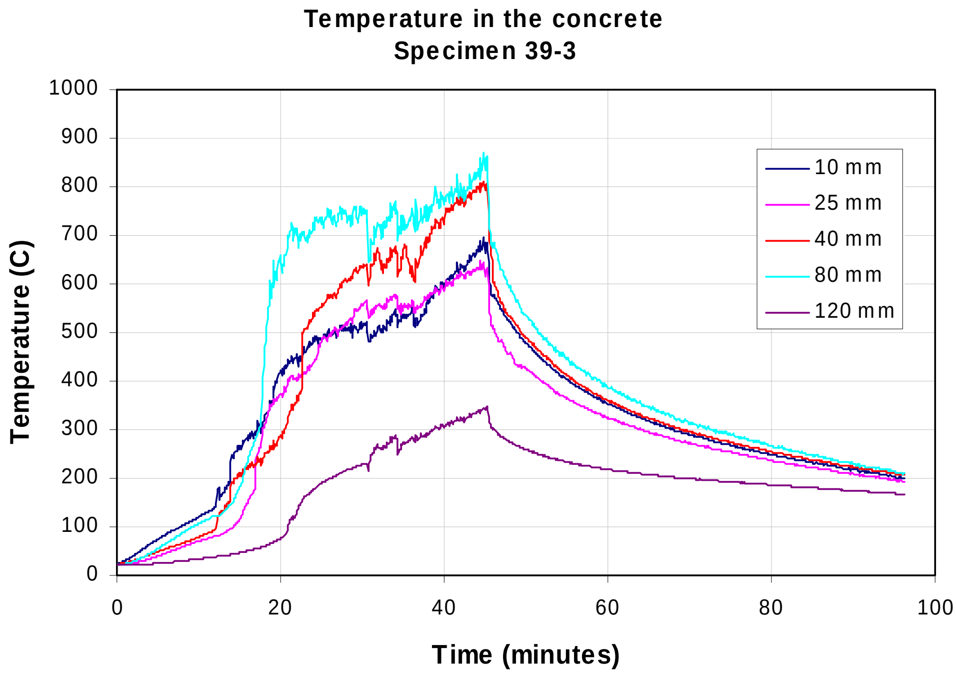

Figure 5.46 Temperatures in slab specimen 39-3 tested on May 31, 2007.

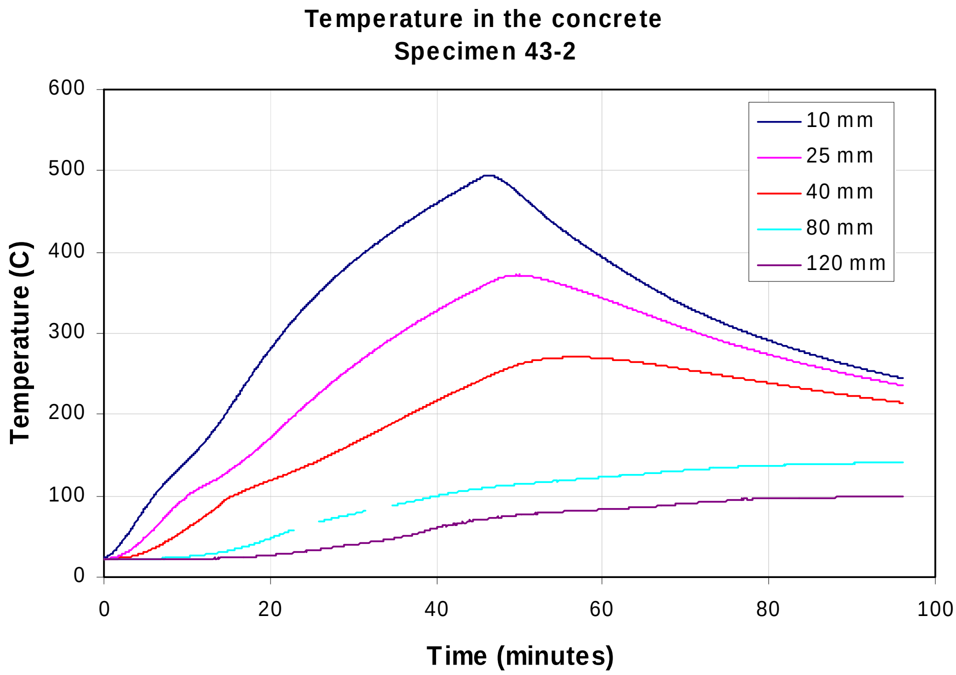

Figure 5.47 Temperatures in slab specimen 43-2 tested on May 31, 2007.

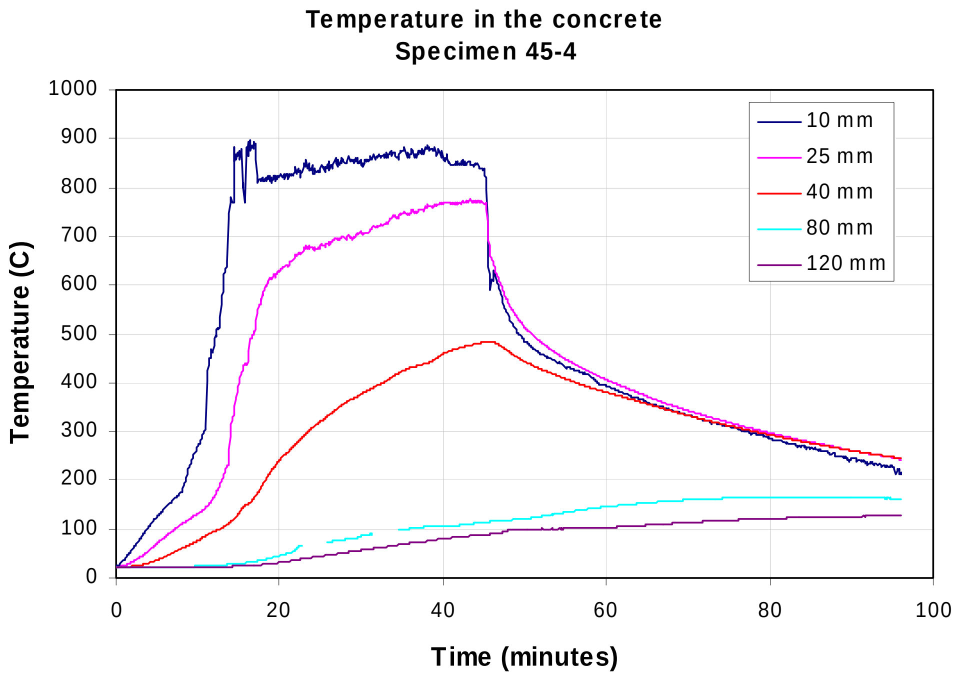

Figure 5.48 Temperatures in slab specimen 45-4 tested on May 31, 2007.

Temperature measurements in the specimens tested on June 5, 2007, are presented in figures 5.49-5.54.

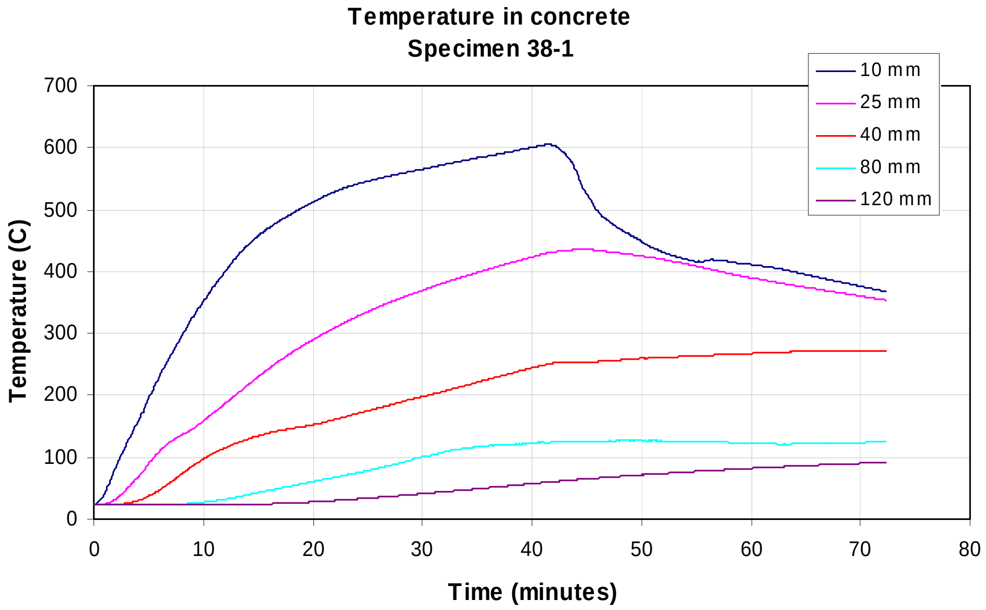

Figure 5.49 Temperatures in slab specimen 38-1 tested on June 5, 2007.

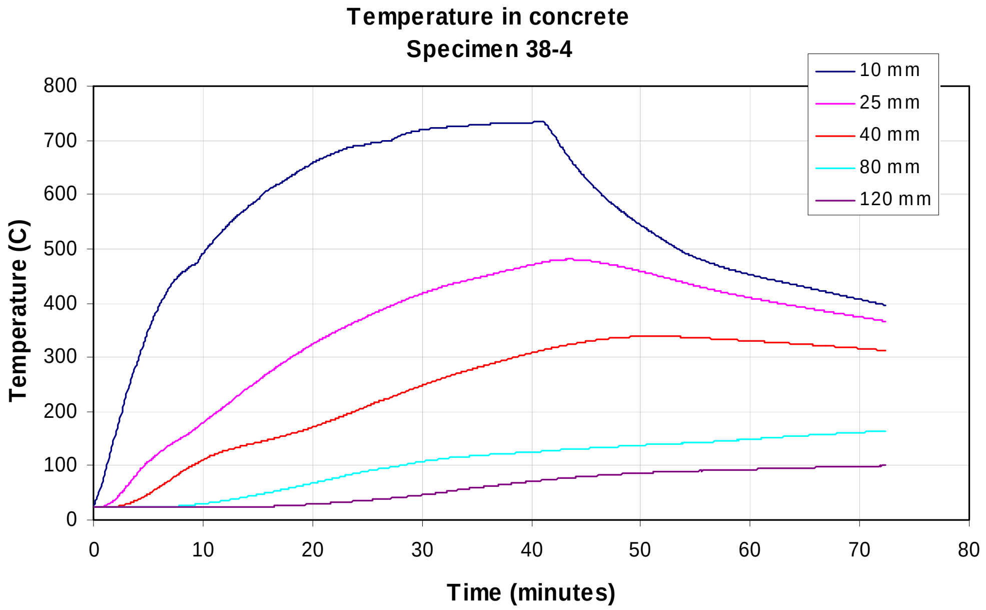

Figure 5.50 Temperatures in slab specimen 38-4 tested on June 5, 2007.

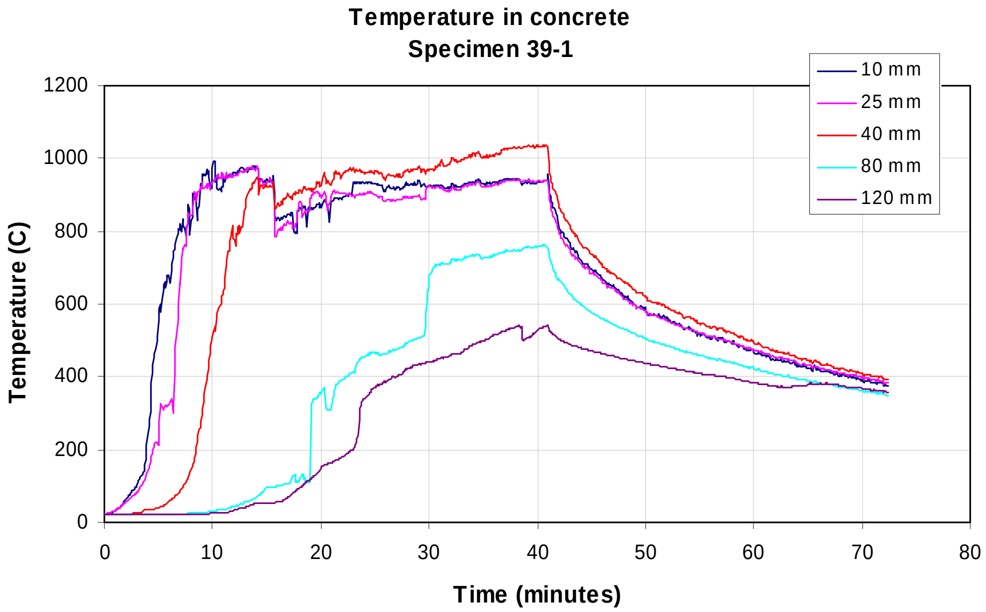

Figure 5.51 Temperatures in slab specimen 39-1 tested on June 5, 2007.

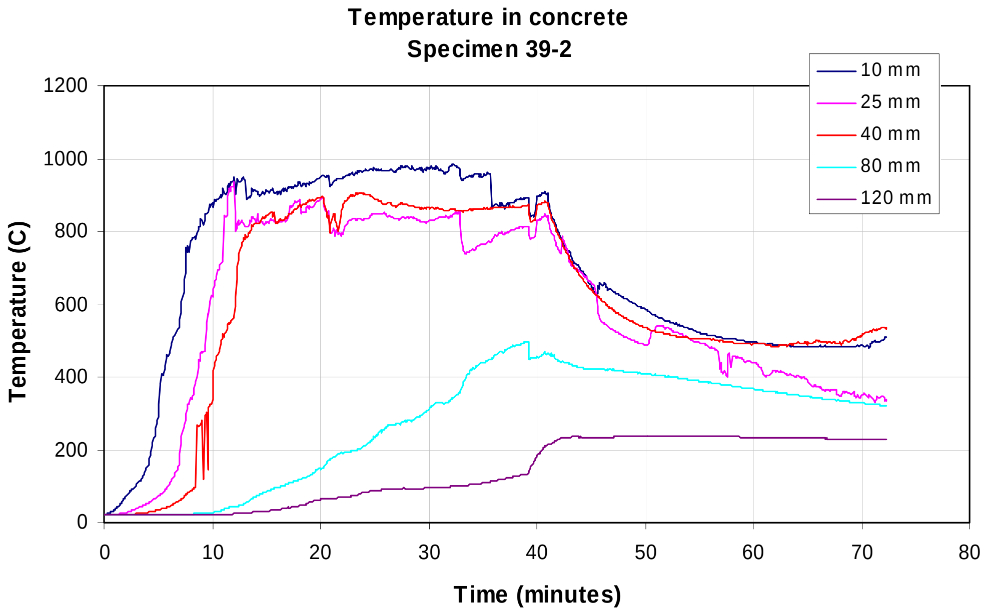

Figure 5.52 Temperatures in slab specimen 39-2 tested on June 5, 2007.

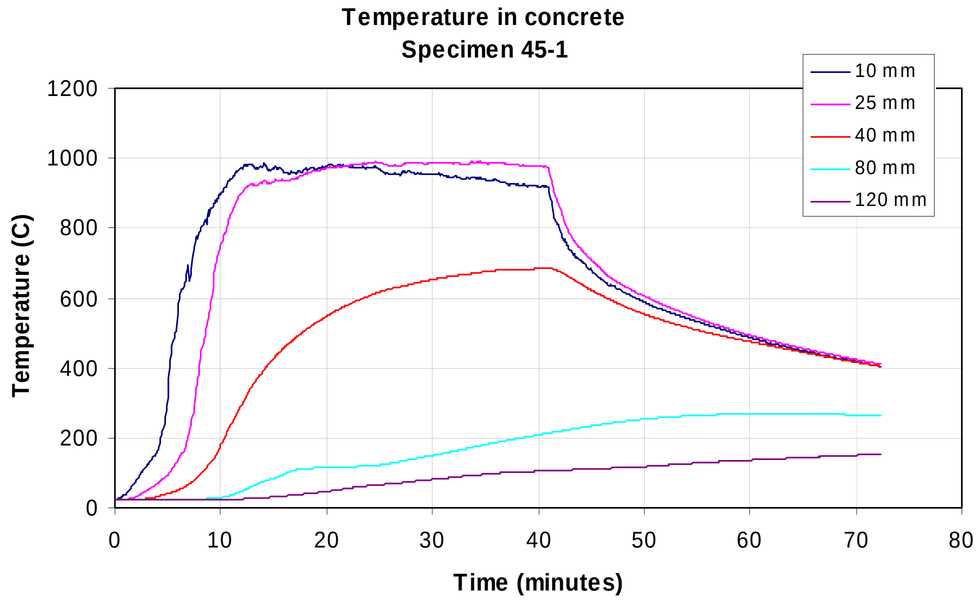

Figure 5.53 Temperatures in slab specimen 45-1 tested on June 5, 2007.

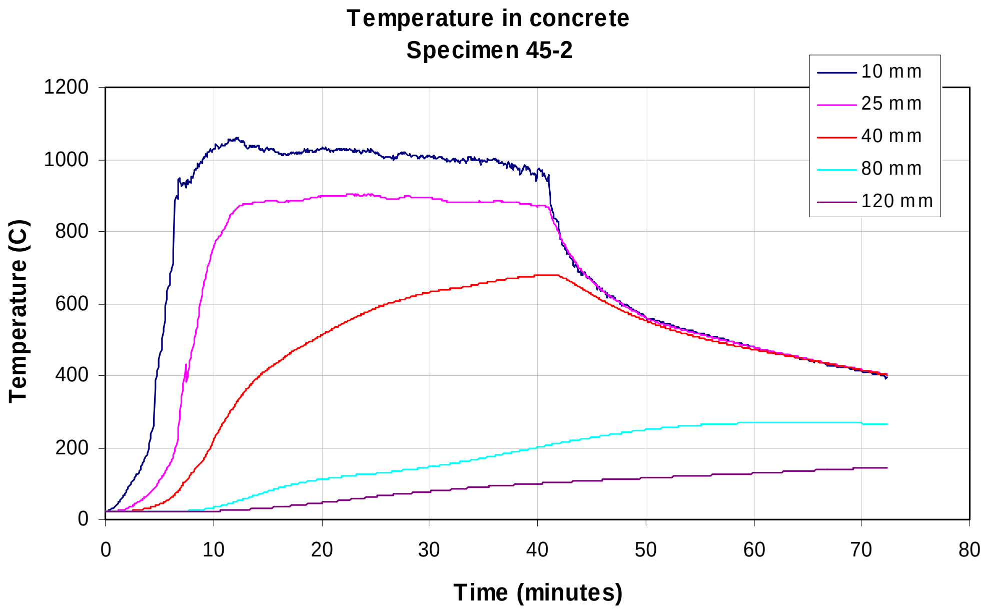

Figure 5.54 Temperatures in slab specimen 45-2 tested on June 5, 2007.

5.2.2.3 Load measurements

The specimen pair consisting of specimens 38-2 and 39-3 was loaded initially to 255 kN per bar giving a compressive stress of 6.4 MPa. The load was measured on two bars, and the results are presented in figure 5.55. The specimen pair consisting of specimens 43-2 and 45-4 was loaded to 274 kN per bar giving a compressive stress of 6.8 MPa. Also in this specimen pair the load was continuously measured in two bars and the results are presented in figure 5.56.

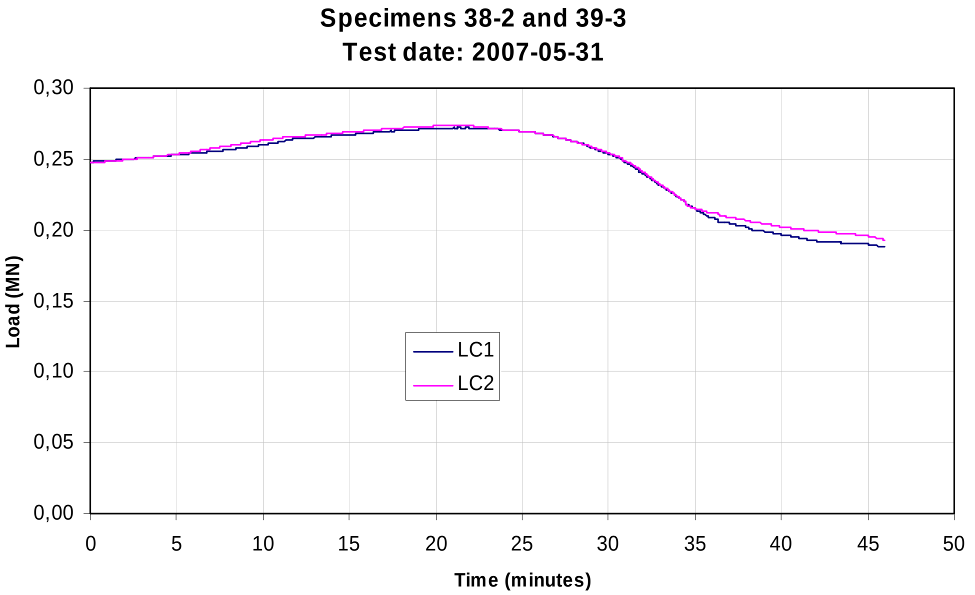

Figure 5.55 Load measurements on specimen pair 38-2 and 39-3 tested on May 31, 2007.

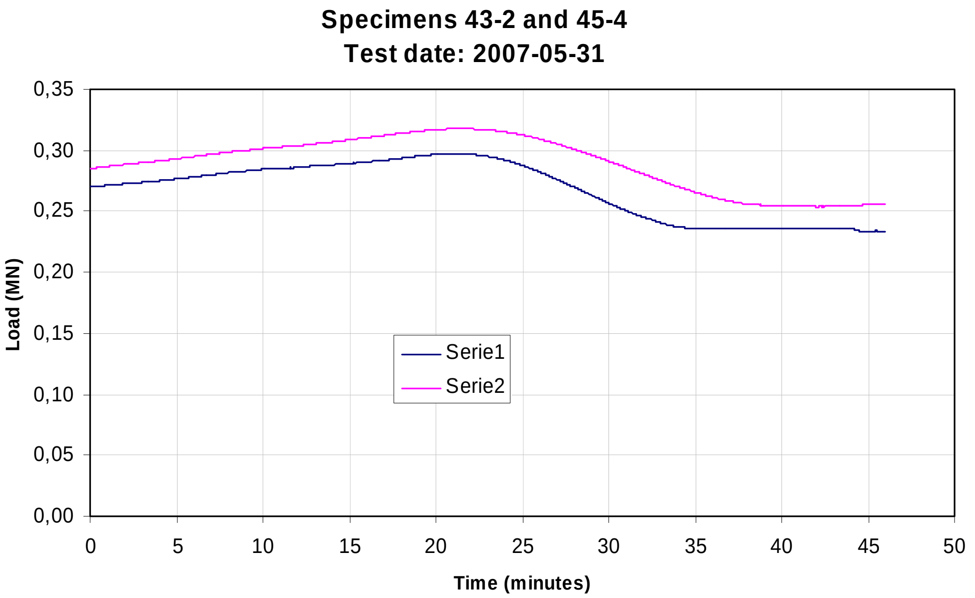

Figure 5.56 Load measurements on specimen pair 43-2 and 45-4 tested on May 31, 2007.

The specimen pair consisting of specimens 45-1 and 45-2 was loaded initially to 274 kN per bar giving a compressive stress of 6.8 MPa. The load was measured on two bars, and the results are presented in figure 5.57. The specimen pair consisting of specimens 38-1 and 38-4 was loaded to 254 kN per bar giving a compressive stress of 6.4 MPa. Also in this specimen pair the load was continuously measured in two bars and the results are presented in figure 5.58. The specimen pair consisting of specimens 39-1 and 39-2 was loaded to 308 kN per bar giving a compressive stress of 7.7 MPa. Also in this specimen pair the load was continuously measured in two bars and the results are presented in figure 5.59.

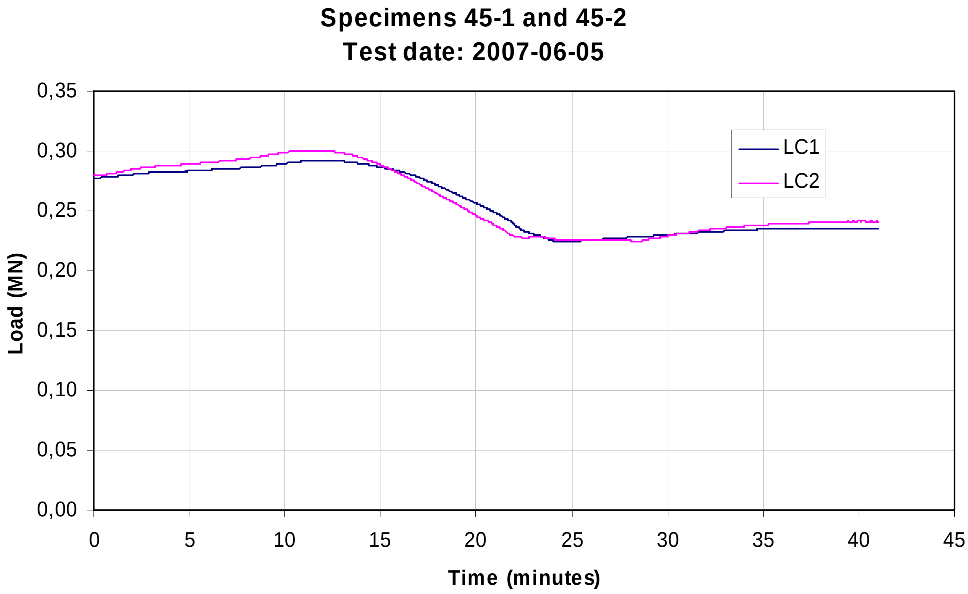

Figure 5.57 Load measurements on specimen pair 45-1 and 45-2 tested on June 5, 2007.

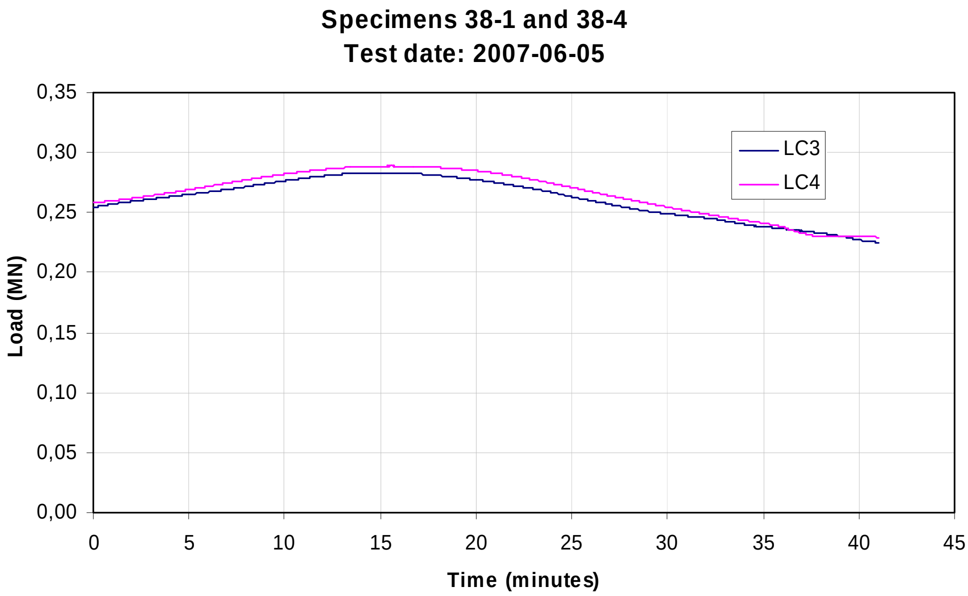

Figure 5.58 Load measurements on specimen pair 38-1 and 38-4 tested on June 5, 2007.

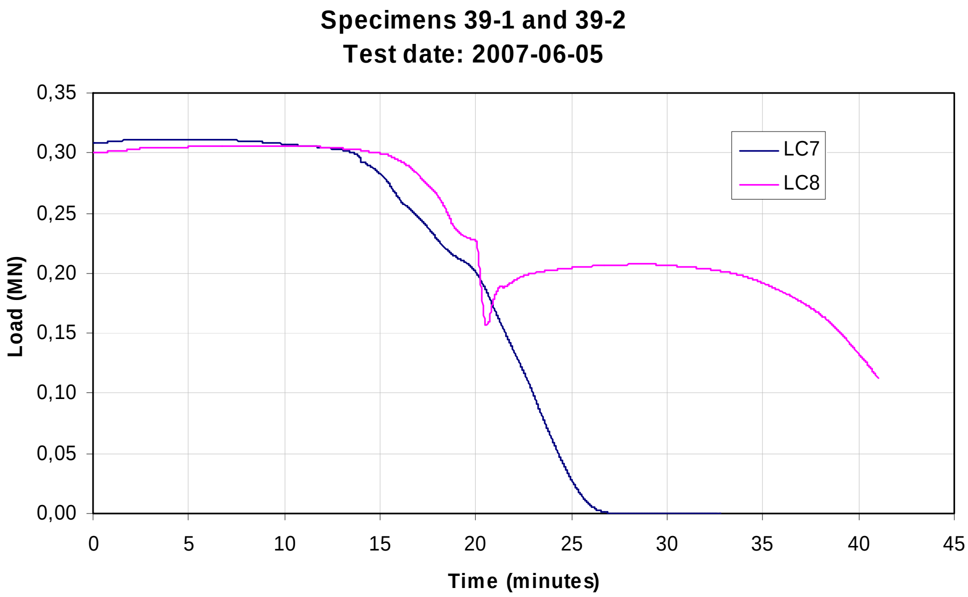

Figure 5.59 Load measurements on specimen pair 39-1 and 39-2 tested on June 5, 2007.

5.2.2.4 Spalling measurements

The spalling was measured as a spalling depth within a 22 x 24 point grid on each specimen. The spalling has been expressed as a mean spalling depth of all measurements on the specimen, a mean spalling depth where two points from the boundary inwards on all sides were taken away, and finally as the maximum spalling depth measured in any individual point.

5.2.2.4.1 Test on May 31, 2007

The measured spalling depths on specimen 38-2 are presented in table 5.38. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.39. A graph showing the spalling depth is presented in figure 5.60.

Table 5.38 Measured spalling depths on slab specimen 38-2.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	8
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	18	16
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	14	15
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	14	15
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	13
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.39 Spalling of slab specimen 38-2.

Mean all	0
Mean inner	0
Max in diagram	18

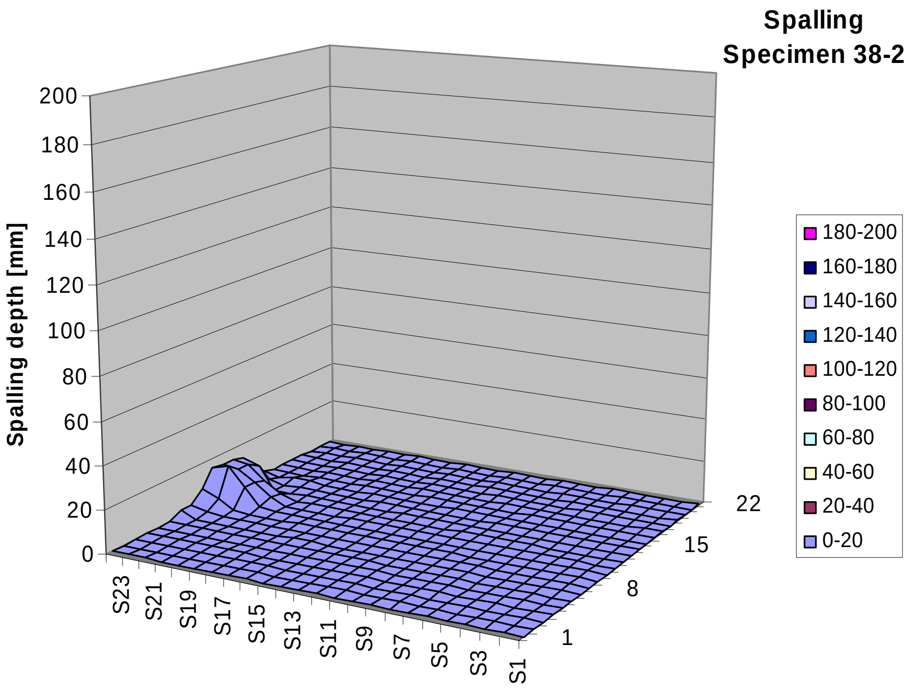

Figure 5.60 Map of spalling depth of slab specimen 38-2.

The measured spalling depths on specimen 39-3 are presented in table 5.40. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.41. A graph showing the spalling depth is presented in figure 5.61.

Table 5.40 Measured spalling depths on slab specimen 39-3.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	19	36	34	38	34	35	45	45	44	47	47	43	50	52	48	49	46	49	55	52	45	34	5	0
2	42	49	49	54	60	59	56	52	63	71	73	72	65	59	60	52	55	65	69	63	56	37	11	0
3	47	54	62	59	62	68	63	69	76	78	75	75	72	60	68	61	63	72	80	84	57	39	5	0
4	56	64	70	65	68	71	68	66	79	77	78	70	65	60	64	69	72	81	89	78	56	23	5	0
5	42	53	63	67	66	62	61	64	65	73	63	55	53	58	84	86	82	81	84	78	60	15	0	0
6	50	63	75	75	81	78	65	71	70	55	55	52	55	72	84	81	91	90	88	81	64	26	0	0
7	82	89	96	89	98	89	84	84	92	81	79	86	87	88	93	88	93	94	104	98	72	33	0	0
8	77	101	123	124	128	121	116	113	120	110	98	96	91	87	94	95	102	110	107	110	91	29	0	0
9	68	106	116	128	83	128	120	128	128	120	114	98	95	89	95	108	111	115	112	113	91	34	1	0
10	83	88	84	85	83	86	118	126	125	124	119	117	115	124	130	129	124	125	123	109	90	60	0	0
11	82	91	88	89	98	92	119	126	119	113	106	104	115	124	123	129	120	119	111	106	91	59	0	0
12	81	82	87	100	116	116	120	119	121	113	105	100	102	108	116	118	116	116	111	103	88	66	14	0
13	77	81	92	103	120	126	120	126	124	120	112	112	104	97	116	121	115	115	117	103	92	69	24	0
14	83	96	105	110	116	123	108	103	103	103	94	93	98	96	82	79	84	92	91	108	97	70	29	0
15	76	88	99	104	100	104	100	94	94	93	86	88	93	86	75	78	83	92	98	110	98	73	18	0
16	47	76	91	81	61	81	76	83	81	97	78	83	83	78	76	79	85	95	103	104	94	65	14	0
17	34	44	55	53	54	45	46	47	65	62	62	46	60	65	72	79	83	96	94	103	83	61	13	0
18	32	39	39	47	43	40	47	40	46	44	54	54	59	62	66	71	67	83	83	81	67	48	7	0
19	28	31	40	48	33	41	47	48	50	49	52	53	58	53	58	55	54	61	63	81	61	38	3	0
20	31	37	42	36	38	41	43	46	47	55	54	50	54	43	51	51	44	50	36	54	31	26	1	0
21	24	30	31	36	34	44	46	42	46	42	47	47	46	42	42	46	33	36	34	25	12	11	0	0
22	19	24	29	31	31	43	44	44	45	44	48	43	44	39	41	45	34	24	21	14	9	4	0	0

Table 5.41 Spalling of slab specimen 39-3.

Mean all	69
Mean inner	83
Max in diagram	130

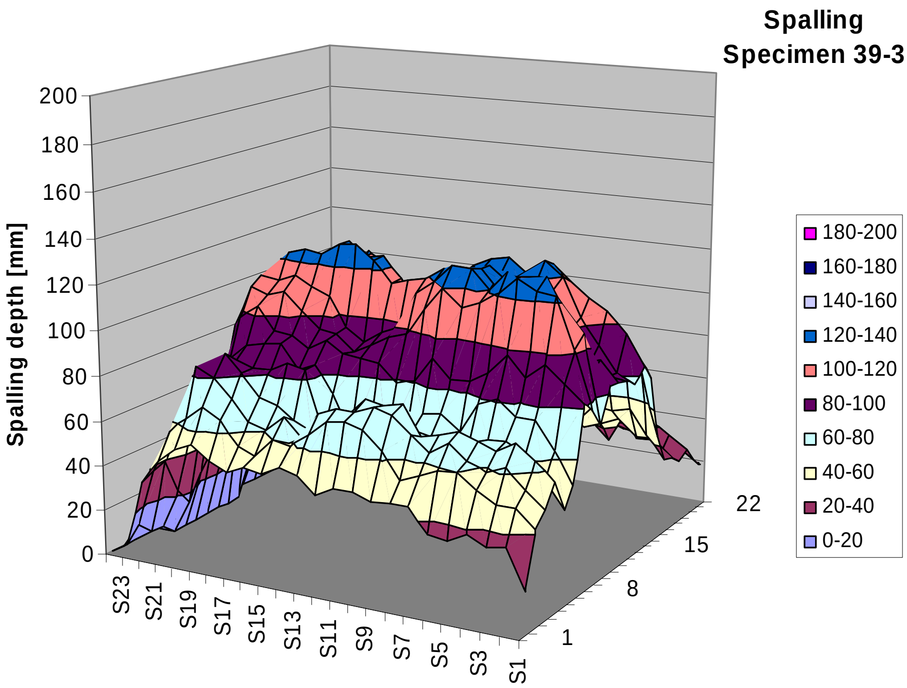

Figure 5.61 Map of spalling depth of slab specimen 39-3.

The measured spalling depths on specimen 43-2 are presented in table 5.42. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.43. A graph showing the spalling depth is presented in figure 5.62.

Table 5.42 Measured spalling depths on slab specimen 43-2.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.43 Spalling of slab specimen 43-2.

Mean all	0
Mean inner	0
Max in diagram	0

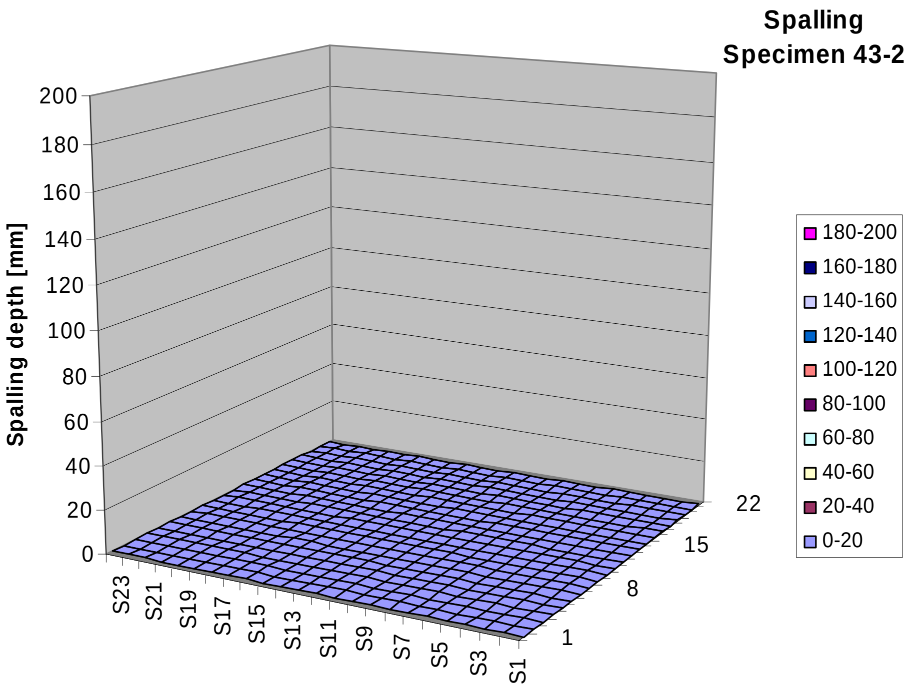

Figure 5.62 Map of spalling depth of slab specimen 43-2.

The measured spalling depths on specimen 45-4 are presented in table 5.44. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.45. A graph showing the spalling depth is presented in figure 5.63.

Table 5.44 Measured spalling depths on slab specimen 45-4.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	3	13	24	28	29	19	19	24	17	23	23	22	22	22	19	12	16	14	12	9	14	7	5
2	0	11	25	26	21	21	24	24	32	21	23	19	28	29	26	19	17	14	15	20	21	15	14	13
3	0	9	29	42	42	38	36	38	40	38	28	29	29	29	30	21	19	22	19	25	27	19	20	20
4	0	1	29	45	44	44	44	42	44	39	31	34	34	35	31	24	28	28	31	31	30	29	25	16
5	0	2	28	42	45	46	43	39	38	26	29	24	29	22	25	24	25	36	29	32	24	25	16	11
6	0	5	17	40	44	45	37	37	30	25	24	22	25	32	29	26	23	29	30	27	32	27	21	14
7	0	11	29	43	46	44	41	37	33	31	23	28	26	28	28	25	36	37	33	28	34	28	25	12
8	0	16	37	48	48	46	32	38	38	32	22	20	24	27	31	27	33	33	28	30	31	28	23	18
9	0	13	32	38	43	34	30	31	34	29	18	20	23	23	18	17	26	29	25	26	25	27	22	13
10	0	2	12	19	26	25	29	30	34	25	25	24	24	28	16	16	27	33	30	30	22	26	19	9
11	0	3	9	19	31	32	32	30	33	31	33	31	33	33	26	23	18	27	29	25	29	28	14	10
12	0	3	9	23	29	33	31	32	29	34	37	39	40	35	29	18	14	23	24	24	24	24	17	8
13	0	0	4	11	22	25	24	34	33	33	32	40	38	42	24	17	22	24	17	18	17	16	11	12
14	0	1	5	15	23	30	31	38	44	41	36	38	40	43	41	22	19	22	11	11	15	17	16	11
15	0	5	8	27	34	38	34	38	44	40	33	34	37	36	32	23	26	23	18	10	12	15	11	13
16	0	6	16	32	35	32	36	36	41	37	30	24	29	27	24	25	21	23	19	11	17	23	15	14
17	0	4	15	21	28	22	34	28	31	29	24	24	22	14	14	22	18	21	14	17	19	23	16	13
18	0	3	14	24	30	29	35	34	30	30	26	26	23	23	24	17	16	15	16	22	21	20	17	8
19	0	6	19	29	35	35	38	35	34	36	27	27	24	32	29	24	18	17	21	27	27	25	20	7
20	0	6	17	32	36	34	34	33	29	32	29	29	27	29	28	24	22	21	25	31	29	26	15	0
21	0	6	16	20	25	23	22	26	26	26	22	24	26	25	23	19	17	18	16	32	16	19	13	0
22	0	7	5	8	8	6	12	18	21	16	19	16	15	18	18	16	10	14	12	17	13	8	1	0

Table 5.45 Spalling of slab specimen 45-4.

Mean all	24
Mean inner	28
Max in diagram	48

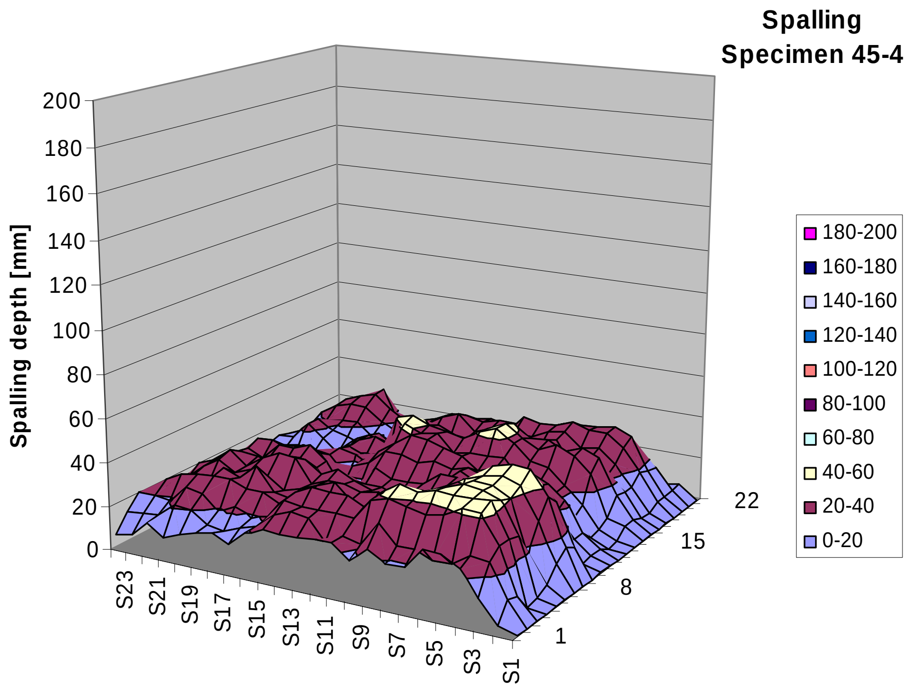

Figure 5.63 Map of spalling depth of slab specimen 45-4.

5.2.2.4.2 Test on June 5, 2007

The measured spalling depths on specimen 38-1 are presented in table 5.46. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.47. A graph showing the spalling depth is presented in figure 5.64.

Table 5.6 Measured spalling depths on slab specimen 38-1.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.47 Spalling of slab specimen 38-1.

Mean all	0
Mean inner	0
Max in diagram	0

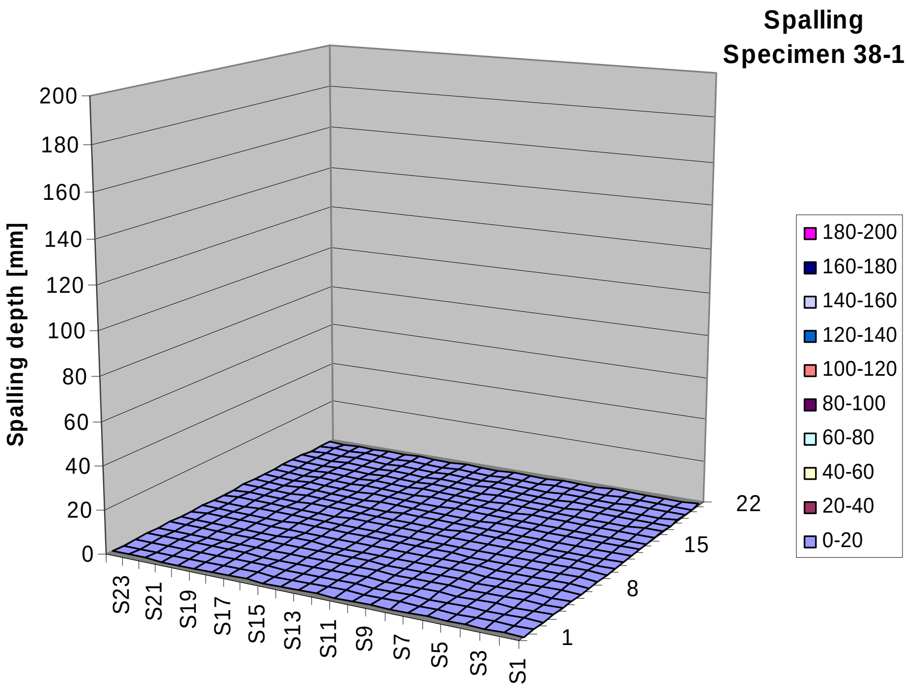

Figure 5.64 Map of spalling depth of slab specimen 38-1.

The measured spalling depths on specimen 38-4 are presented in table 5.48. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.49. A graph showing the spalling depth is presented in figure 5.65.

Table 5.48 Measured spalling depths on slab specimen 38-4.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.49 Spalling of slab specimen 38-4.

Mean all	0
Mean inner	0
Max in diagram	0

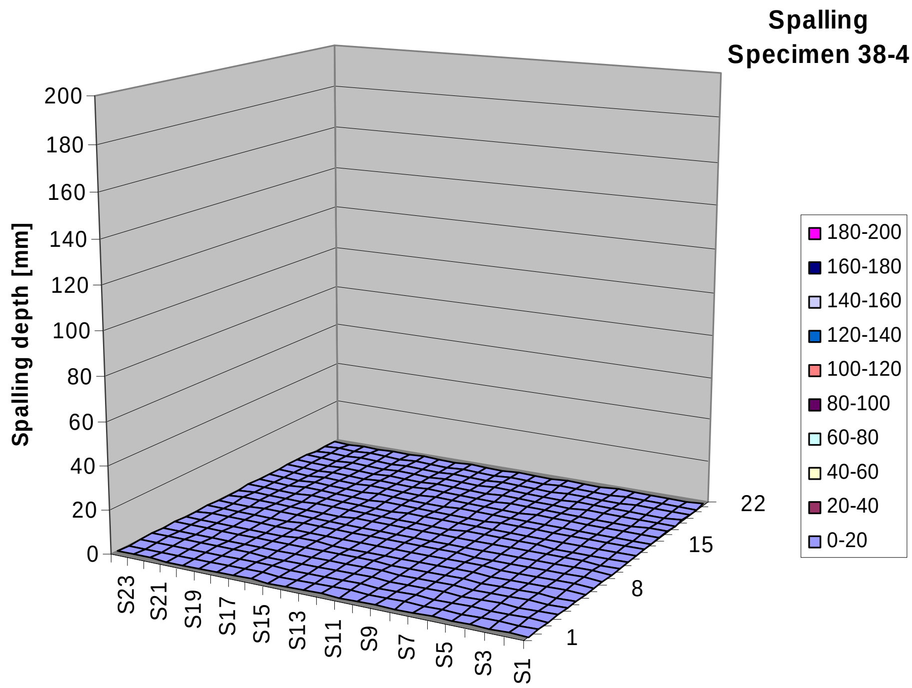

Figure 5.65 Map of spalling depth of slab specimen 38-4.

The measured spalling depths on specimen 39-1 are presented in table 5.50. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.51. A graph showing the spalling depth is presented in figure 5.66.

Table 5.50 Measured spalling depths on slab specimen 39-1.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	21	18	16	12	14	12	15	15	13	14	20	17	23	21	25	20	26	34	23	26	24	9	0	0
2	27	24	25	26	33	26	29	33	38	35	29	20	33	34	36	32	38	43	44	38	54	27	0	0
3	39	38	42	33	45	43	48	42	52	49	51	50	54	69	69	69	61	65	74	65	70	41	0	0
4	43	40	54	64	66	74	80	76	71	73	76	83	79	84	86	90	87	93	104	91	89	37	0	0
5	40	51	79	75	76	85	89	93	109	98	116	115	116	113	95	105	104	102	105	84	60	46	10	0
6	70	73	83	87	75	74	80	90	84	93	121	129	133	143	139	142	153	134	118	109	63	32	10	0
7	73	86	91	90	90	80	85	87	78	87	111	128	136	147	155	157	155	138	103	108	84	26	0	0
8	73	94	104	122	123	130	114	111	107	102	115	140	149	157	158	159	147	110	94	92	95	29	0	0
9	71	95	120	132	134	129	149	134	128	118	123	138	140	145	150	148	141	103	84	77	63	6	0	0
10	62	68	98	98	120	120	132	128	123	123	130	129	130	145	147	153	140	104	96	82	62	4	0	0
11	61	78	83	99	105	93	101	113	112	90	84	92	99	135	117	133	127	105	99	102	65	4	0	0
12	56	65	76	84	76	68	70	59	66	66	62	74	83	95	99	114	120	116	103	104	34	6	0	0
13	45	52	52	50	49	56	54	41	56	50	63	79	87	100	122	126	124	120	120	91	35	17	0	0
14	49	66	61	59	51	53	50	45	44	51	68	75	109	129	134	130	105	81	79	77	49	26	0	0
15	49	68	80	75	63	59	67	63	67	64	62	80	92	126	134	121	106	85	89	92	53	28	0	0
16	38	68	78	71	62	60	64	54	63	60	51	63	66	120	113	104	104	83	89	85	70	33	0	0
17	30	58	66	60	61	59	63	50	46	40	49	44	52	114	115	108	107	66	68	64	57	30	0	0
18	29	44	51	56	61	64	63	62	70	67	61	59	54	76	80	75	76	69	62	68	54	15	0	0
19	24	49	53	54	49	63	56	65	68	73	64	71	68	74	76	68	70	64	63	60	52	8	0	0
20	13	27	46	51	41	51	53	58	55	56	50	65	41	50	45	53	48	47	50	50	35	5	0	0
21	2	7	18	28	29	32	30	26	31	37	32	22	23	31	24	27	29	33	25	20	13	3	0	0
22	4	4	5	17	16	15	0	15	18	27	23	20	15	16	13	13	10	10	13	8	14	3	0	0

Table 5.51 Spalling of slab specimen 39-1.

Mean all	64
Mean inner	83
Max in diagram	159

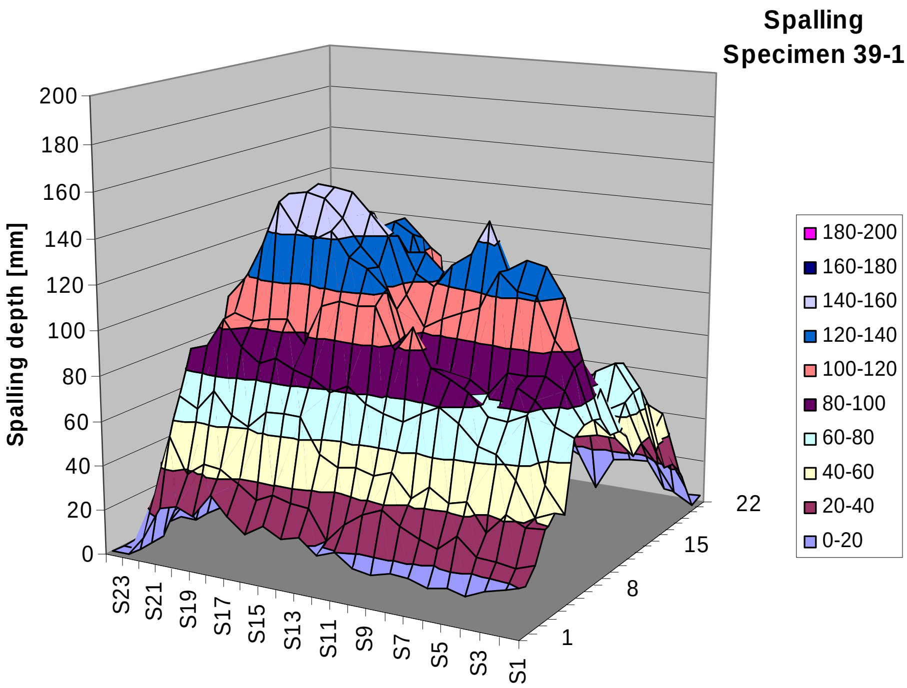

Figure 5.66 Map of spalling depth of slab specimen 39-1.

The measured spalling depths on specimen 39-2 are presented in table 5.52. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.53. A graph showing the spalling depth is presented in figure 5.67.

Table 5.52 Measured spalling depths on slab specimen 39-2.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	5	9	14	19	22	24	27	25	19	17	18	22	15	15	14	18	23	24	27	22	24	13	0	0
2	12	25	30	44	49	30	44	36	34	30	28	29	25	26	33	35	40	36	39	32	40	14	0	0
3	23	39	46	56	54	50	49	52	47	43	30	37	29	41	40	53	43	39	47	38	39	14	0	0
4	27	48	60	62	57	53	59	64	64	64	59	62	67	61	69	64	51	47	50	46	38	20	0	0
5	31	45	50	55	58	78	80	79	69	63	64	67	82	69	71	68	54	51	47	52	47	15	0	0
6	30	54	58	70	80	99	105	78	136	146	142	156	141	135	130	126	123	48	54	69	53	19	0	0
7	39	67	77	84	92	104	118	125	146	160	175	162	150	140	141	137	123	112	102	93	57	25	0	0
8	45	71	82	95	104	120	125	137	149	174	179	173	165	149	141	136	125	113	107	88	59	28	0	0
9	50	61	100	112	111	129	134	142	151	164	174	176	167	155	148	130	138	123	68	69	54	22	0	0
10	74	79	81	80	103	100	121	133	135	149	159	166	160	143	126	87	85	94	69	62	28	8	0	0
11	86	93	85	79	81	89	83	83	88	95	118	103	88	107	112	79	73	73	70	61	30	7	0	0
12	78	94	84	74	86	87	74	79	83	64	60	65	69	74	70	61	70	60	57	48	25	8	0	0
13	66	63	65	65	62	68	65	57	59	57	52	54	47	60	61	55	48	44	46	41	19	0	0	0
14	74	71	66	66	63	54	51	50	51	53	50	47	43	47	48	50	44	40	45	41	24	5	0	0
15	78	78	66	70	63	61	53	54	67	48	59	60	46	41	50	69	58	53	44	43	30	14	0	0
16	66	63	55	55	57	55	53	49	58	65	67	58	61	44	62	74	73	71	62	52	38	21	0	0
17	56	52	37	38	42	48	49	47	49	54	55	57	54	53	58	51	54	64	67	53	41	25	0	0
18	46	42	41	43	43	48	48	50	44	54	48	55	53	50	46	48	53	55	51	49	37	16	0	0
19	43	50	54	50	54	52	43	48	53	55	51	53	58	58	53	52	54	54	62	61	37	3	0	0
20	43	45	53	49	53	41	45	41	55	45	51	52	49	53	47	58	47	58	55	58	39	9	0	0
21	33	35	38	34	40	34	34	28	34	33	33	40	31	21	26	36	34	44	43	34	27	9	0	0
22	5	3	13	18	15	13	15	24	24	21	15	19	14	16	14	23	18	15	13	19	18	9	0	0

Table 5.53 Spalling of slab specimen 39-2.

Mean all	56
Mean inner	71
Max in diagram	179

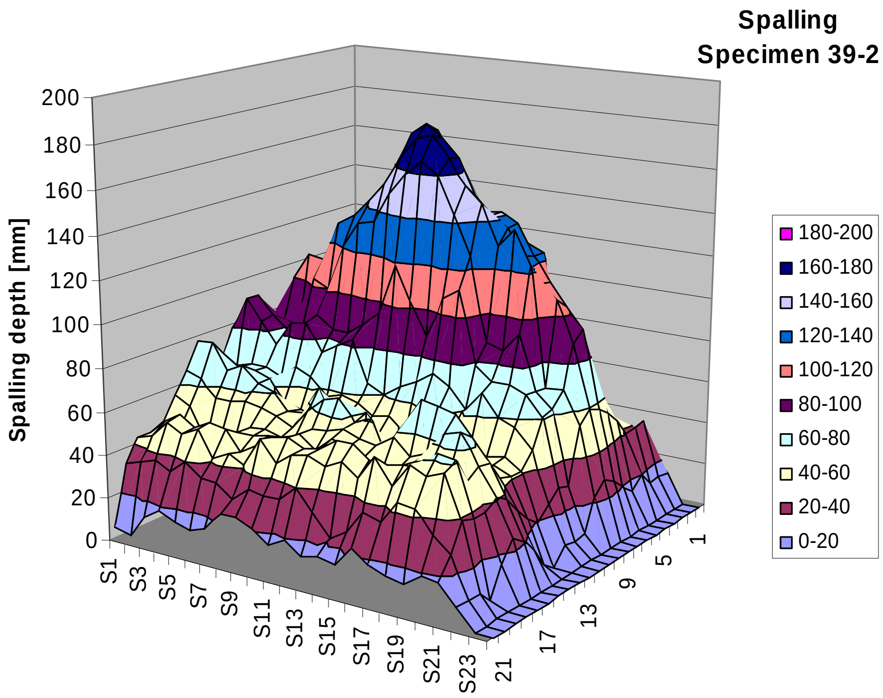

Figure 5.67 Map of spalling depth of slab specimen 39-2.

The measured spalling depths on specimen 45-1 are presented in table 5.54. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.55. A graph showing the spalling depth is presented in figure 5.68.

Table 5.54 Measured spalling depths on slab specimen 45-1.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	0	1	5	4	3	2	0	0	0	0	0	0	5	9	4	2	0	5	4	3	4	0	0
2	0	0	5	19	15	12	14	8	9	2	2	1	7	6	14	18	10	13	7	15	17	16	2	2
3	0	0	9	24	28	22	27	20	20	18	17	18	19	14	21	22	19	23	19	30	28	27	10	5
4	0	0	13	29	35	30	32	31	32	35	32	30	26	21	27	32	31	32	31	28	31	30	17	11
5	0	0	8	22	26	25	24	23	32	26	24	33	29	31	31	31	26	26	30	20	18	21	16	11
6	0	0	11	25	29	28	27	26	30	25	27	32	35	33	33	31	31	24	25	24	20	22	20	15
7	0	0	14	37	38	33	33	33	31	29	31	36	37	38	35	38	36	31	34	34	31	30	23	16
8	0	0	10	32	32	29	31	30	26	30	28	35	31	33	31	32	31	28	32	30	33	35	27	16
9	0	0	7	23	30	26	26	20	19	21	18	22	28	25	20	22	23	24	24	24	28	26	16	14
10	0	0	2	24	29	32	33	25	19	15	17	19	19	20	20	20	20	23	25	28	30	33	21	14
11	0	0	2	26	30	27	26	21	25	21	27	30	32	22	23	23	34	34	31	32	35	36	28	17
12	0	0	7	27	27	20	24	20	21	20	28	27	28	19	14	18	31	33	32	37	44	38	27	16
13	0	0	7	13	27	18	14	19	20	18	23	23	20	9	9	11	26	32	30	36	41	40	28	11
14	0	0	10	34	30	30	14	20	27	26	26	24	19	14	18	22	25	26	32	35	37	41	37	18
15	0	0	13	35	32	32	29	31	38	34	33	34	28	32	21	28	32	31	36	37	38	38	38	19
16	0	0	2	25	28	33	29	34	35	39	33	37	35	39	26	28	31	33	40	42	42	41	44	19
17	0	0	4	24	28	35	40	35	31	31	37	40	34	37	38	29	33	34	36	35	38	39	33	18
18	0	0	1	22	32	38	44	39	38	41	36	38	35	35	39	35	32	35	37	40	47	43	32	11
19	0	0	2	28	33	39	36	38	38	39	42	36	27	32	35	34	31	35	38	36	39	45	29	9
20	0	0	2	31	31	25	31	29	24	25	25	24	11	20	21	18	22	23	28	21	22	26	23	8
21	0	0	1	13	15	5	12	9	3	8	3	5	3	9	9	3	5	7	9	13	5	8	14	0
22	0	0	0	1	3	0	1	0	0	0	0	0	0	3	2	2	0	0	0	0	0	6	8	0

Table 5.55 Spalling of slab specimen 45-1.

Mean all	21
Mean inner	28
Max in diagram	47

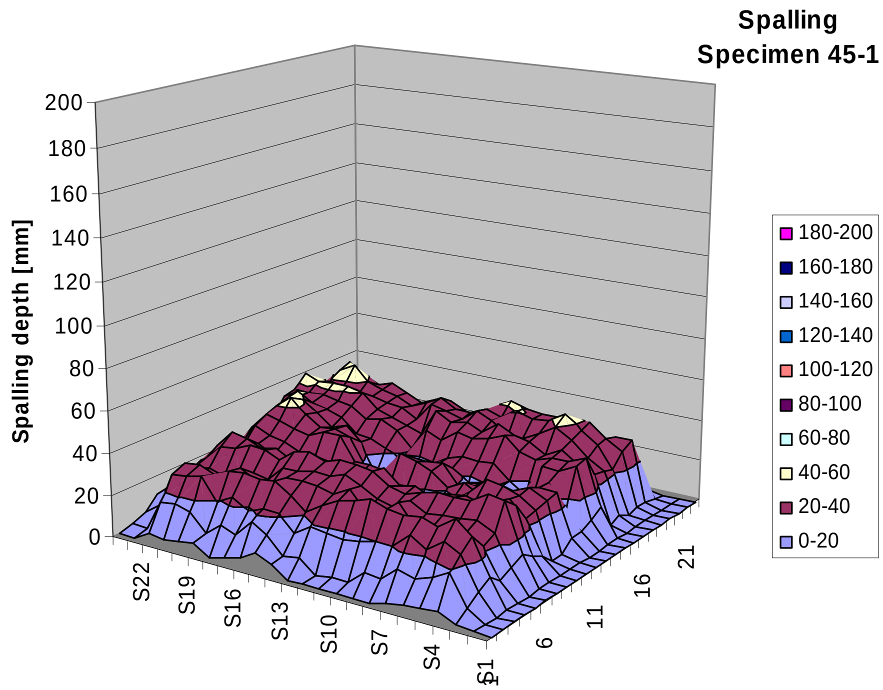

Figure 5.68 Map of spalling depth of slab specimen 45-1.

The measured spalling depths on specimen 45-2 are presented in table 5.56. The mean spalling depth of the whole surface, the mean spalling depth of an area 100 mm from the fire exposed edge of the specimen and the maximum spalling depth are presented in table 5.57. A graph showing the spalling depth is presented in figure 5.69.

Table 5.56 Measured spalling depths on slab specimen 45-2.

Pos	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X	Y
1	0	0	5	3	8	9	7	7	8	9	0	1	2	4	0	4	0	6	4	13	14	5	0	0
2	3	9	17	12	23	26	22	21	20	18	15	11	16	12	13	13	14	9	13	24	17	9	0	0
3	7	20	33	28	36	40	42	32	37	30	26	29	28	34	30	29	34	24	27	27	28	8	0	0
4	9	21	41	38	38	37	36	36	39	32	25	23	28	33	34	37	42	44	39	29	30	11	0	0
5	15	27	36	36	38	26	30	37	34	26	24	16	16	24	26	30	33	39	37	26	24	7	0	0
6	27	39	39	37	37	35	40	41	34	35	37	29	29	29	27	28	32	30	37	27	14	6	0	0
7	32	39	44	42	42	42	42	43	44	43	46	41	28	43	37	41	43	36	30	18	11	3	0	0
8	33	39	43	44	44	37	39	41	38	38	38	41	47	39	36	40	36	24	16	8	5	1	0	0
9	27	30	40	41	36	30	30	31	31	32	27	27	39	33	33	36	29	26	8	6	6	1	0	0
10	29	29	38	36	37	34	33	36	35	33	26	22	27	31	32	33	31	20	21	18	13	0	0	0
11	29	34	43	41	35	39	37	37	40	41	37	35	28	34	33	41	40	37	35	31	16	3	0	0
12	25	31	32	37	33	34	27	29	35	38	31	35	42	33	32	35	35	39	26	20	15	8	0	0
13	28	24	26	20	19	11	11	20	36	33	33	32	37	27	28	25	13	8	15	20	13	4	0	0
14	32	34	31	27	18	14	24	27	23	24	30	32	30	33	31	30	24	19	18	25	16	5	0	0
15	22	38	43	33	34	29	33	38	32	34	35	39	32	34	33	34	33	29	31	34	27	8	0	0
16	19	30	37	35	34	36	37	38	36	35	40	39	41	34	35	30	33	33	35	35	29	15	0	0
17	16	18	29	29	31	33	30	34	23	28	33	37	36	29	20	25	32	30	23	32	24	14	0	0
18	10	16	30	34	36	32	28	37	30	34	36	36	29	23	28	29	32	33	30	34	35	26	0	0
19	4	14	35	37	33	29	28	32	38	36	36	36	30	39	35	27	30	33	31	33	33	30	0	0
20	0	5	24	21	18	21	20	6	16	15	16	18	34	20	16	18	20	20	22	27	20	10	0	0
21	0	4	13	4	12	9	8	5	3	0	5	10	22	9	8	8	4	12	15	12	10	4	0	0
22	0	0	0	0	0	0	0	0	0	0	5	7	7	0	0	0	0	0	6	5	4	4	0	0

Table 5.57 Spalling of slab specimen 45-2.

Mean all	23
Mean inner	30
Max in diagram	47

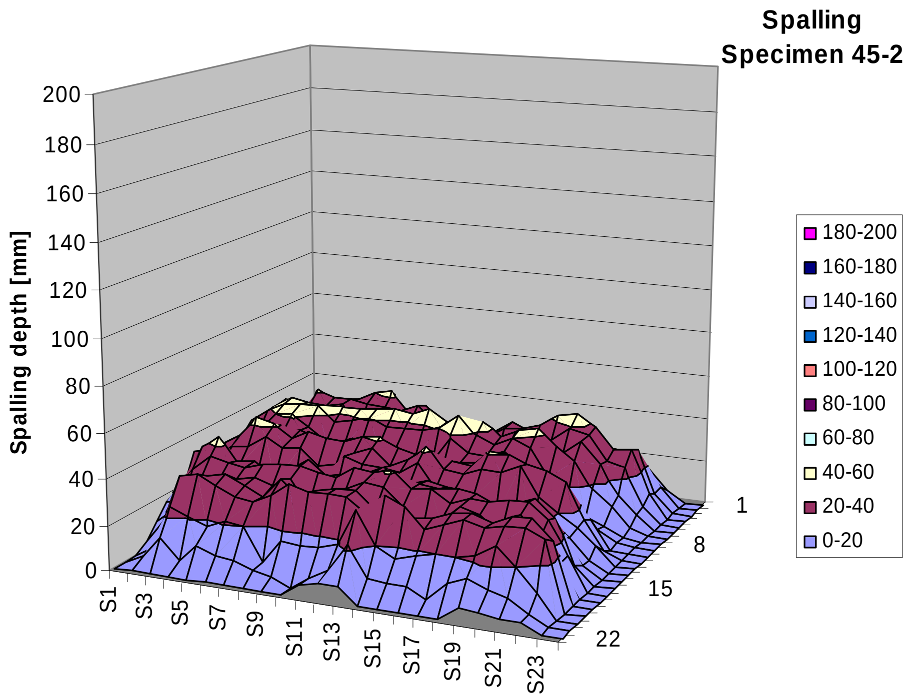

Figure 5.69 Map of spalling depth of slab specimen 45-2.

5.2.2.5 Pressure measurements

5.2.2.5.1 Test on May 31, 2007

The pressure within the concrete was measured at different depths. The measured pressures in the tested specimens are presented in figures 5.70-71.

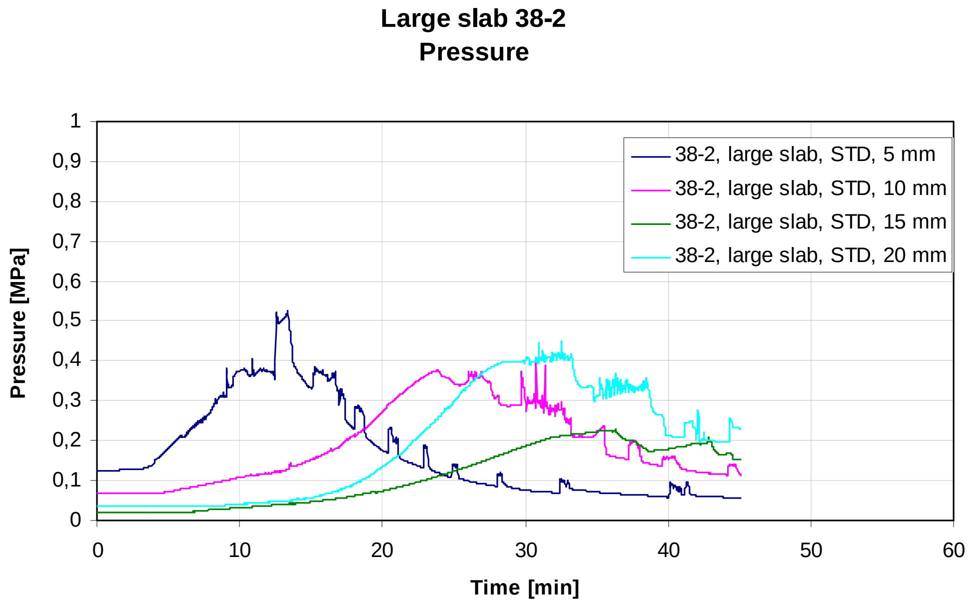

Figure 5.70 Measured pressure on different depths of slab specimen 38-2.

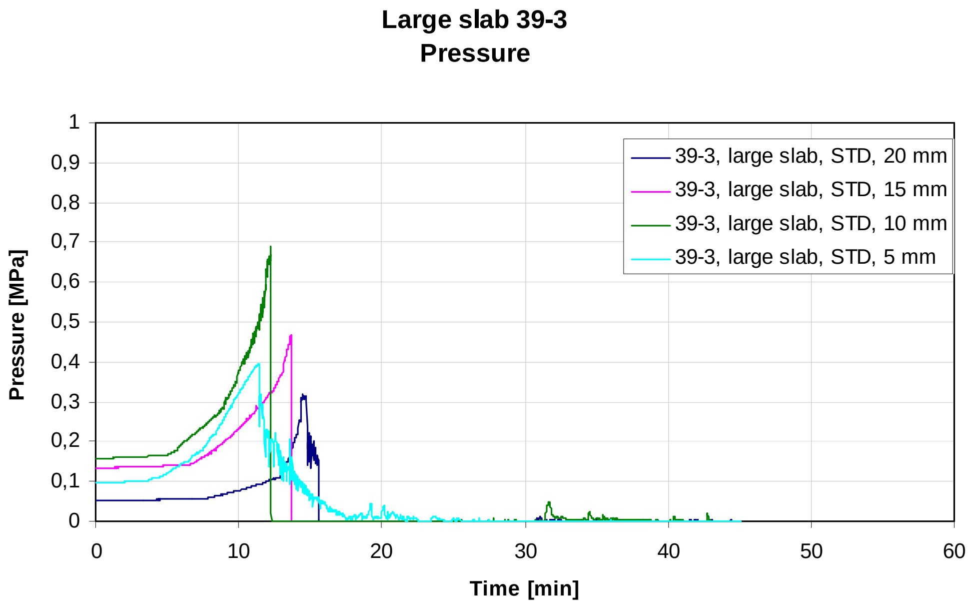

Figure 5.71 Measured pressure on different depths of slab specimen 39-3.

5.2.2.5.2 Test on June 05, 2007

The pressure within the concrete was measured at different depths. The measured pressures in the tested specimens are presented in figures 5.72-75.

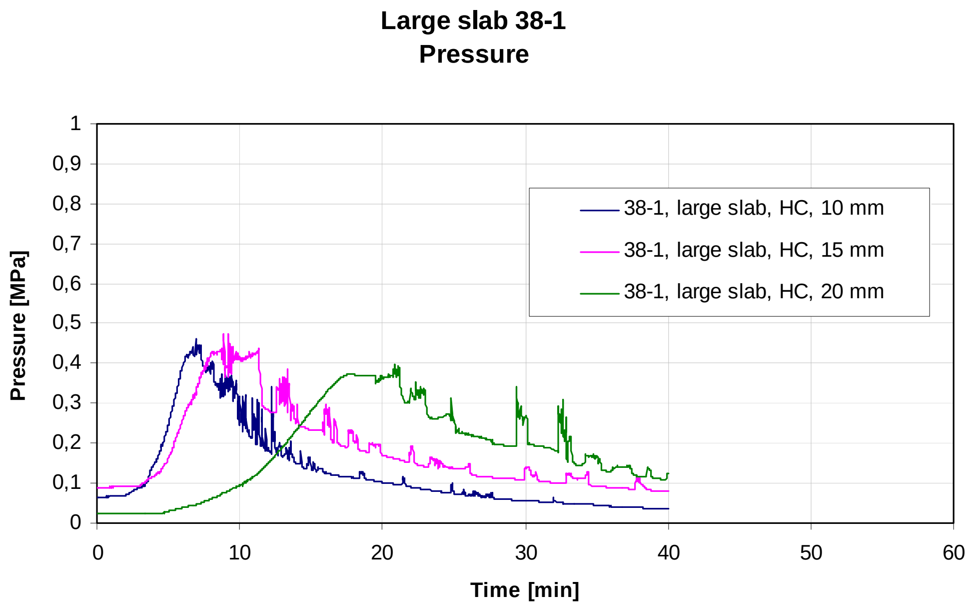

Figure 5.72 Measured pressure on different depths of slab specimen 38-1.

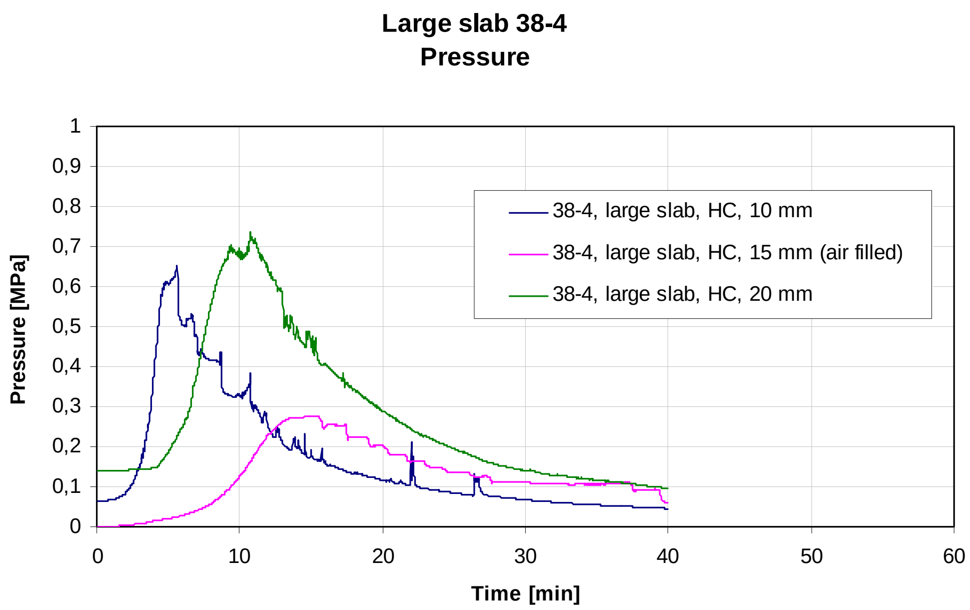

Figure 5.73 Measured pressure on different depths of slab specimen 38-4.

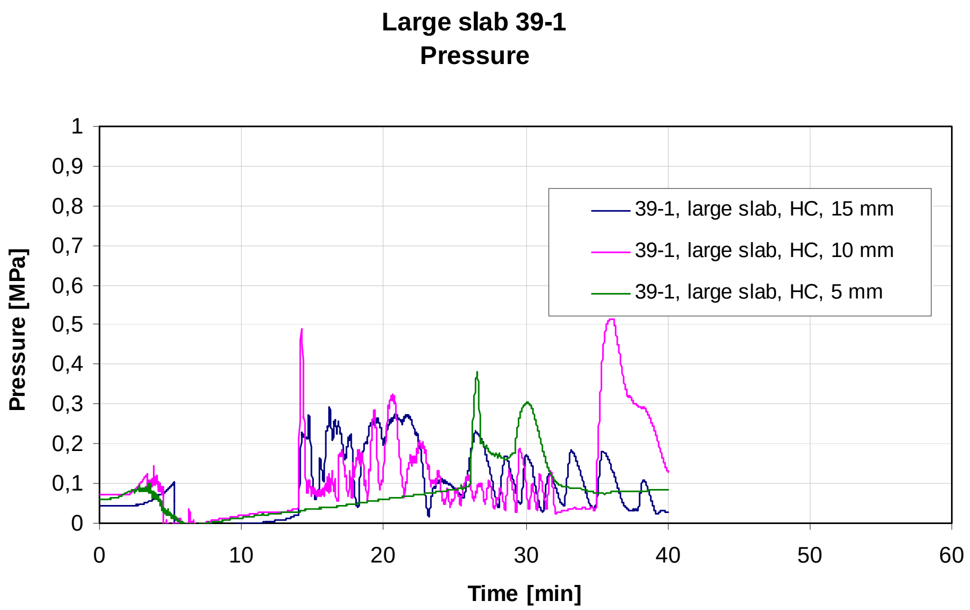

Figure 5.74 Measured pressure on different depths of slab specimen 39-1.

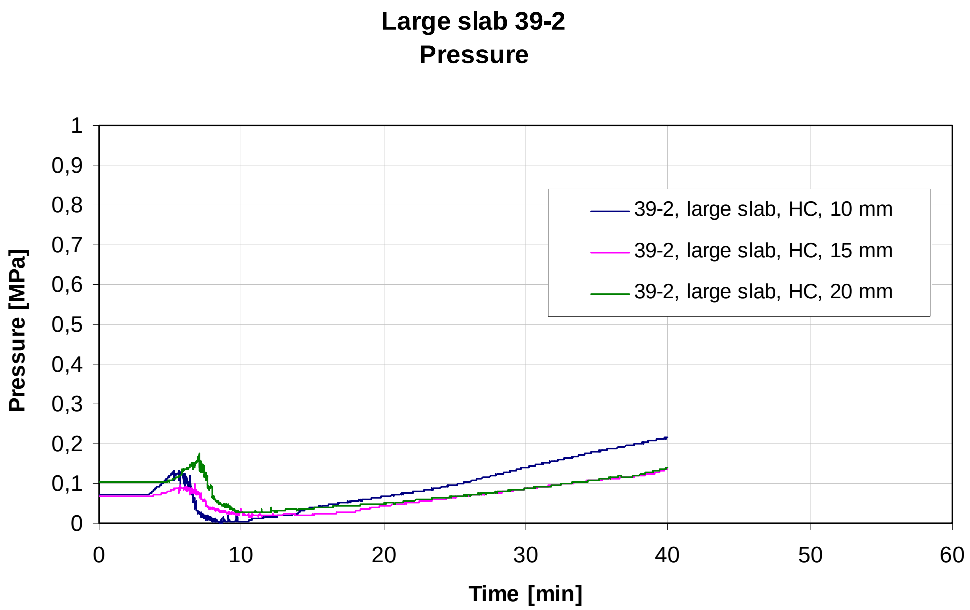

Figure 5.75 Measured pressure on different depths of slab specimen 39-2.

5.3 Norwegian tunnel concrete

The results from the tests on the small slab specimens are presented in appendix A. A summary of the test results is given in Table 5.58 below.

Table 5.58 Summary of test results from tests on Norwegian tunnel concretes.

Specimen	Max spalling (mm)	Mean spalling (mm)	Spalling time (min)	Weight loss (%)	Fire curve (-)	Appl. load (kN)	Appl. stress (MPa)	Age (days)	Moisture content (%)	Comp. strength (MPa)
58-1	0	0	-	1,9	hc	574	5,7	217	5,2	57
58-2	0	0	-	1,9	hc	598	6,0	217	5,2	57
59-1	0	0	-	0,2	hc	530	5,3	213	5,4	53
59-2	0	0	-	0,4	hc	567	5,7	213	5,4	53
60-3	0	0	-	0,9	hc	542	5,4	218	5,3	54
60-4	0	0	-	1,5	hc	548	5,5	221	5,3	54
61-3	0	0	-	3,1	hc	506	5,1	218	4,9	52
61-4	0	0	-	3,1	hc	516	5,2	219	4,9	52
62-1	50	22	4,0	11,5	hc	890	8,9	222	4,5	89
62-2	66	28	3,5	13,1	hc	930	9,3	222	4,5	89

6 Discussion

6.1 Experimental methods

The main test series has been performed using a small scale test. The method was examined in a previous project (Boström, 2004) which showed that the small scale test is a good estimation of the behaviour of the concrete when tested in a larger scale. There will be differences in the results, mainly the amount of spalling or the spalling depth. This is, however, more of academic interest. The small scale method works well as an indicator whether there is a risk for spalling or not. There have been cases when the small scale method did not show any spalling, but spalling was observed on the large test specimens. In these cases the spalling was very limited, and no progressive or explosive spalling was observed.

In order to ensure that the results are reliable some large scale tests have been performed on the same concrete as the small scale tests. The results have showed a good agreement.

The tests on small and large slab specimens of house building concrete recipes 7, 8, 10 and 46 showed similar results. The concretes made with recipes 7 and 8 did not spall at all, neither the small nor the large slabs. Both recipes 10 and 46 spalled and the results showed that the large slabs spalled more and the spalling started earlier. Of the small slabs of recipe 10 did 12 specimens out of 17 specimens spall. Of the five specimens that did not spall were four 12 months at the time of testing and the fifth one had an age of 6 months. The spalling depths of the small specimens were between 24-66 mm while the large slabs showed a spalling depth of 87-117 mm. The time when the spalling started was for the small slabs between 15-23 minutes while the large slabs started spalling at around 10 minutes. A similar behaviour was found for concrete recipe 46 where the small slabs showed a spalling depth of 30-84 mm and the large slab 156 mm. Also here the spalling started earlier for the large slab.

Also the tests on small and large slab specimens of civil engineering concrete recipes 38, 39, 43 and 45 showed similar results. Neither small nor large slabs of concrete recipes 38 and 43 spalled. Recipe 39 showed a maximum spalling depth of 24-67 mm on the small specimens while the large slabs had a maximum spalling depth of 159 mm and 179 mm. The spalling started slightly later on the small slabs. Recipe 45 showed a maximum spalling depth of 10-26 mm on the small specimens while the large slabs had a maximum spalling depth of 47 mm on both specimens tested. The spalling started slightly later on the small slabs.

6.2 Self-compacting concrete without fibres

6.2.1 Effect of age on spalling

Some of the concretes were tested at different ages. A summary of the results is shown in figure 6.1. The figure shows clearly that the maximum spalling depth is not affected by the age of the concrete up to 12 months. This is in contradiction with for example Morita et al. (2000) who did experiments on unloaded reinforced high strength concrete tested after 6 and 12 month. A common understanding is that the spalling decreases with age since the concrete dries and thus contains less water. This may be true but when dealing with self-compacting concrete the drying is very slow. In this study all specimens had a moisture content of more than 4 %, even after 12 months drying. It may well be that the spalling decreases at higher ages, but up to 12 months the age has no effect on the maximum spalling depth on the tested concretes.

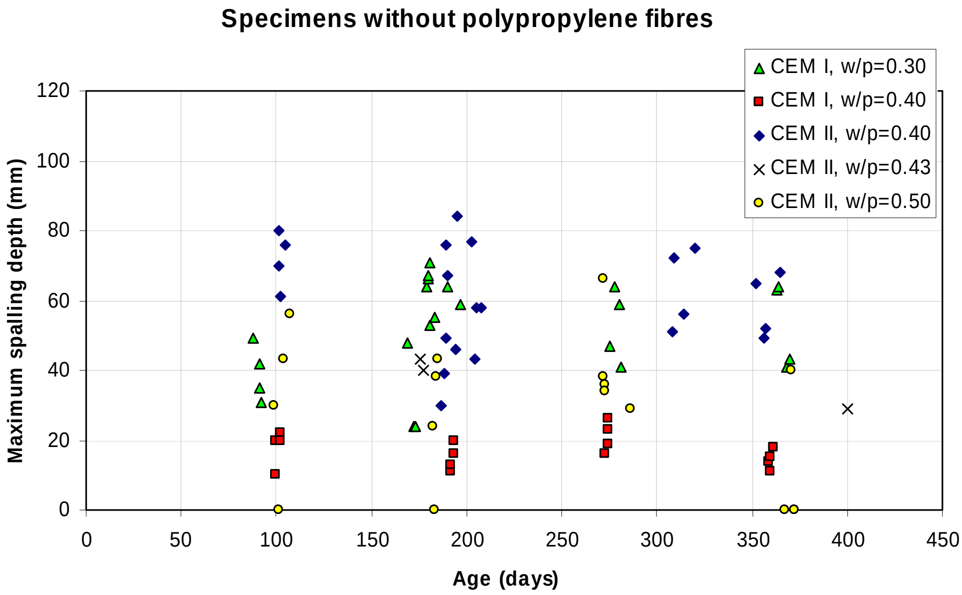

Figure 6.1 Effect of age on the maximum spalling depth.

The tests were made on specimens with an age from three months up to one year. The moisture content was measured on separate cubes (on which also the compressive strength was measured) stored together with the slabs. The moisture content measurement started the same day as the fire test. In figure 6.2 is the effect of moisture content on the spalling shown. It is clear that the drying of these self-compacting concretes is a very slow process. Even after over a year is the moisture content still well above 4 %. The results do not show any significant effect on the spalling due to the moisture content. It should, however, be noted that the moisture content was high in all tests, but probably representative for what is expected in practice.

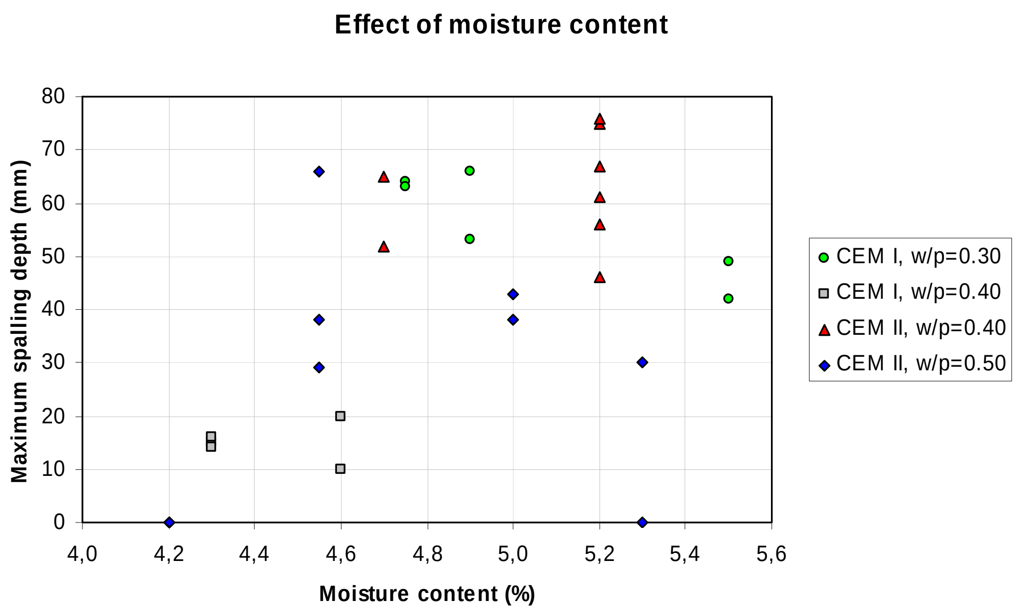

Figure 6.2 Effect of moisture content on the maximum spalling depth.

6.2.2 Effect of load on spalling

Some of the concretes were tested using different compressive load levels. Since the small slabs were unreinforced it was not possible to apply high loads, and therefore the maximum tested load level was chosen to 10 % of the compressive strength. The tests were performed on either unloaded specimens or on specimens loaded in compression, i.e. no tests were performed on small slabs loaded in tension.

Some beam specimens were tested at the same time as the large slabs. The beams were loaded in four point bending, i.e. the fire exposed surface is loaded in tension. When comparing results obtained with the slabs and beams of concrete recipe 10 it is clear that the beams spall less. The spalling depth of the slabs were 69-117 mm while the beams spalled 32 mm and 37 mm. Concrete recipe 46 was also tested with large slabs and beam specimens. A similar result was obtained. The maximum spalling depth of the slab was 156 mm while the beams spalled 43 and 51 mm. These results show that specimens loaded in tension spall less compared to the ones loaded in compression. Although, the results also show that these self-compacting concretes also spall when loaded in tension. This is in line with previous research (Copier, 1979) which concluded that there is a large influence if an external compressive load is present but the size of the load is less important.

The results from tests on the small slabs show that the load level up to 10 % of the compressive strength did not affect the maximum spalling depth see figures 6.3-4. The unloaded specimens, however, showed slightly less spalling. It may be that higher load levels will result in more severe spalling. Large slabs of concrete recipe 10 were tested unloaded as well as with a compressive stress of 3.9 MPa. The results showed no significant difference on the maximum spalling depth. The loaded specimens spalled 87 and 117 mm respectively, and the unloaded ones spalled 69 and 104 mm.

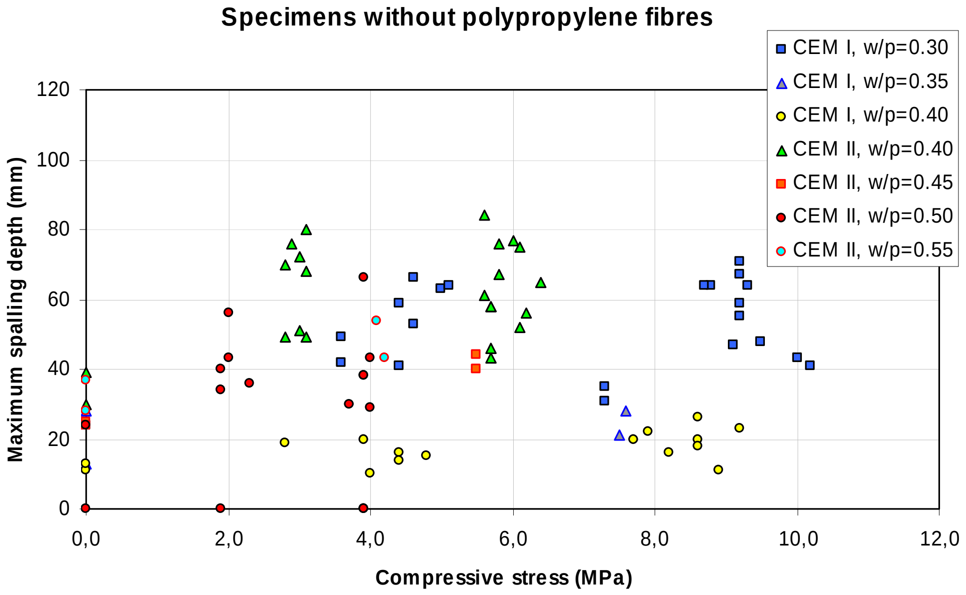

Figure 6.3 Effect of applied compressive stress on the spalling depth.

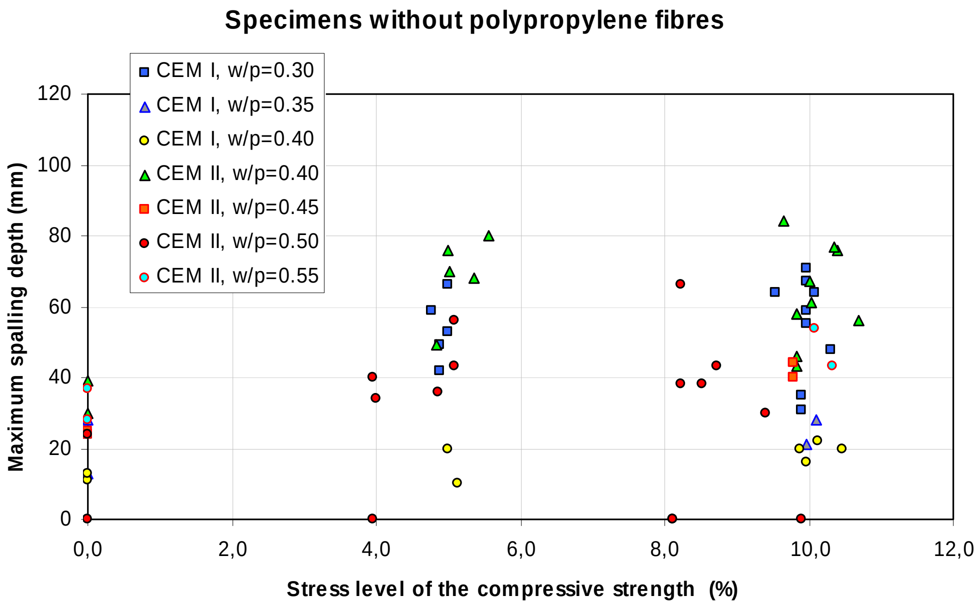

Figure 6.4 Effect of stress level on the spalling depth.

6.2.3 Effect of concrete admixture on spalling

It is generally difficult to compare results when more than one factor is changed at the time. This will always be the case when examining the effect of concrete admixture on the spalling. For example, it is in practice impossible to change the content of limestone filler without changing the content of water, superplasticiser or other ingredient and still have the same consistency. Nevertheless a comparison has been done on concretes with different limestone filler content. Figures 6.5-6 show the effect on the maximum spalling depth versus amount of limestone filler. There is a tendency that the spalling depth increases with the amount of limestone filler up to 100-150 kg/m^3, and thereafter decreases. There are, however, too few tests done to statistically ensure the effect.

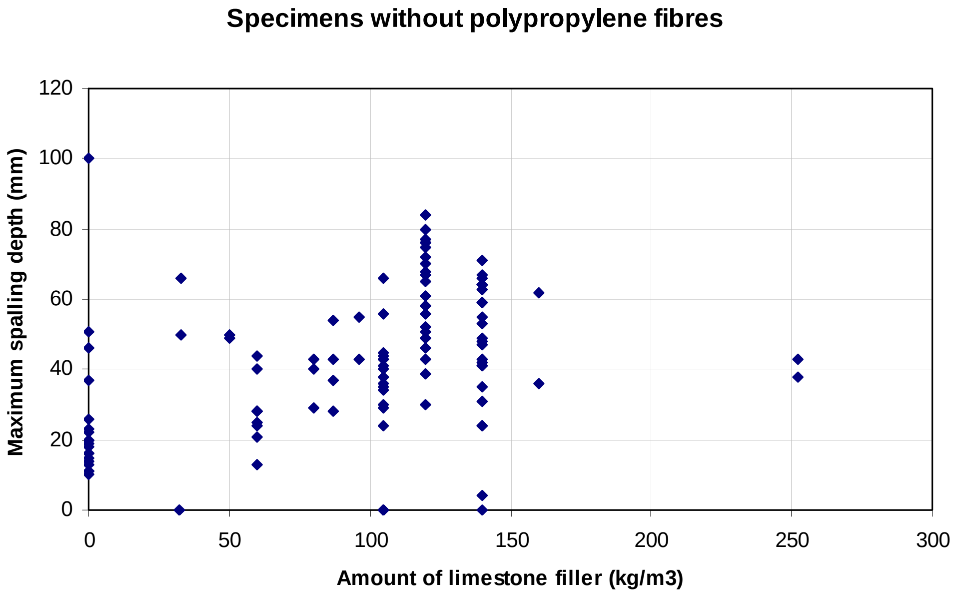

Figure 6.5 Influence of limestone filler on the spalling depth independent of cement type.

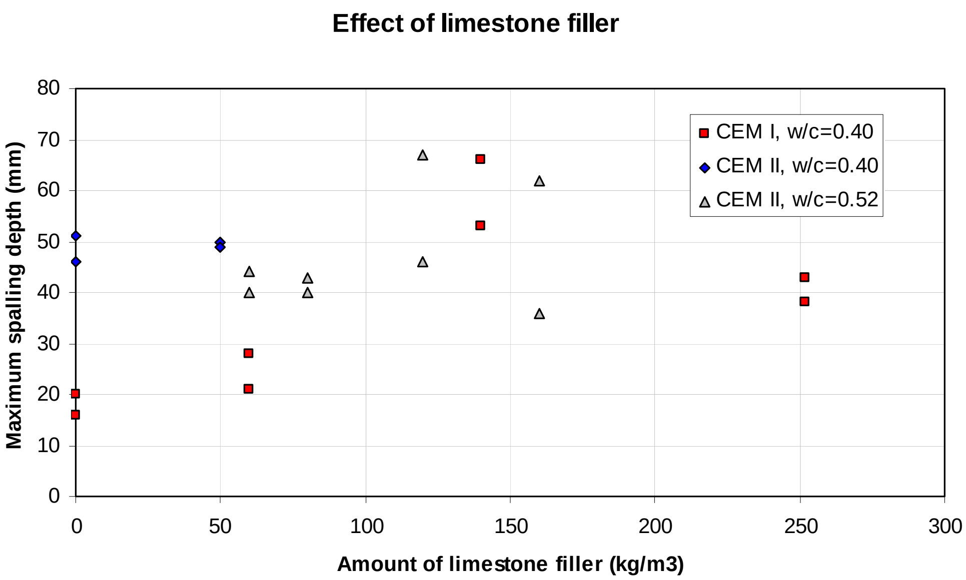

Figure 6.6 Influence of limestone filler on the spalling depth.

A general conception is that the spalling decreases with increasing water-powder (w/p) ratio. This has been observed in other studies such as Boström (2002). In figures 6.7-8 is the effect of w/p-ratio on the maximum spalling depth presented. In the figures the data has been divided with respect of the load level used when tested. There is a tendency that the maximum spalling depth decreases with the w/p-ratio, but the effect is not significant. Hence these results contradict, to some extent, the general conception as there not was any significant effect of the w/p-ratio on the spalling.

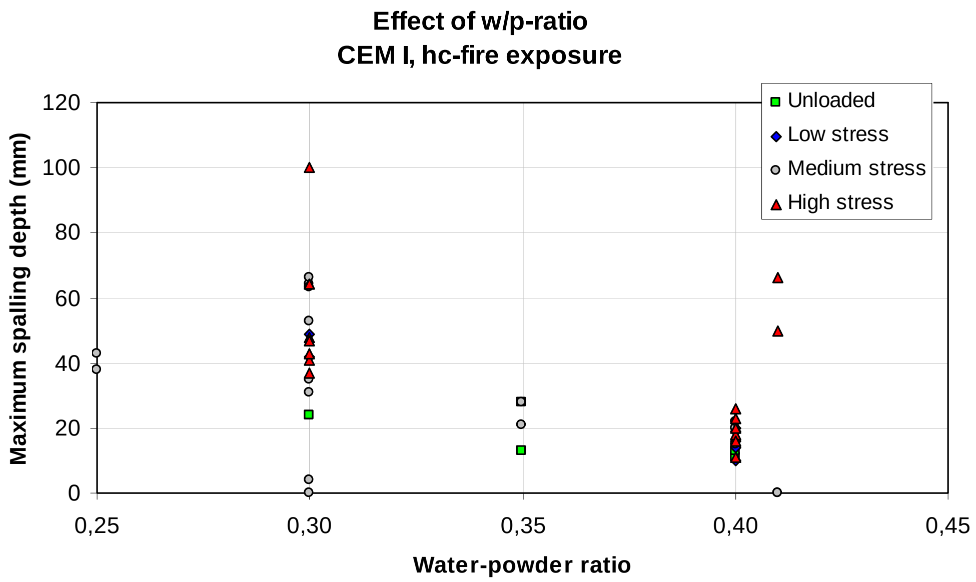

Figure 6.7 Effect of w/p-ratio on the maximum spalling depth of CEM I concrete with a HC fire curve exposure.

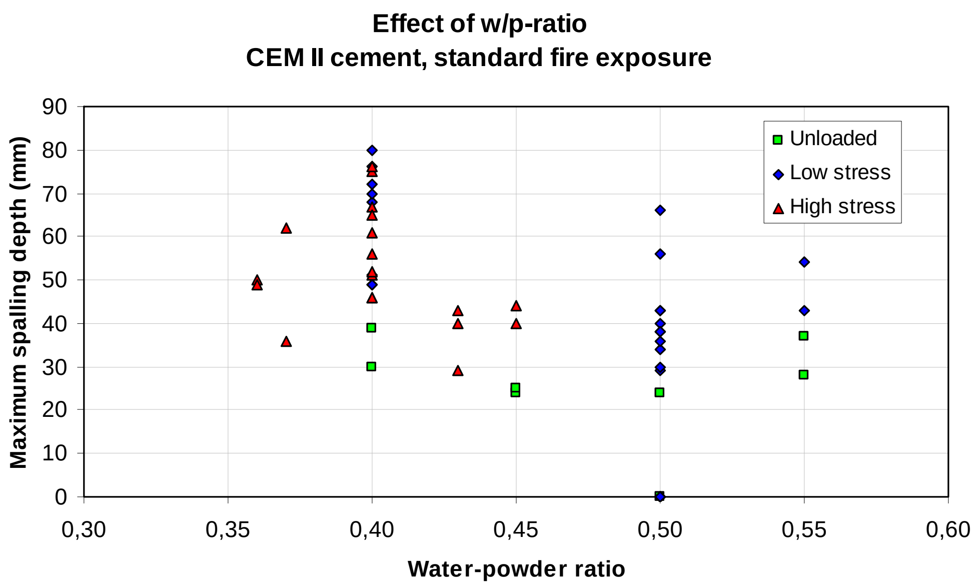

Figure 6.8 Effect of w/p-ratio on the maximum spalling depth of CEM II concrete with a standard fire curve (ISO 834) exposure.

6.3 Effect of polypropylene fibres

There is a significant effect on the spalling when polypropylene fibres are added to the concrete. The fibres decrease the probability of spalling and the eventual amount of spalling. Different geometries of the fibres have been examined, two diameters (18 µm and 32 µm) and two lengths (6 mm and 12 mm). The amount of fibres has been varied from 0.5 kg/m^3 up to 3 kg/m^3. Concrete with fibres has been tested with three different types of civil engineering concretes, three different building concretes and one concrete based on Norwegian cement.

6.3.1 Civil engineering concrete

The civil engineering concrete had a w/c-ratio = 0.40 and varying amount of limestone filler from non at all up to 252 kg/m^3 giving a w/p-ratio equal to 0.40, 0.30 and 0.25. A total of 8 specimens with w/p = 0.25 have been compared, two without addition of fibres which both spalled during the fire tests. One out of two specimens with 0.5 kg/m^3 fibres with diameter 18 μm and length 6 mm did spall as well as one out of two specimens with 1.0 kg/m^3 fibres with diameter 32 μm and length 6 mm.

A total of 41 specimens with w/p = 0.30 have been compared, 16 without addition of fibres which all except one spalled during the fire tests. No spalling at all was observed on the specimens with fibres. The amount of fibres studied was 0.5 kg/m^3 for fibres with diameter 18 μm and 1.0 kg/m^3 for fibres with diameter 32 μm.

A total of 22 specimens with w/p = 0.40 have been compared, 16 without addition of fibres which all spalled during the fire tests. Specimens with 0.5 kg/m^3 fibres with diameter 18 μm and length 6 mm did spall. No spalling was observed for specimens with 1.0 kg/m^3 fibres diameter 18 μm and length 6 mm and 1.4 kg/m^3 for fibres with diameter 32 μm and the same length.

The results show that the amount of fibres needed in order to prevent fire spalling is different and depends on the concrete. These tests show that an amount of 1.0-1.5 kg/m^3 fibres is needed.

6.3.2 House building concrete

The house building concrete had a w/c-ratio = 0.52 with a w/p of 0.40 and 0.45, and a w/c-ratio = 0.65 with w/p = 0.50. A total of 38 specimens with w/c = 0.52 and w/p = 0.40 have been compared, 23 without addition of fibres which all spalled during the fire tests. None of the specimens with polypropylene fibres spalled. An amount from 0.5 kg/m^3 fibres with diameter 18 μm and length 6 mm and 1.0 kg/m^3 fibres with diameter 32 μm and length 6 mm were examined.

A total of 12 specimens with w/c = 0.52 and w/p = 0.45 have been compared, 4 without addition of fibres which all spalled during the fire tests. No spalling at all was observed on the specimens with fibres. The amount of fibres studied was 0.5 kg/m^3 for fibres with diameter 18 μm and 1.0 kg/m^3 for fibres with diameter 32 μm.

A total of 27 specimens with w/c = 0.65 and w/p = 0.50 have been compared, 17 without addition of fibres which all except 5 spalled during the fire tests. Two specimens with fibres with diameter 18 μm and length 6 mm did spall, one with 0.5 kg/m^3 and one with 1.0 kg/m^3.

Also for the house building concrete the results show that the amount of fibres needed in order to prevent fire spalling is different and depends on the concrete. These tests show that an amount of 1.0-1.5 kg/m^3 fibres is needed.

6.3.3 Norwegian concrete

A total of 10 specimens of Norwegian concrete were studied, four specimens without addition of polypropylene fibres of which two were manufactured without air entrainment. Polypropylene fibres with diameter 18 μm and length 6 mm were used with an amount from 0.5 kg/m^3. Both specimens without air entrainment and polypropylene fibres spalled. On all other specimens no spalling was observed.

6.4 Effect of polypropylene filler

Some tests were made on concrete where filler of polypropylene had been added. The amount of filler varied from 0.5 kg/m^3 up to 10 kg/m^3. The advantage with the polypropylene filler compared to the fibres is that they do not influence on the workability of the fresh concrete. The tests showed that the polypropylene filler did not improve the fire resistance of the concrete, i.e. the filler cannot replace the use of polypropylene fibres.

6.5 Effect of fire curve

Generally it is assumed that a more severe fire exposure would give more spalling. Two different concretes were examined with regard to the severity of the fire exposure. The test results are presented in figure 6.9. These tests show that the amount of spalling does not increasing with increasing fire severity, rather the opposite could be the case. This was also found in the experiments conducted by Morita et al. (2000) were high strength concrete specimens exposed to a slow heating curve spalled more than specimens exposed to the standard fire curve. Although, the time to the spalling starts is of course dependent on the type of fire curve. In the case of the very low heating rate, i.e. the 10 K/minute ramp test, the spalling started after 50-60 minutes, while in the case with the hydrocarbon curve the spalling started after 2-4 minutes. Generally the spalling started when the furnace temperature was measured to 500-700 °C.

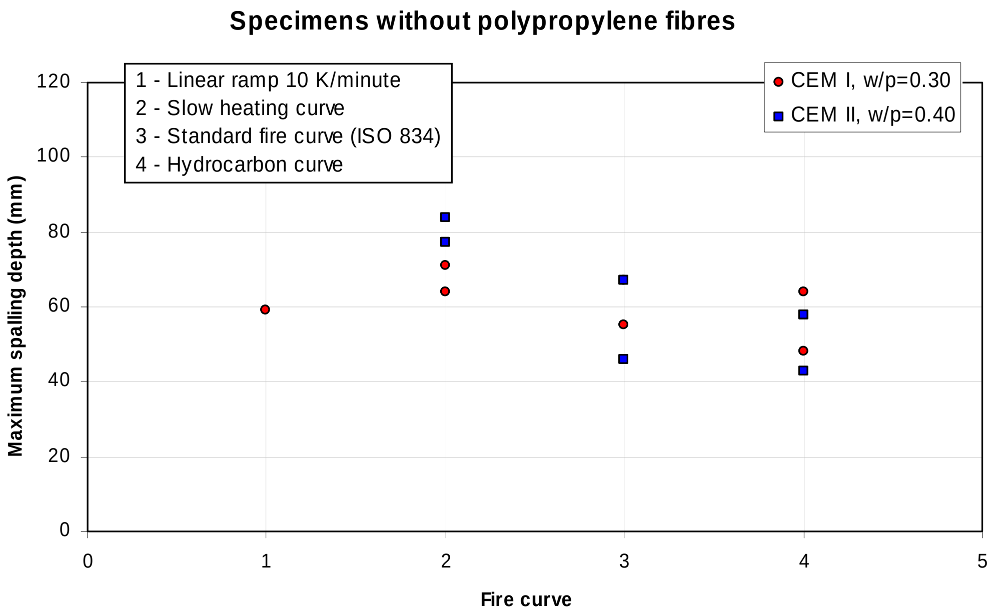

Figure 6.9 Effect of the fire curve on the maximum spalling depth.

6.6 Pressure measurements

In some of the large slab specimens were the pressure measured within the concrete. The measured pressures within the concretes were generally low. The highest pressures were measured on concrete with addition of fibres that did not spall. This has been showed in other studies as well, Jansson (2008). There is a contradiction here with studies made by for example Kalifa et al. (2000) who measured much higher pressures. One explanation to the differences is the heating gradient. A slow heating results in higher pressures.

7 Conclusions

An extensive experimental test series have been carried out with self-compacting concrete. The tests were mainly carried out on small slab specimens. In order to verify the results from the small scale tests also medium sized specimens have been tested. A total of 24 medium sized specimens were used in this verification. The tests showed a good agreement regarding when and if spalling occurred. The measured spalling depth was generally larger on the medium sized specimens compared to the small ones. The conclusion was that the small scale specimens give reliable results on the risk for spalling, but they would not fully represent the correct spalling behaviour in larger concrete slabs.

Different factors regarding the composition of the concrete as well as the loading conditions and age have been examined. The general results, i.e. when looking on all test data on self-compacting and tunnel concrete, show that these test results contradicts some of the results found in the literature, Morita et al. (2000).

The experiments showed that in principle all self-compacting concretes without addition of polypropylene fibres spall when exposed to fire. An addition of 1.0-1.5 kg/m^3 polypropylene fibres with a diameter of 18 μm or 32 μm gave a good protection regarding progressive spalling which would be acceptable in most applications. There are cases, however, when more fibres or other types of protection will be required. It could for example be in tunnel applications where no spalling is acceptable or in pre-cast elements where the design and geometry has been optimized.

In the present tests the level of compressive load did not affect the spalling of self-compacting concrete, except that unloaded specimens spalled slightly less compared with the ones loaded in compression.

Regarding the concrete composition it was not possible to see any significant effect of the amount of limestone filler or the water-powder ratio used in the concrete. The filler content was varied from no filler at all up to 250 kg/m^3. Although, the results indicate that it may be some effect and that a filler content of around 100-150 kg/m^3 gives a maximum on the amount of spalling. There is also a tendency that by increasing the water-powder ratio the amount of spalling decreases, which is in line with previous results such as Boström (2002).

The effect of the fire exposure, i.e. the type of fire curve used, was examined on some concretes. It was found that the type of fire exposure did not affect the risk of spalling, even with such slow heating rates as 10 K/minute. An interesting finding was that the furnace temperature was 500-700 °C when the spalling started in all cases. Hence the spalling starts after 2-4 minutes when a hydrocarbon (HC) fire curve is used, and after 50-60 minutes when the 10 K/minute ramp is employed for self-compacting concrete. The amount of spalling was generally larger when slower heating rates were used.

A parameter that is often regarded as a driving force for spalling is the moisture content. In the study was some concretes cured different long time before testing. The moisture content was determined on cube specimens stored together with the fire specimens. The results showed as expected that the drying is very slow for these dense concretes. Even after over one year storage in air the moisture content is well over 4 %. In the fire tests no influence of the curing time could be shown on the spalling. One explanation could be that the moisture content never decreased below a critical level. A medium sized self compacting concrete specimen made with CEM II cement was tested after over two years storage, and even after this time did it spall severely.

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EN 1363-1 Fire resistance tests –Part 1: General requirements. 1999

EN 1363-2 Fire resistance tests – Part 2: Alternative and additional procedures. 1999

EN 1365 Fire resistance tests for loadbearing elements – Parts 1-6. 1999

EN 12390-3 Testing hardened concrete – Part 3: Compressive strength of teat specimens. 2002

ENV 13381-3 Test methods for determining the contribution to the fire resistance of structural members – Part 3: Applied protection to concrete members. 2003

Dissemination of results

The following publications, seminars and conference papers have been made based on the results from the research projects on spalling of concrete at SP Fire Technology:

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Jansson R. “Material properties related to fire spalling of concrete”, Report TVBM-3143, Lund, 2008, licentiate thesis

Häggström J., Wahlström B., Hjohlman M. ”Brandskydd av tunnelkonstruktioner” (eng. Fire protection of tunnel structures), SveBeFo Rapport 82, Stockholm, 2007 (in Swedish)

Boström L., Jansson R. “State-of-the-art report – Durability of self-compacting concrete – Chapter on Fire Resistance”, RILEM Report 38, 2007

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Boström L. “Polypropylene fibres improve the fire resistance of self compacting concrete”, Concrete Plane + Precast Technology, no 1, 2003

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Appendix A – Test results

A1 Concrete 1

Table A.1 Concrete admixture recipe 1.

Recipe	1
Water (kg/m^3)	198
CEM II 42,5R A-LL (Byggcement) (kg/m^3)	380
Limestone filler, Limus 25 (kg/m^3)	80
Water-powder ratio, w/p	0,43
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5.5
Sikament 20HE 50 (% of cement weight)	1.45
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	690
T50 (s)	2-3
Air (%)	1,7
Compressive strength, 28 days (MPa)	52.0

Specimen 1-1

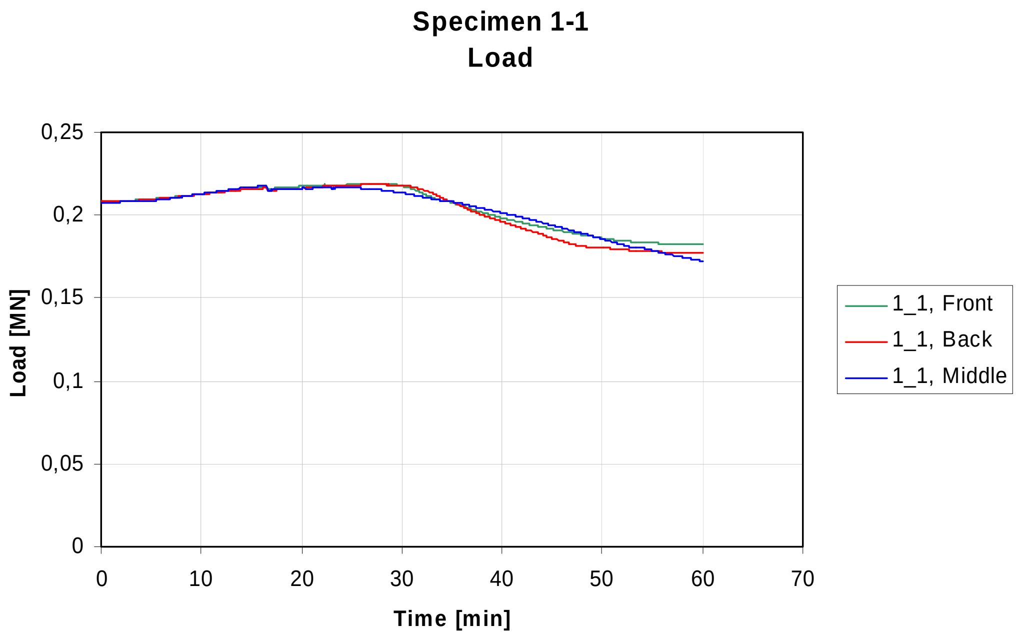


Figure A.1 Load measurements on specimen 1-1.

Table A.2 Spalling measurements on specimen 1-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	5	15	28	11	0
200	0	9	16	13	20	14
300	0	18	33	20	21	12
400	0	26	35	22	18	7
500	0	13	31	21	17	6
600	0	1	6	6	15	6

Mean all	11
Mean inner	20
Max in diagram	35
Max measured	43

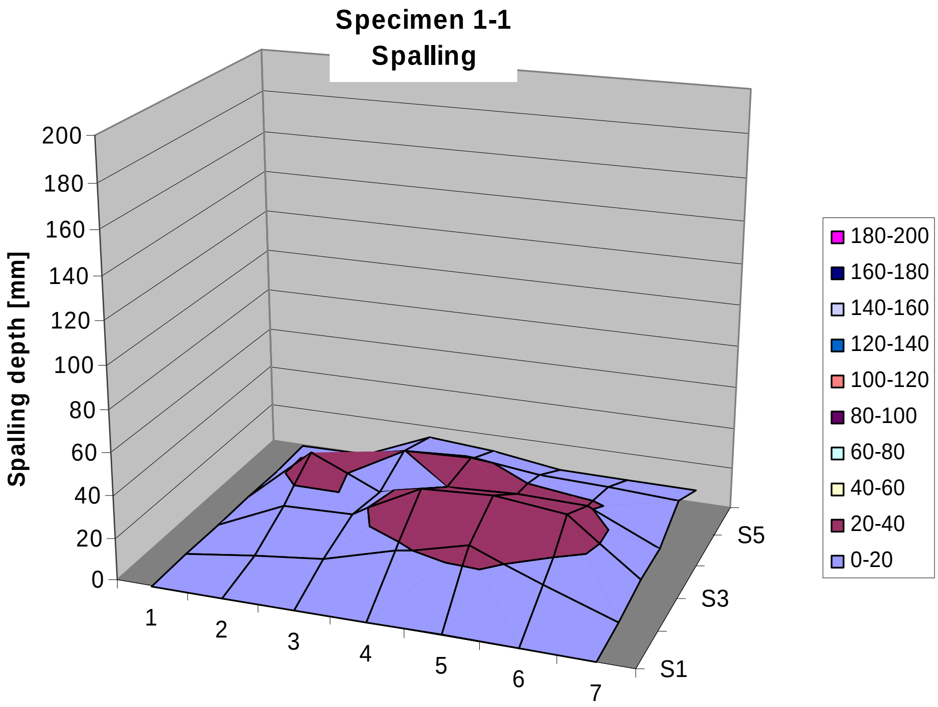


Figure A.2 Spalling measurements on specimen 1-1.

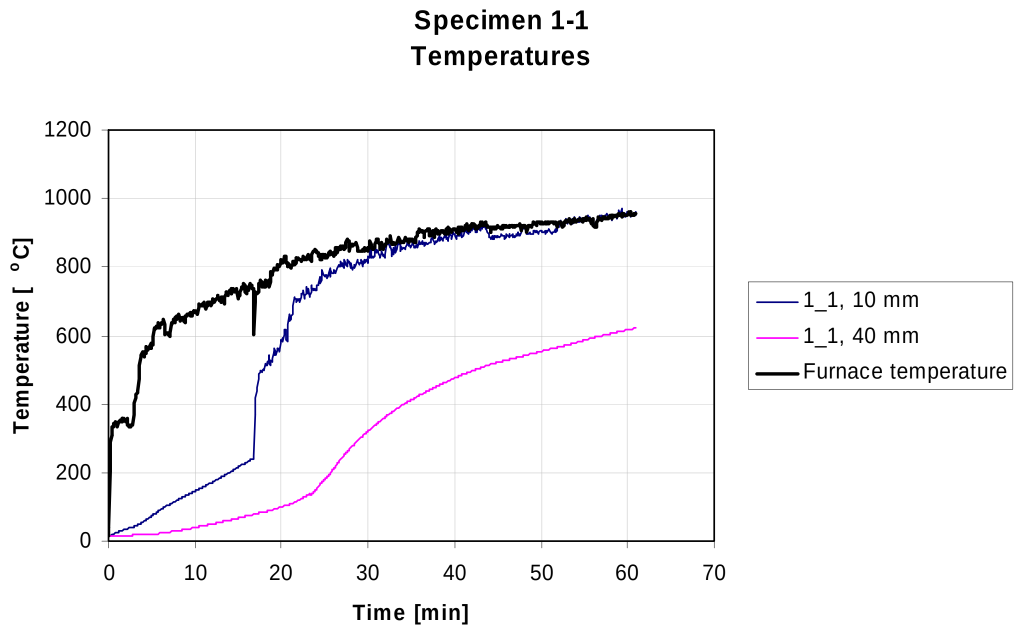


Figure A.3 Measured temperatures in furnace and in specimen 1-1.

Table A.3 Observations made on specimen 1-1.

Time	Observation			
0,00	Start of test	Test date:	2005-11-24	
14,83	One explosion	Specimen:	1-1	
16,12	One small explosion	Load level:	208	kN/bar
16,75	One loud explosion	Weight loss:	8	kg
17,67	Two small explosions, thereafter continuous			
57,00	Moisture on sides			
60,00	Test terminated			

Figure A.4 Specimen 1-1 during test.

Figure A.5 Specimen 1-1 after test.

Specimen 1-4

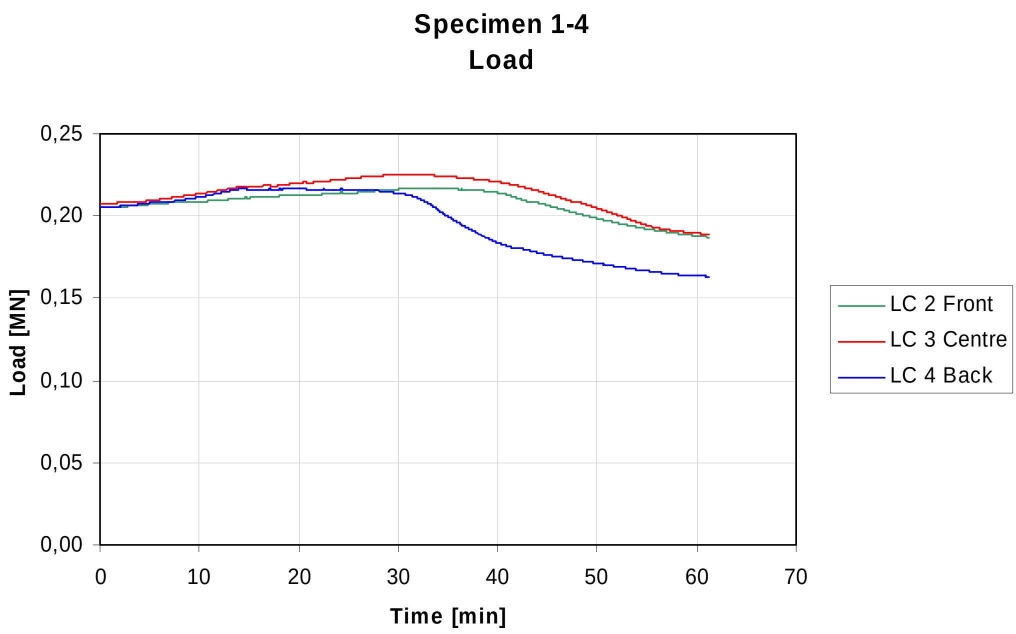


Figure A.6 Load measurements on specimen 1-4.

Table A.4 Spalling measurements on specimen 1-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	9	5	11	11	0
200	5	14	19	21	22	0
300	2	11	30	29	31	3
400	0	27	34	27	20	0
500	0	20	27	29	13	0
600	0	9	4	11	2	0

Mean all	11
Mean inner	21
Max in diagram	34
Max measured	40

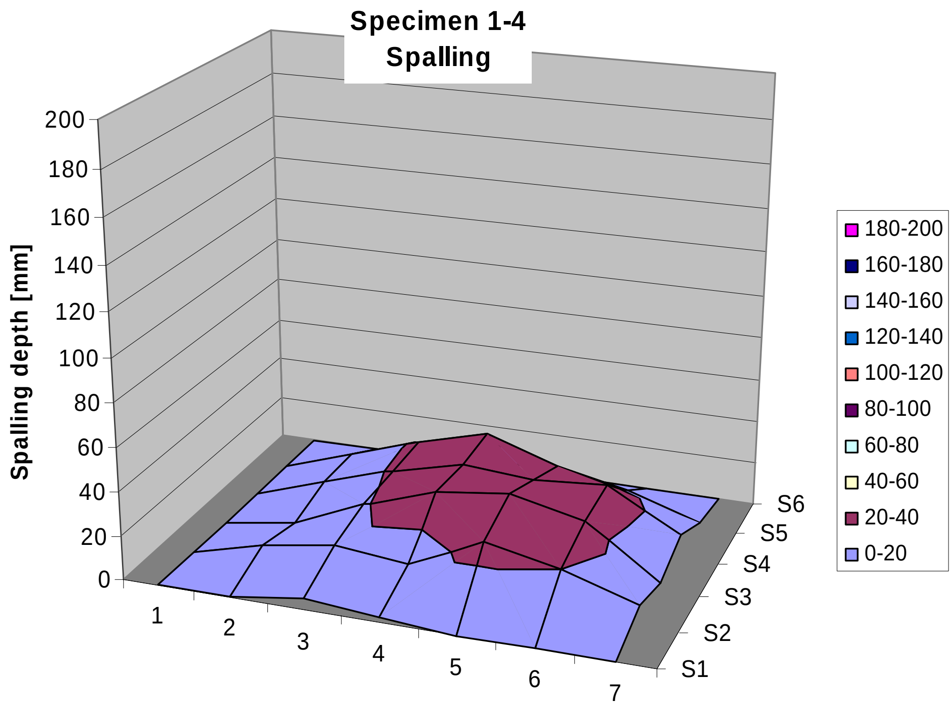


Figure A.7 Spalling measurements on specimen 1-4.

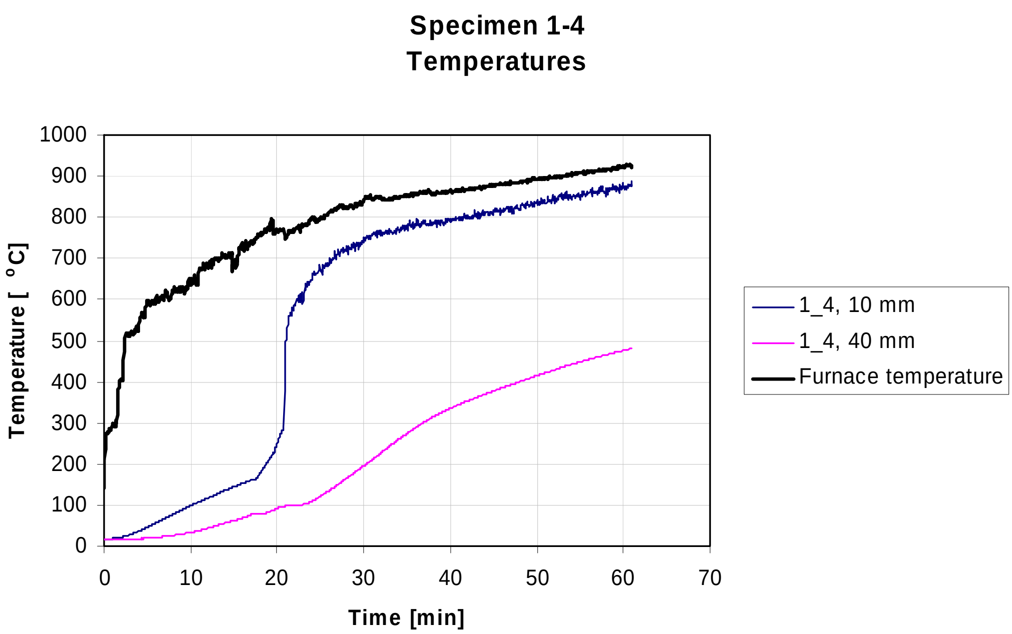


Figure A.8 Measured temperatures in furnace and in specimen 1-4.

Table A.5 Observations made on specimen 1-4.

Time	Observation
0,00	Start of test
14,80	One very loud explosion
16,00	One small explosion
17,17	One loud explosion
19,83	One small explosion
21,00	One small explosion
25,00	Explosions have stopped
60,00	Test terminates

Test date:	2005-11-25	
Specimen:	1-4	
Load level:	206	kN/bar
Weight loss:	9	kg

Figure A.9 Specimen 1-4 after test.

Specimen 1-5

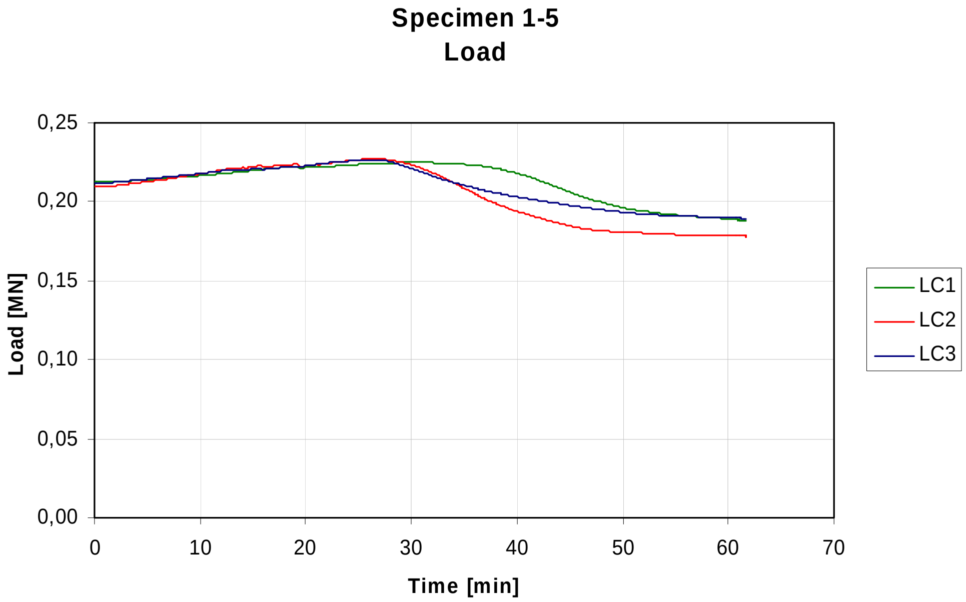


Figure A.10 Load measurements on specimen 1-5.

Table A.6 Spalling measurements on specimen 1-5.

Position	0	100	200	300	400	500
0	0	0	0	7	9	0
100	0	0	14	17	18	4
200	0	1	19	24	19	3
300	0	16	21	16	19	0
400	0	22	28	19	12	4
500	0	15	21	25	15	3
600	0	0	4	4	0	0

Mean all	9
Mean inner	17
Max in diagram	28
Max measured	29

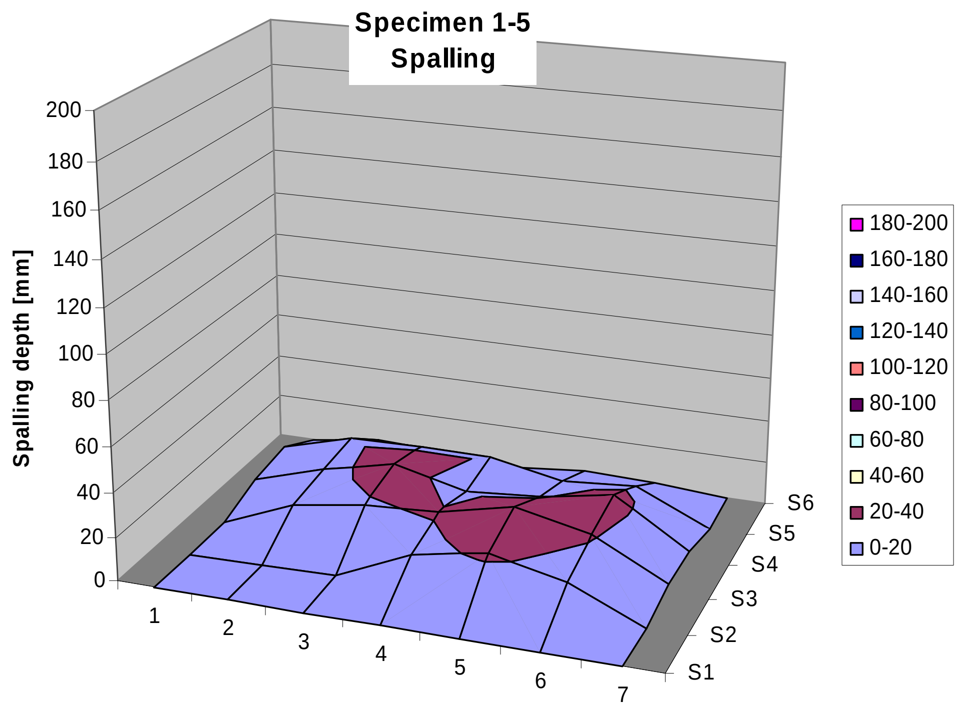


Figure A.11 Spalling measurements on specimen 1-5.

Table A.7 Observations made on specimen 1-5.

Time	Observation
0,00	Start of test
12,73	One explosion
13,88	One small explosion
13,92	One small explosion
14,23	One small explosion
15,58	One explosion
16,02	One small explosion
16,80	One small explosion
17,72	One small explosion
17,87	One small explosion
18,68	One small explosion
18,75	One small explosion
19,13	One explosion
20,00	One small explosion
20,33	One small explosion
20,87	One explosion
21,70	One small explosion
60,00	Test terminates

Test date:	2006-07-06	
Specimen:	1-5	
Load level:	211	kN/bar
Weight loss:	3,2	kg

Figure A.12 Specimen 1-5 after test.

A2 Concrete 2

Table A.8 Concrete admixture recipe 2.

Recipe	**2**
Water (kg/m^3)	198
CEM II 42,5R A-LL (Byggcement) (kg/m^3)	380
Limestone filler, Limus 25 (kg/m^3)	160
Water-powder ratio, w/p	0,37
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,8
Sikament 20HE 50 (% of cement weight)	1,53
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	690
T50 (s)	2-3
Air (%)	1,7
Compressive strength, 28 days (MPa)	52.0

Specimen 2-1

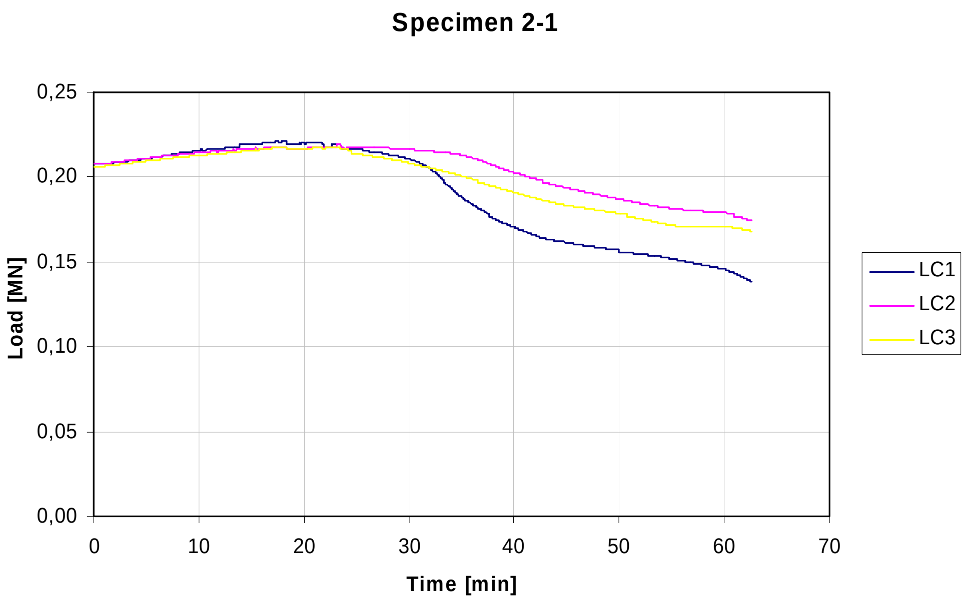


Figure A.13 External load on specimen 2-1.

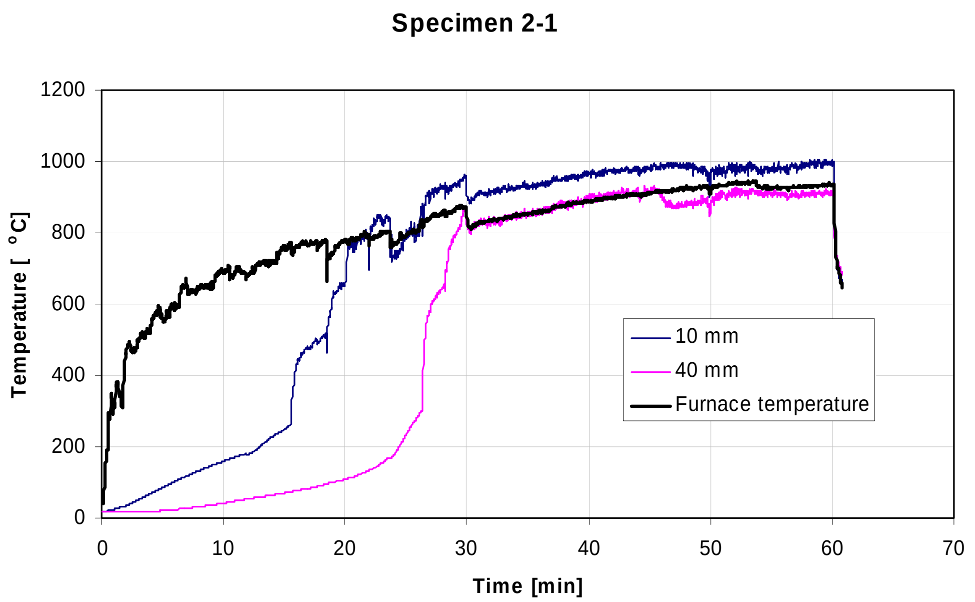


Figure A.14 Temperature measurements, specimen 2-1.

Table A.9 Spalling measurements on specimen 2-1.

Position	0	100	200	300	400	500
0	6	5	7	6	0	0
100	12	23	37	15	16	0
200	19	21	45	35	16	0
300	19	27	46	49	15	4
400	15	39	62	58	17	0
500	2	13	36	40	24	2
600	0	0	1	1	4	0

Mean all	18
Mean inner	32
Max in diagram	62
Max measured	62

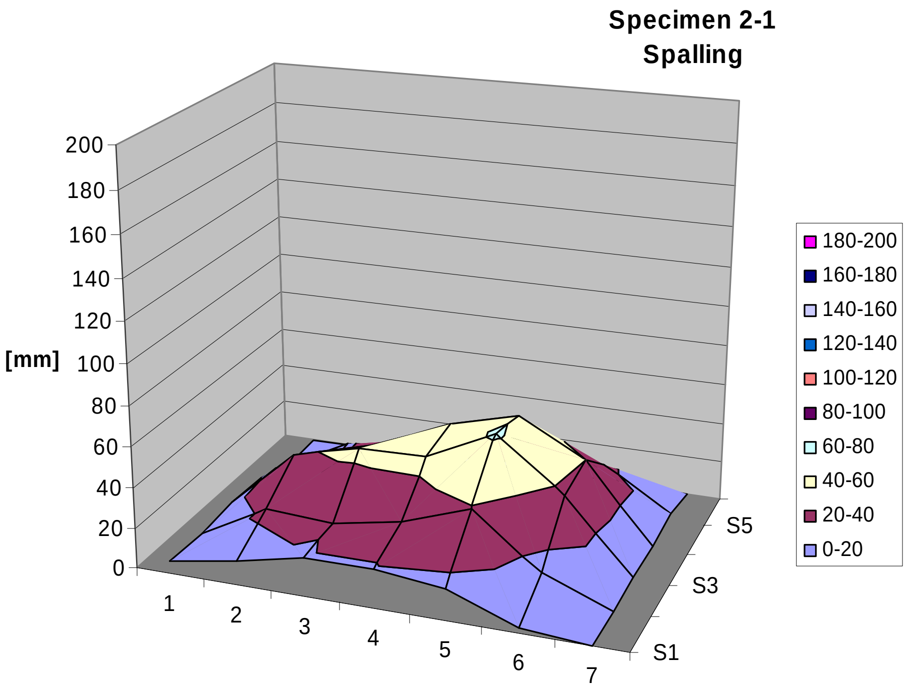


Figure A.15 Spalling on specimen 2-1.

Table A.10 Observations and other measures on specimen 2-1.

Time	Observation			
		Test date:	2005-11-28	
0,00	Start of test	Specimen:	2-1	
9,03	One explosion	Load level:	207	kN/bar
10,28	One small explosion	Weight loss:	13,3	kg
10,42	One small explosion			
11,38	One small explosion			
11,52	One small explosion			
11,78	One explosion, thereafter continuous small explosion			
18,63	One loud explosion, thereafter continuous small explosion			
21,97	One loud explosion			
23,72	Two loud explosions			
24,67	One small explosion			
25,77	One small explosion			
26,37	One small explosion			
27,45	One small explosion			
28,20	One small explosion			
32,83	Water on front and back sides			
60,17	Test terminates			

Figure A.16 Specimen 2-1 after test.

Specimen 2-4

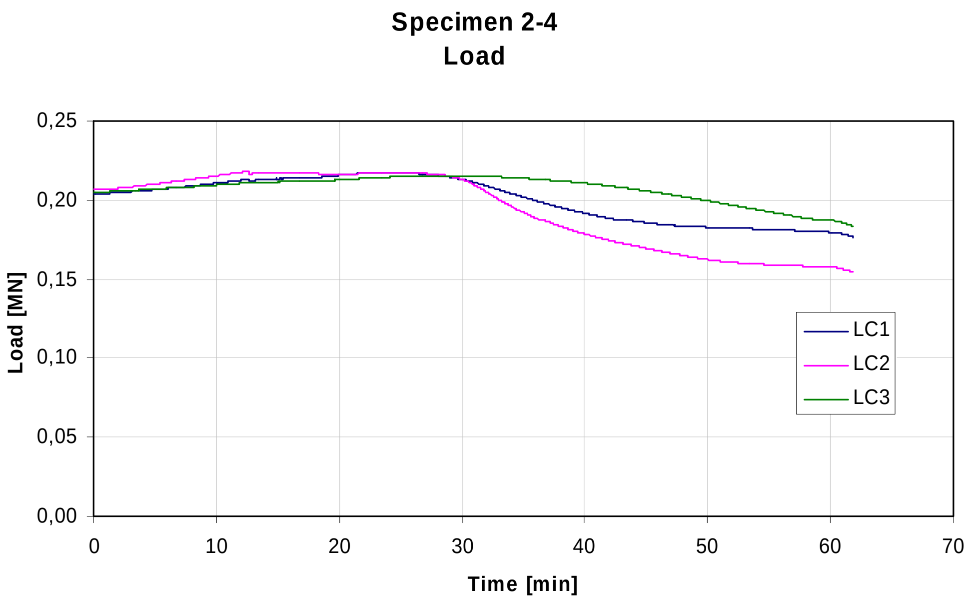


Figure A.17 Load measurements on specimen 2-4.

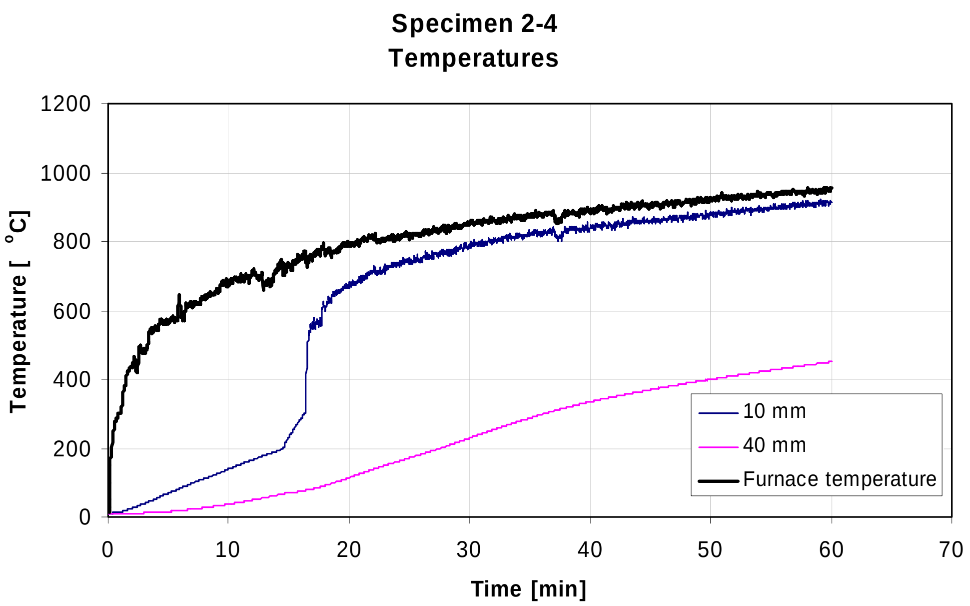


Figure A.18 Measured temperatures in furnace and in specimen 2-4.

Table A.11 Spalling measurements on specimen 2-4.

Position	0	100	200	300	400	500
0	0	0	0	4	3	0
100	0	20	18	33	22	0
200	0	25	25	30	15	0
300	0	19	15	19	14	0
400	0	15	22	10	13	0
500	0	13	11	16	15	0
600	0	0	0	2	0	0

Mean all	9
Mean inner	19
Max in diagram	33
Max measured	36

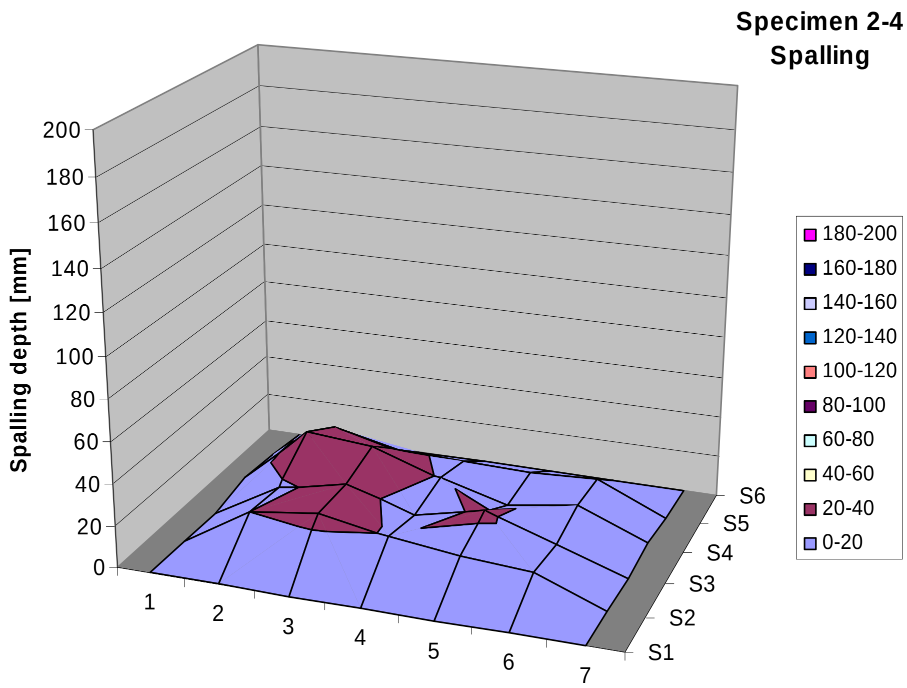


Figure A.19 Spalling measurements on specimen 2-4.

Table A.12 Observations made on specimen 2-4.

Time	Observation			
0,00	Start of test	Specimen:	2-4	
12,83	One explosion	Load level:	205	kN/bar
14,00	Continuous small explosion	Weight loss:	10,1	kg
15,48	One explosion			
16,38	One explosion			
18,27	Continuous small explosion			
19,17	Continuous small explosion			
19,68	One small explosion			
19,98	One small explosion			
20,17	One small explosion			
27,50	Water on top face			
60,17	Test terminates			

Test date: 2005-11-28

Figure A.20 Specimen 2-4 after test.

A3 Concrete 3

Table A.13 Concrete admixture recipe 3.

Recipe	**3**
Water (kg/m^3)	198
CEM II 42,5R A-LL (Byggcement) (kg/m^3)	500
Limestone filler, Limus 25 (kg/m^3)	0
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	4,0
Sikament 20HE 50 (% of cement weight)	0,80
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	690
T50 (s)	2-3
Air (%)	1,7
Compressive strength, 28 days (MPa)	52.0

Specimen 3-3

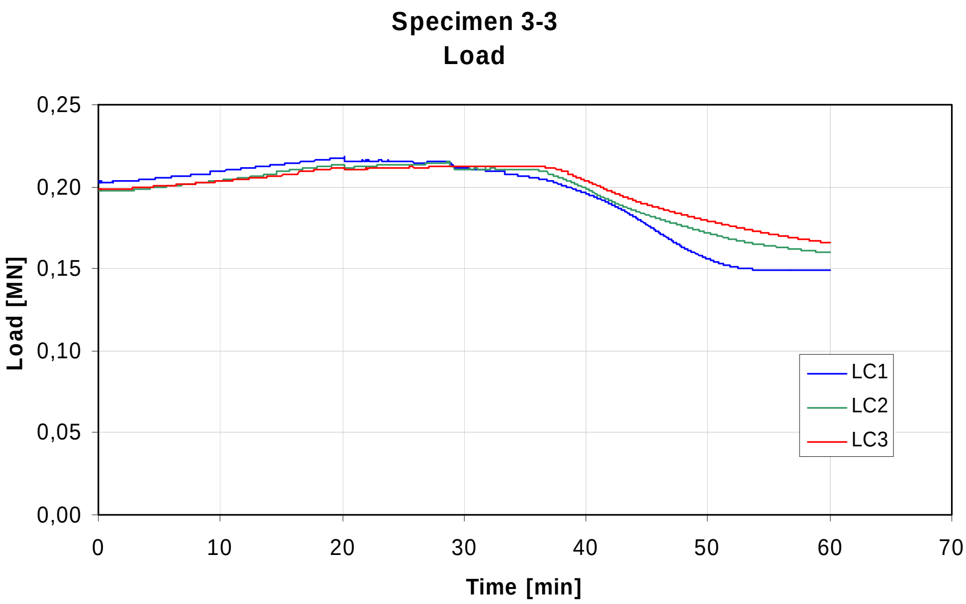


Figure A.21 Load measurements on specimen 3-3.

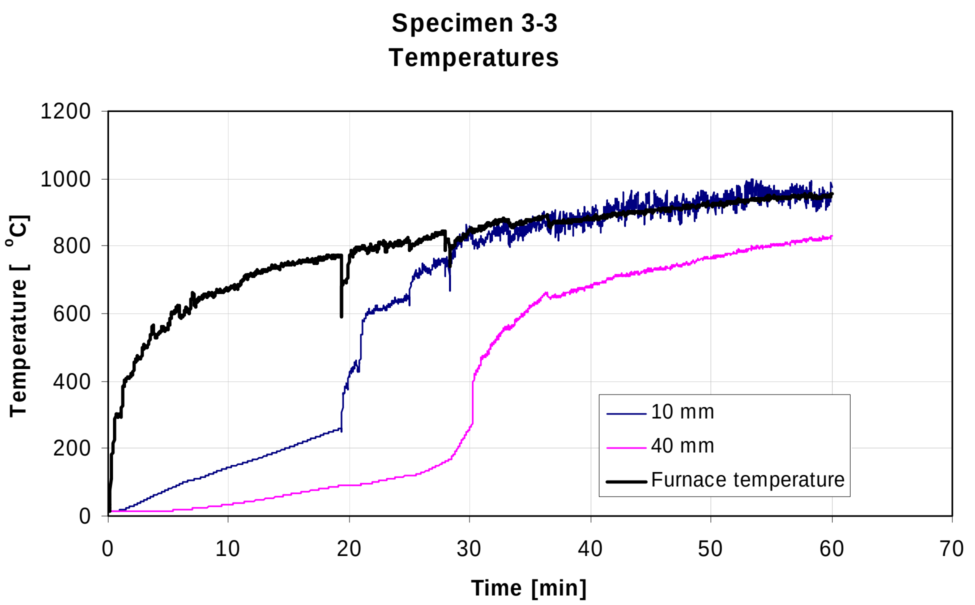


Figure A.22 Measured temperatures in furnace and in specimen 3-3.

Table A.14 Spalling measurements on specimen 3-3.

Position	0	100	200	300	400	500
0	0	3	1	1	3	0
100	5	23	15	25	24	11
200	4	19	28	29	27	17
300	4	34	40	40	31	21
400	8	40	43	49	41	20
500	12	31	40	45	36	18
600	0	3	24	22	50	0

Mean all	21
Mean inner	33
Max in diagram	50
Max measured	51

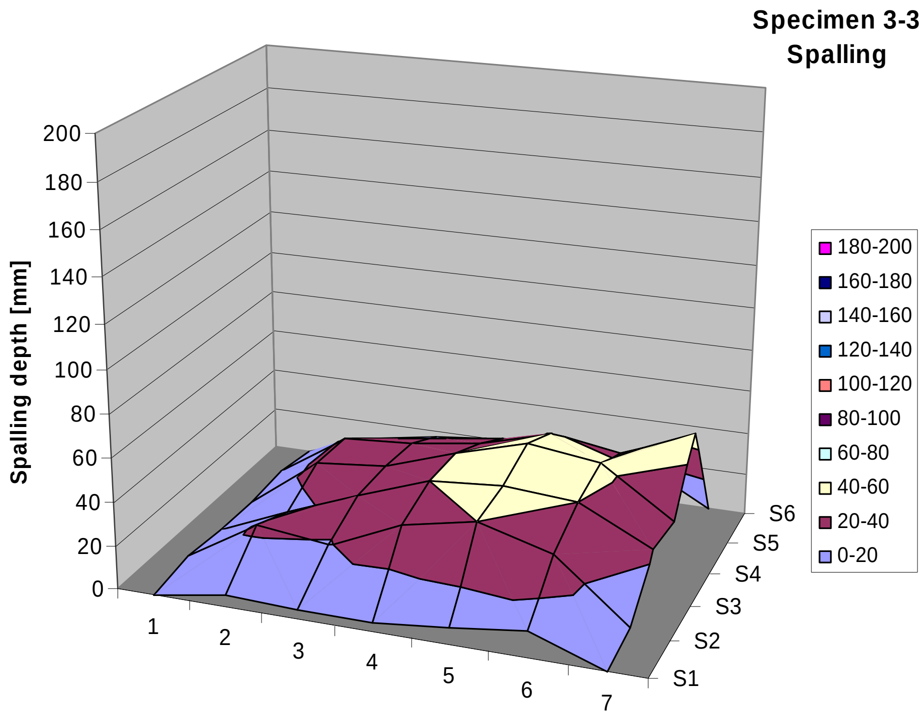


Figure A.23 Spalling measurements on specimen 3-3.

Table A.15 Observations made on specimen 3-3.

Time	Observation			
0,00	Start of test	Test date:	2005-12-01	
19,40	One very loud explosion	Specimen:	3-3	
20,28	One small explosion	Load level:	200	kN/bar
20,35	One small explosion	Weight loss:	17,4	kg
20,48	One small explosion			
20,60	One small explosion			
20,90	Continuous small explosion			
22,97	Two loud explosions, thereafter continuous small explosions			
24,98	One loud explosion			
28,00	One loud explosion			
28,30	One loud explosion			
29,50	One small explosion			
30,98	One small explosion			
31,72	One small explosion			
34,83	Water on front side			
60,00	Test terminates			

Figure A.24 Specimen 3-3 after test

Specimen 3-5

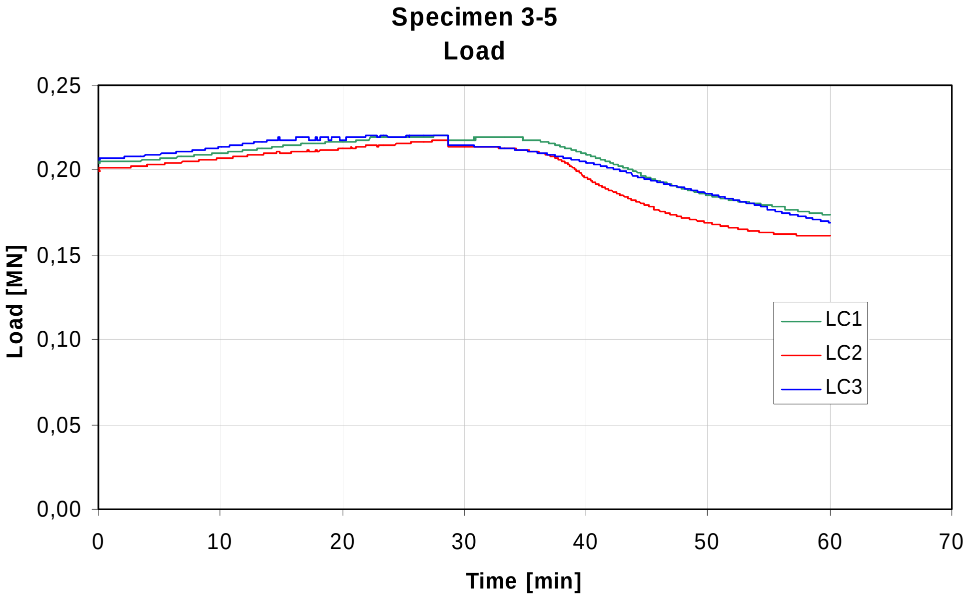


Figure A.25 Load measurements on specimen 3-5.

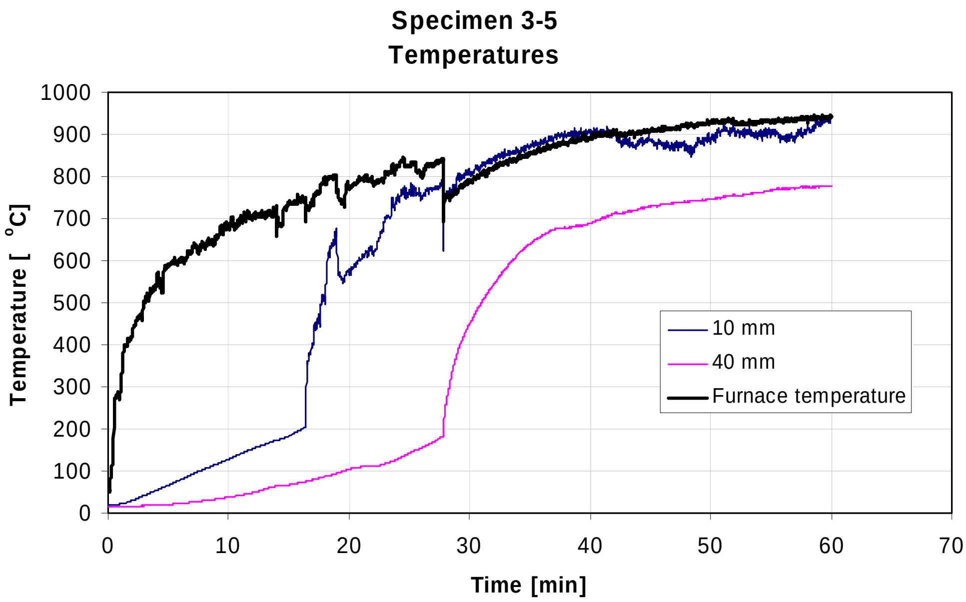


Figure A.26 Measured temperatures in furnace and in specimen 3-5.

Table A.16 Spalling measurements on specimen 3-5

Position	0	100	200	300	400	500
0	0	0	5	6	1	0
100	4	12	28	29	24	4
200	14	23	37	42	30	9
300	23	30	35	43	44	9
400	19	32	42	45	43	9
500	5	18	38	37	29	19
600	0	0	11	22	19	14

Mean all	20
Mean inner	33
Max in diagram	45
Max measured	46

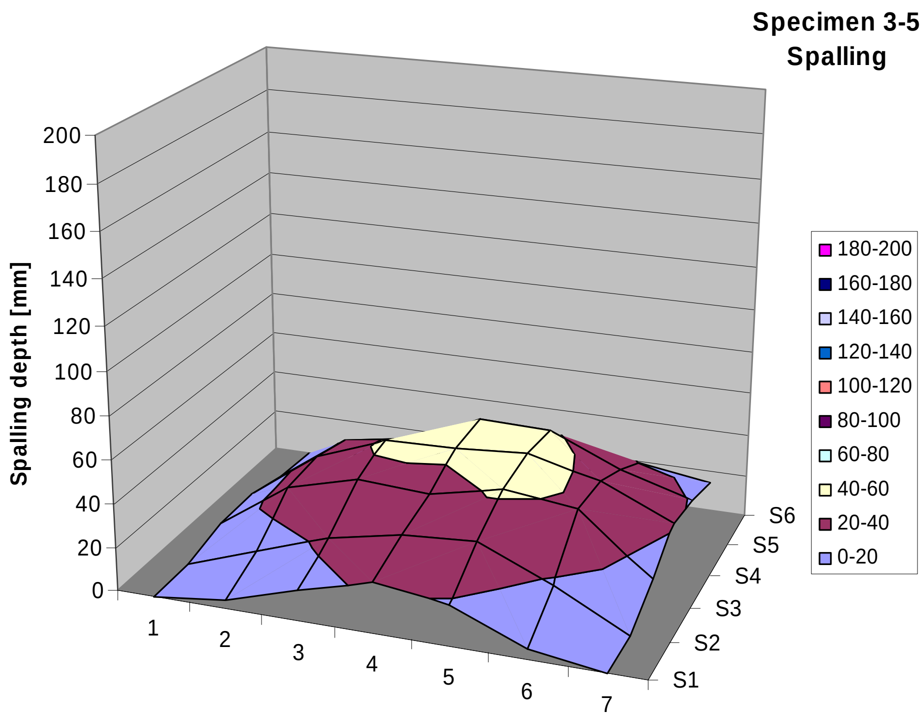


Figure A.27 Spalling measurements on specimen 3-5.

Table A.17 Observations made on specimen 3-5.

Time	Observation			
0,00	Start of test	Test date:	2005-12-01	
14,00	One loud explosion	Specimen:	3-5	
14,63	One small explosion	Load level:	203	kN/bar
14,78	One small explosion	Weight loss:	17,5	kg
14,83	One small explosion			
15,25	One small explosion			
15,52	One small explosion			
15,58	One small explosion			
15,75	One small explosion			
15,97	One explosion			
16,40	One loud explosion			
17,10	One small explosion			
17,53	One loud explosion			
17,77	One small explosion			
17,97	Continuous small explosions			
18,92	One loud explosion, thereafter continuous small explosions			
20,35	A piece of the back side is missing			
21,75	One small explosion			
21,87	One small explosion			
21,97	Two explosions			
23,83	A piece of the front side is missing			
27,87	One loud explosion			
47,00	Water on front side and top face			
60,00	Test terminates			

Figure A.28 Specimen 3-5 after test

Concrete 4

Table A.18 Concrete admixture recipe 4.

Recipe	**4**

Water (kg/m^3)	201
CEM II 42,5R A-LL (Byggcement) (kg/m^3)	390
Limestone filler, Limus 25 (kg/m^3)	110
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,4
Sikament 20HE 50 (% of cement weight)	1,38
Fiber, Sika Crackstop ϕ=18 μm, l=6 mm (kg/m^3)	0,50
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	630
T50 (s)	2-3
Air (%)	1.7
Compressive strength, 28 days (MPa)	45.2

Specimen 4-1

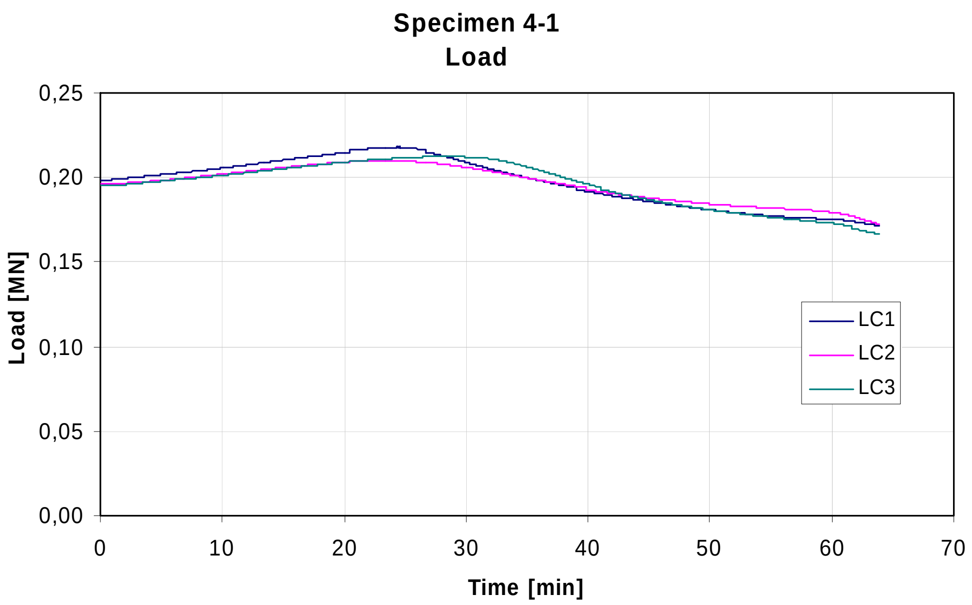


Figure A.29 Load measurements on specimen 4-1.

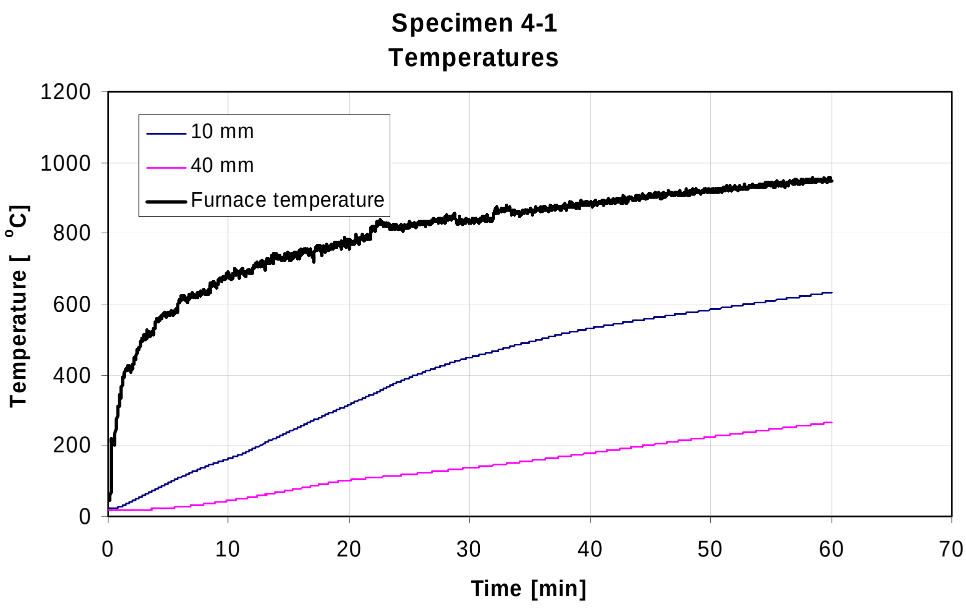


Figure A.30 Measured temperatures in furnace and in specimen 4-1.

Table A.19 Spalling measurements on specimen 4-1.

Position	100	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

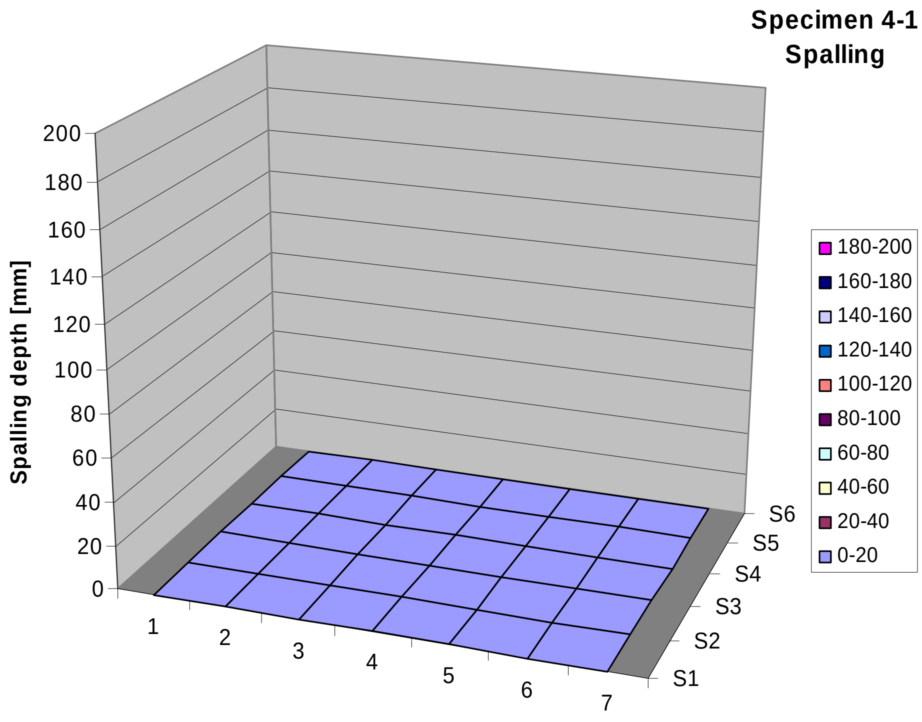


Figure A.31 Spalling measurements on specimen 4-1.

Table A.20 Observations made on specimen 4-1.

Time	Observation			
0,00	Start of test	Test date:	2005-12-02	
59,00	No water visible on any of the faces	Specimen:	4-1	
60,00	Test terminates	Load level:	0	kN/bar
		Weight loss:	2,2	kg

Figure A.32 Specimen 4-1 after test.

Specimen 4-3

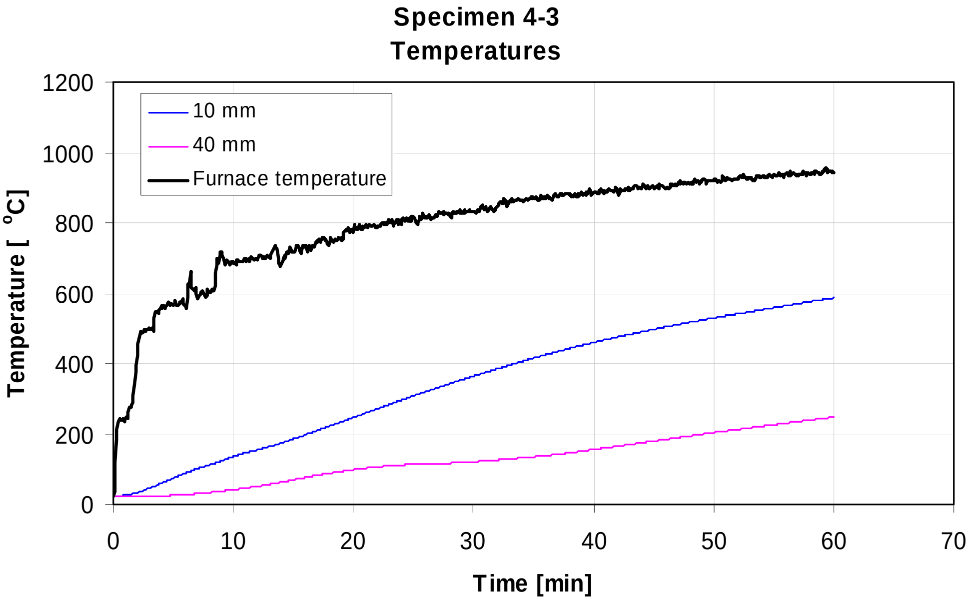


Figure A.33 Temperature measurements on specimen 4-3.

Figure A.34 Specimen 4-3 during test.

Figure A.35 Specimen 4-3 during test.

Figure A.36 Specimen 4-3 after test.

Specimen 4-4

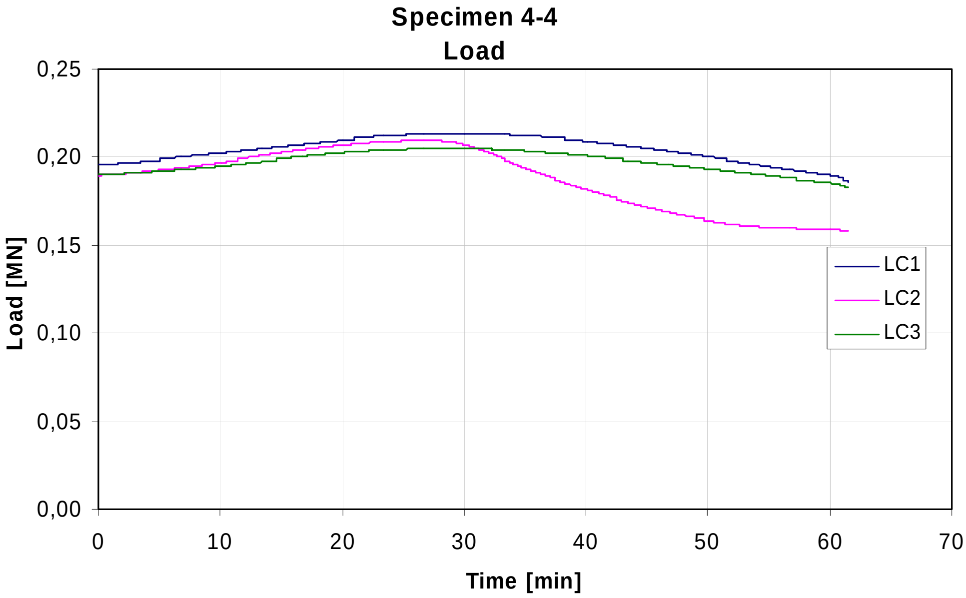


Figure A.37 Load measurements on specimen 4-4.

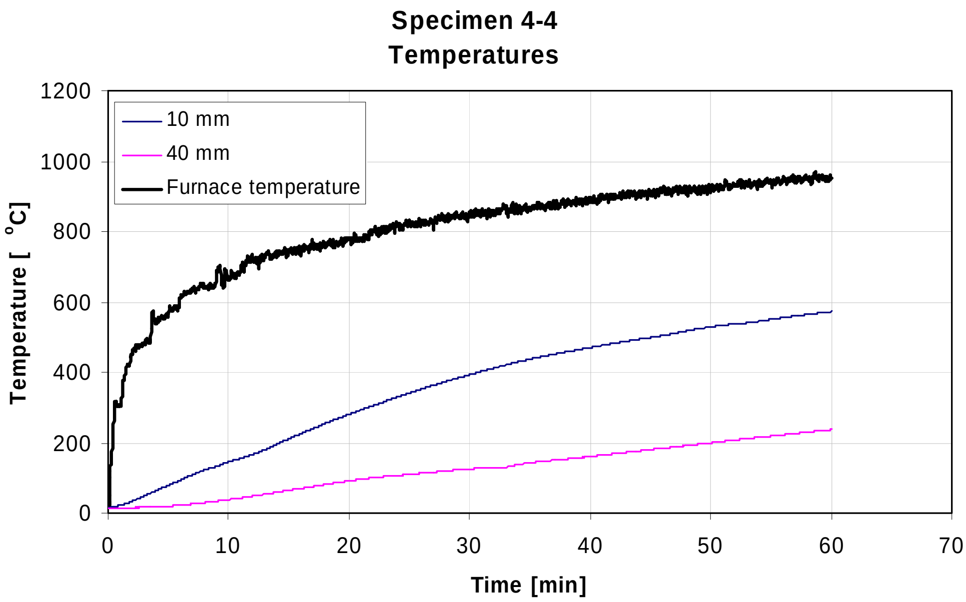


Figure A.38 Measured temperatures on specimen 4-4.

Table A.21 Spalling measurements on specimen 4-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

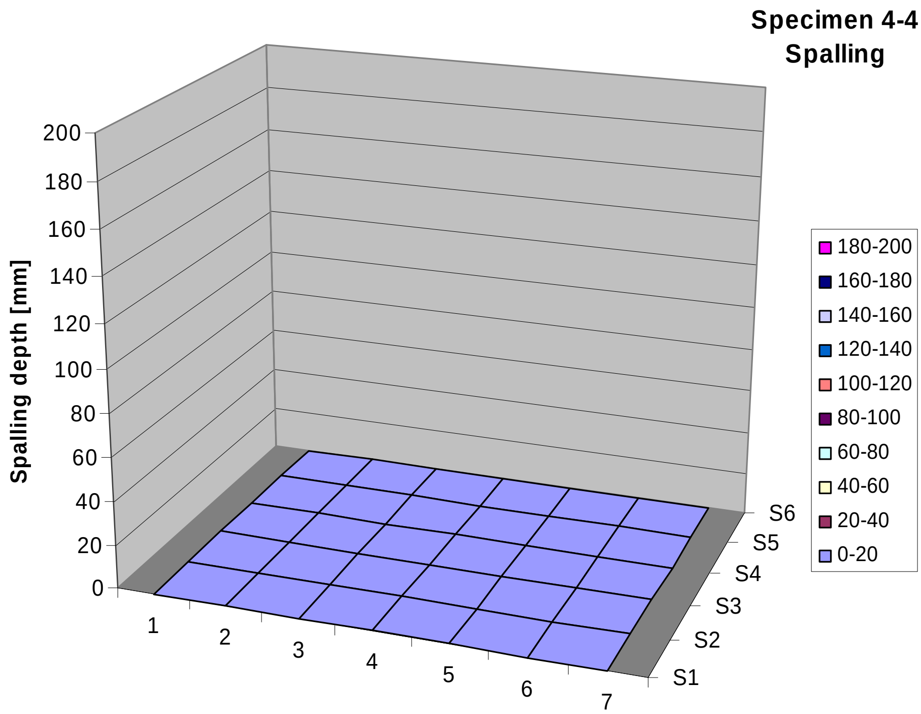


Figure A.39 Spalling measurements on specimen 4-4.

Table A.22 Observations made on specimen 4-4.

Time	Observation			
0,00	Start of test	Test date:	2005-12-02	
48,00	Water on front side	Specimen:	4-4	
60,00	Test terminates	Load level:	0	kN/bar
		Weight loss:	1,4	kg

Figure A.40 Specimen 4-4 after test.

Concrete 5

Table A.23 Concrete admixture recipe 5.

Recipe	**5**
Water (kg/m^3)	222
CEM II 42,5R A-LL (Byggcement) (kg/m^3)	430
Limestone filler, Limus 25 (kg/m^3)	124
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,3
Sikament 20HE 50 (% of cement weight)	1,23
Fiber, Sika Crackstop ϕ=32 μm, l=12 mm (kg/m^3)	1,00
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	670
T50 (s)	1-2
Air (%)	1.7
Compressive strength, 28 days (MPa)	47.3

Specimen 5-2

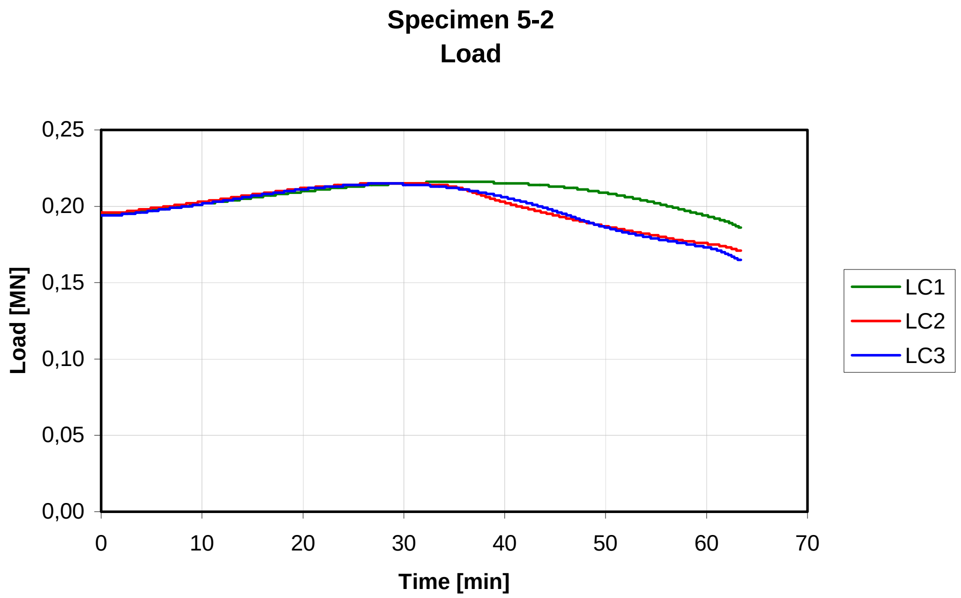


Figure A.41 Load measurements on specimen 5-2.

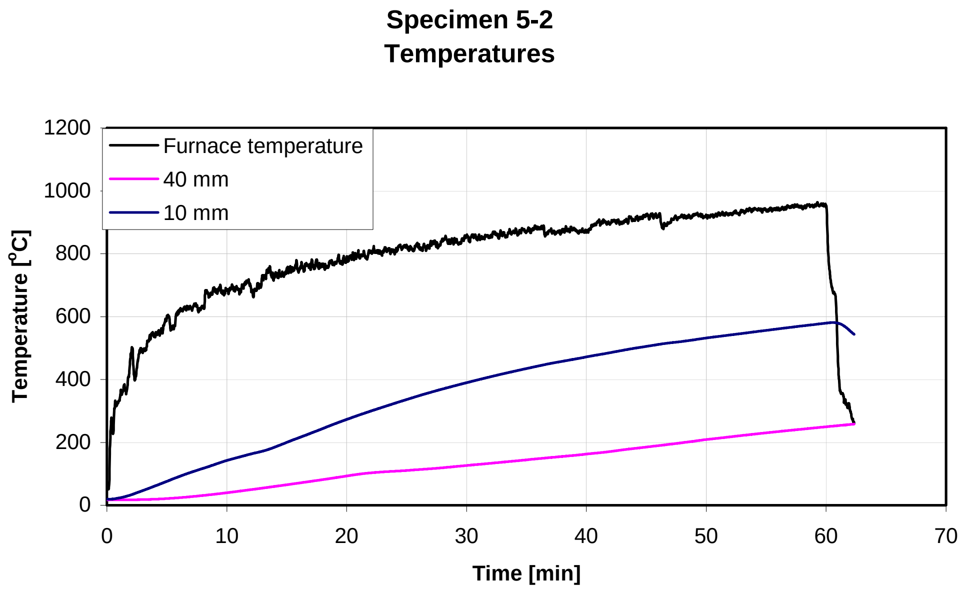


Figure A.42 Measured temperatures in furnace and in specimen 5-2.

Table A.24 Spalling measurements on specimen 5-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

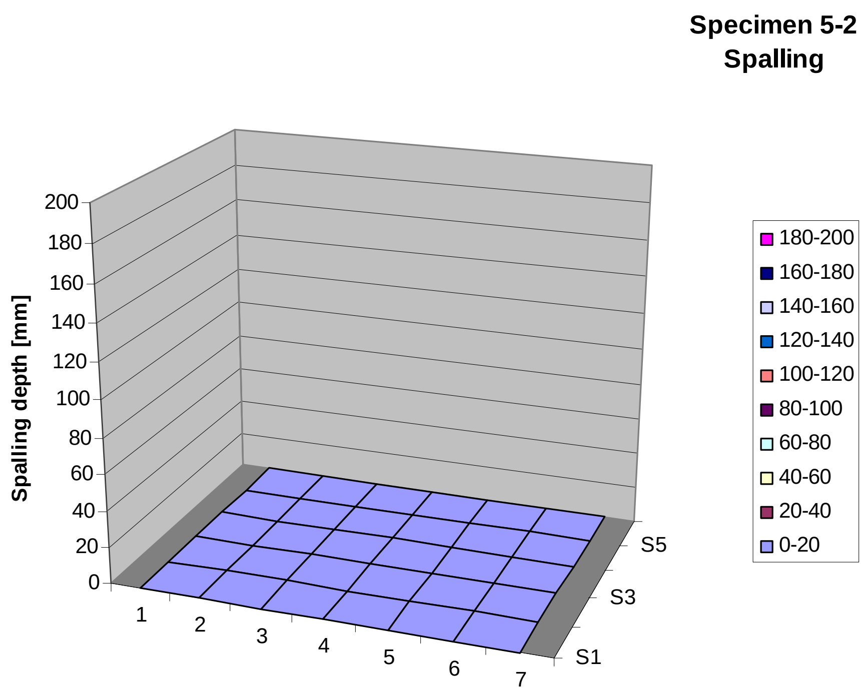


Figure A.43 Spalling measurements on specimen 5-2.

Table A.25 Observations made on specimen 5-2.

Time	Observation			
0,00	Start of test	Test date:	05/12/2005	
48,00	Water on top face	Specimen:	5-2	
60,00	Test terminates	Load level:	195	kN/bar
		Weight loss:	3,3	kg

Figure A.44 Specimen 5-2 after test

Specimen 5-6

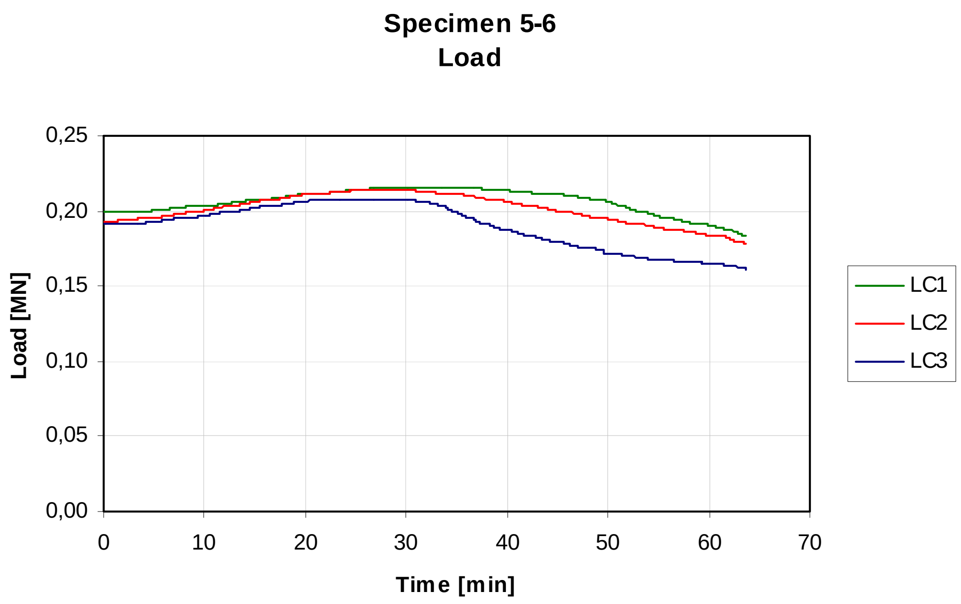


Figure A.45 Load measurements on specimen 5-6.

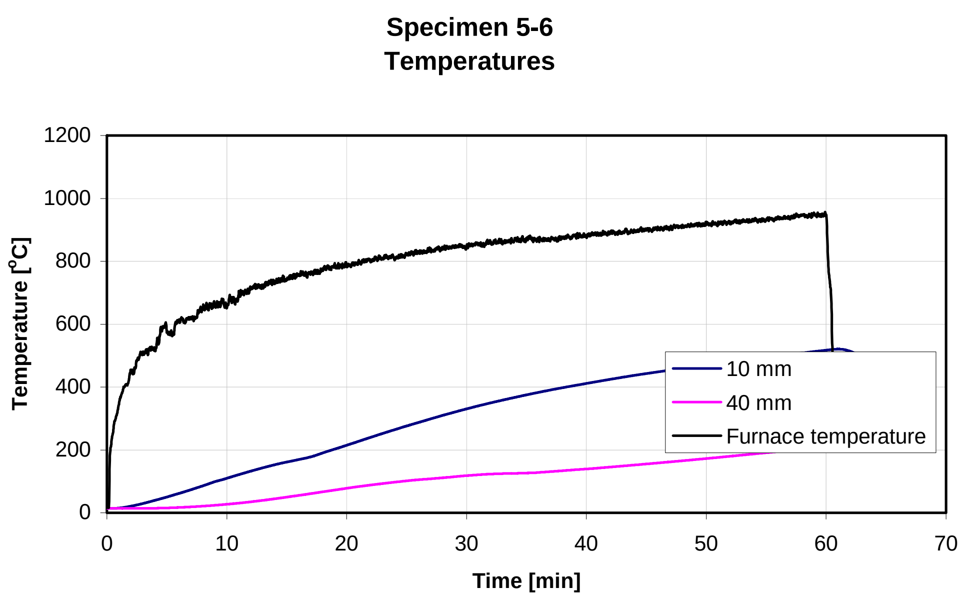


Figure A.46 Measured temperatures in furnace and in specimen 5-6.

Table A.26 Spalling measurements on specimen 5-6.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

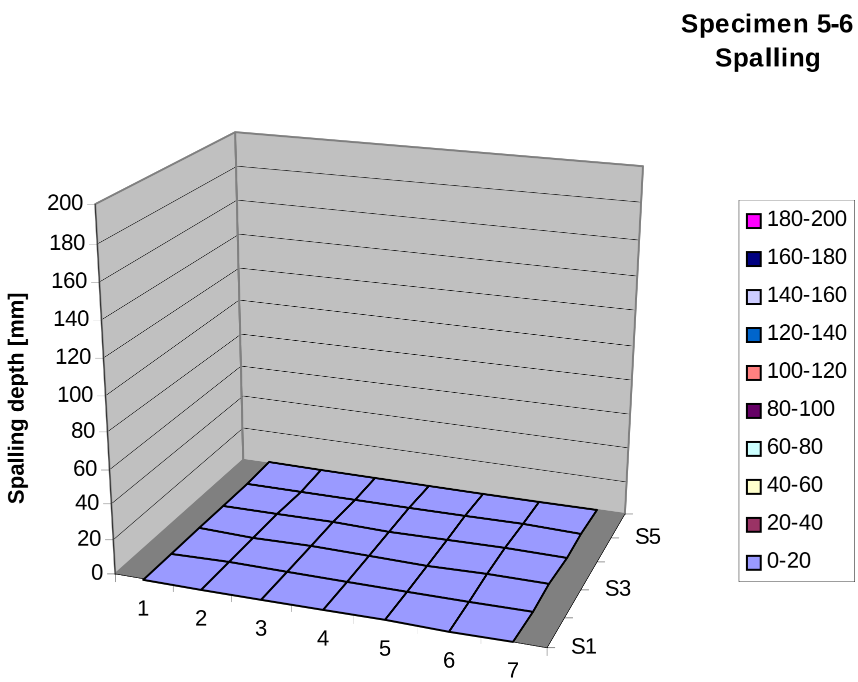


Figure A.47 Spalling measurements on specimen 5-6.

Table A.27 Observations made on specimen 5-6.

Time	Observation
0,00	Start of test
60,00	Test terminates

Test date:	05/12/2005	
Specimen:	5-6	
Load level:	194	kN/bar
Weight loss:	1,3	kg

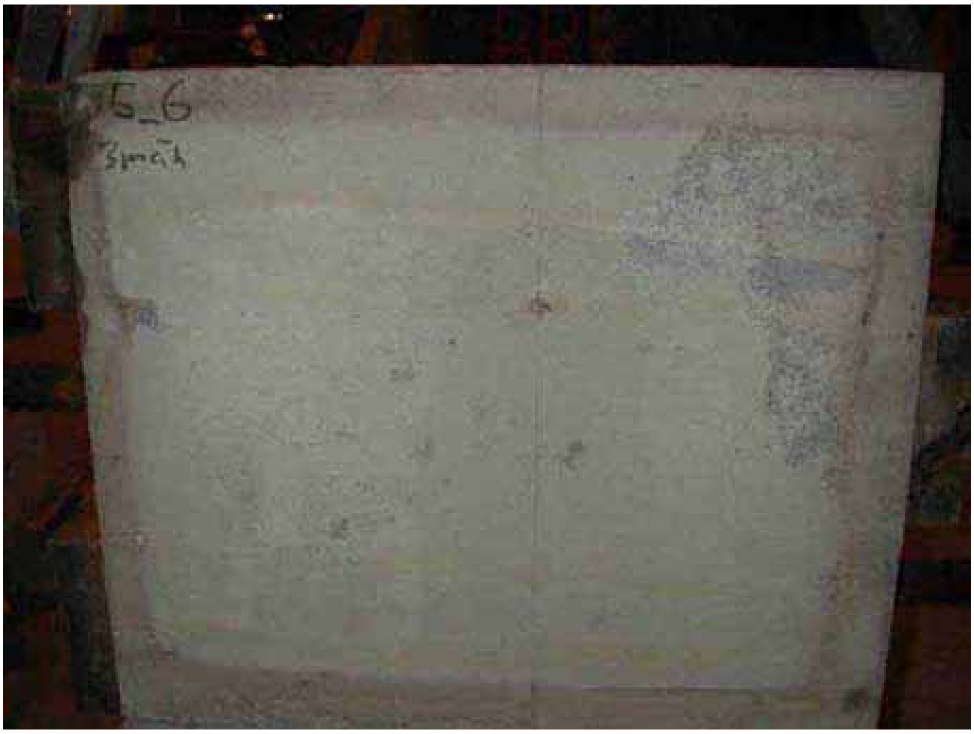


Figure A.48 Specimen 5-6 after test.

Concrete 6

Table A.28 Concrete admixture recipe 6.

Recipe	**6**
Water (kg/m^3)	230
CEM II 42,5R A-LL (kg/m^3)	355
Limestone filler, Limus 25 (kg/m^3)	105
Water-powder ratio, w/p	0,50
Water-cement ratio, w/c	0,65
Sikament 20HE 50 (20% torrhalt)	3,90
Sikament 20HE 50 (% of cement weight)	1,10
Sika IgniFill (kg/m^3)	5,00
Gravel 0 – 8 mm (%)	65
Partly crushed 8 – 16 mm (%)	35
Slump flow (mm)	610
T50 (s)	1
Air (%)	1.2
Compressive strength, 28 days (MPa)	35.2

Specimen 6-2

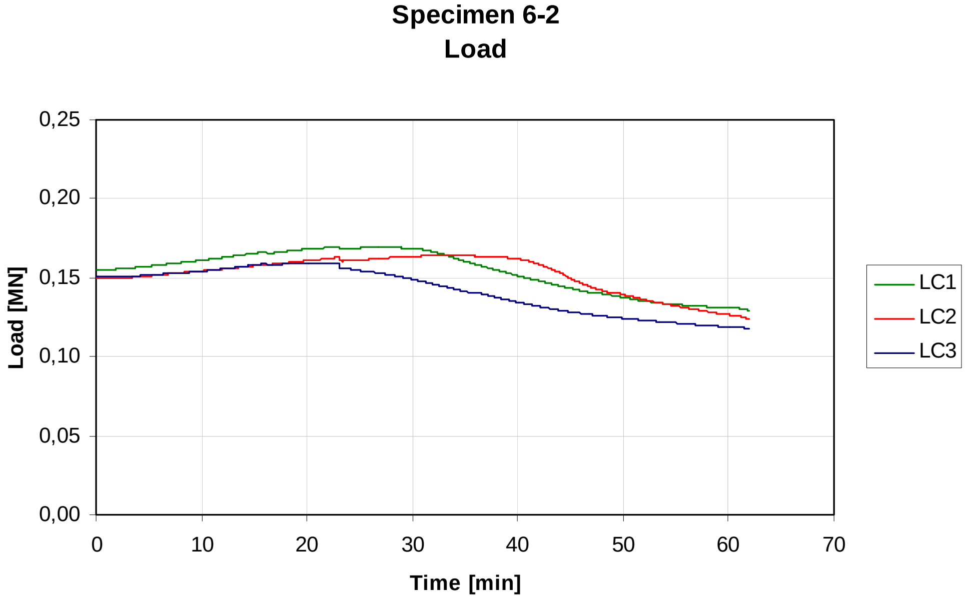


Figure A.49 Load measurements on specimen 6-2.

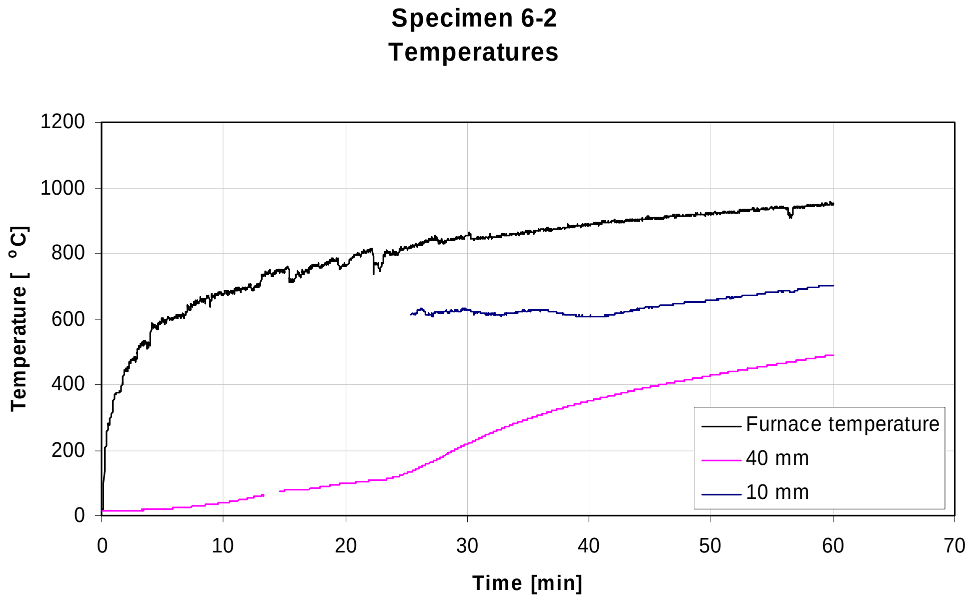


Figure A.50 Measured temperatures in furnace and in specimen 6-2.

Table A.29 Spalling measurements on specimen 6-2.

Position	0	100	200	300	400	500
0	0	10	9	6	0	0
100	0	15	25	21	18	0
200	0	21	25	25	25	2
300	0	18	24	28	16	6
400	0	14	16	18	22	5
500	0	1	3	10	18	4
600	0	0	0	0	0	0

Mean all	10
Mean inner	18
Max in diagram	28
Max measured	35

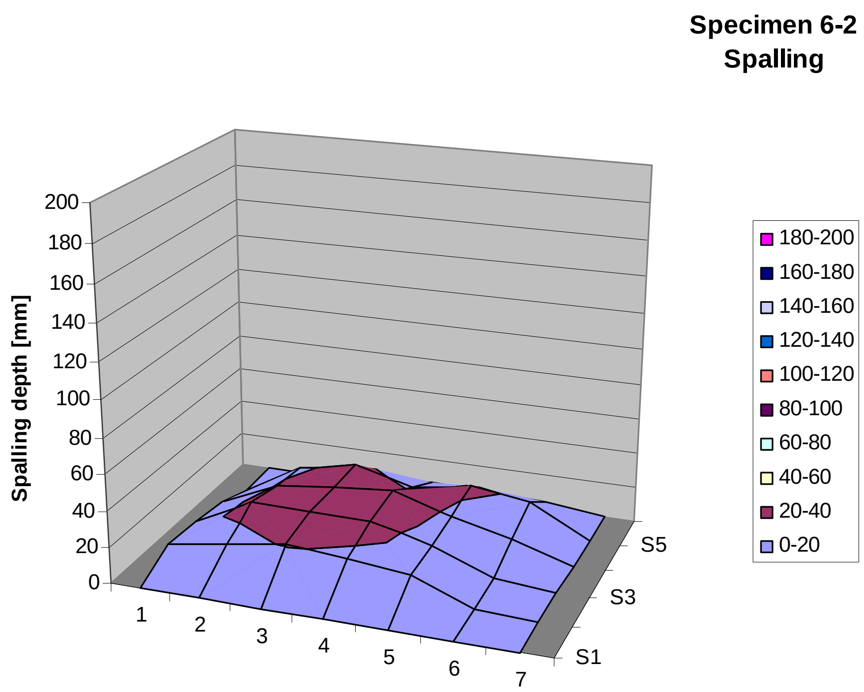


Figure A.51 Spalling measurements on specimen 6-2.

Table A.30 Observations made on specimen 6-2.

Time	Observation
0,00	Start of test
15,42	One loud explosion
16,80	One small explosion
17,00	One small explosion
19,47	One explosion
22,28	One loud explosion
23,78	One small explosion
24,00	One small explosion
26,27	Horizontal crack on front side
33,00	Water on top face
60,00	Test terminates

Test date:	2005-12-05	
Specimen:	6-2	
Load level:	152	kN/bar
Weight loss:	11,0	kg

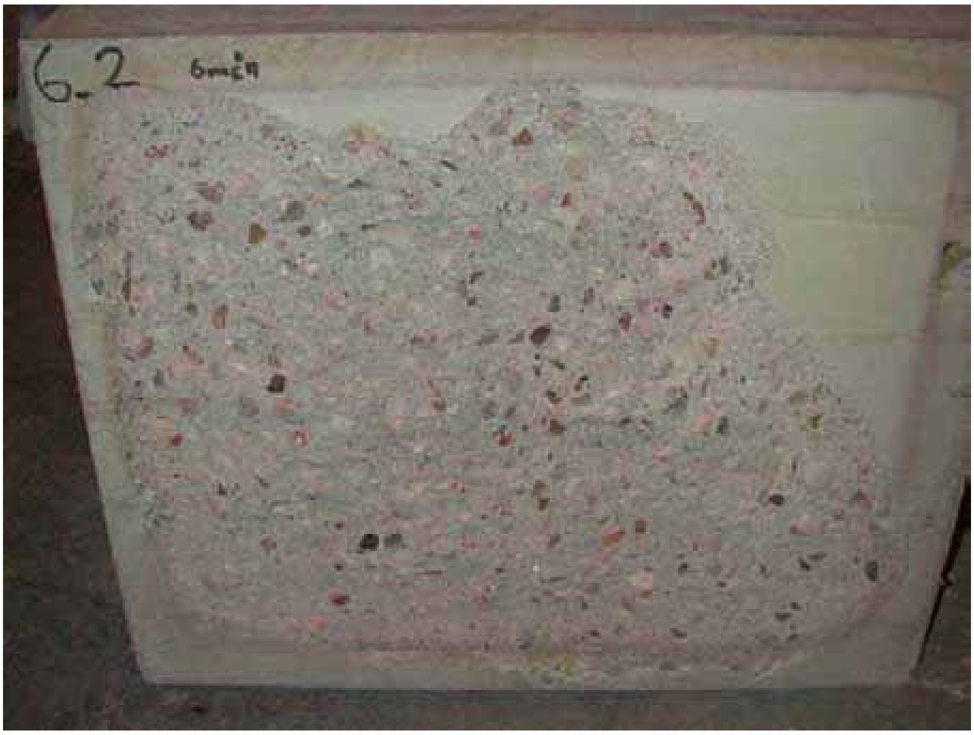


Figure A.52 Specimen 6-2 after test.

Specimen 6-4

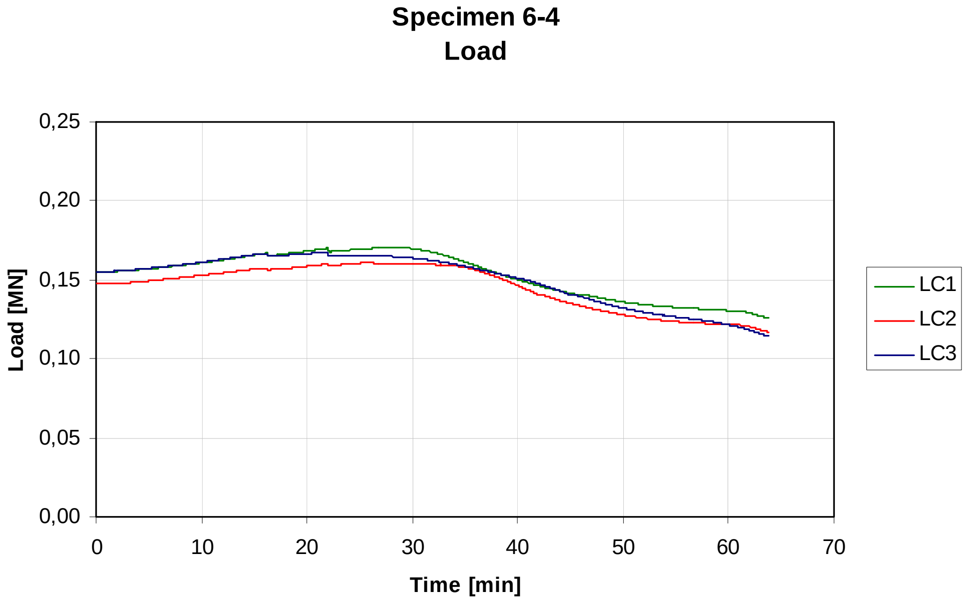


Figure A.53 Load measurements on specimen 6-4.

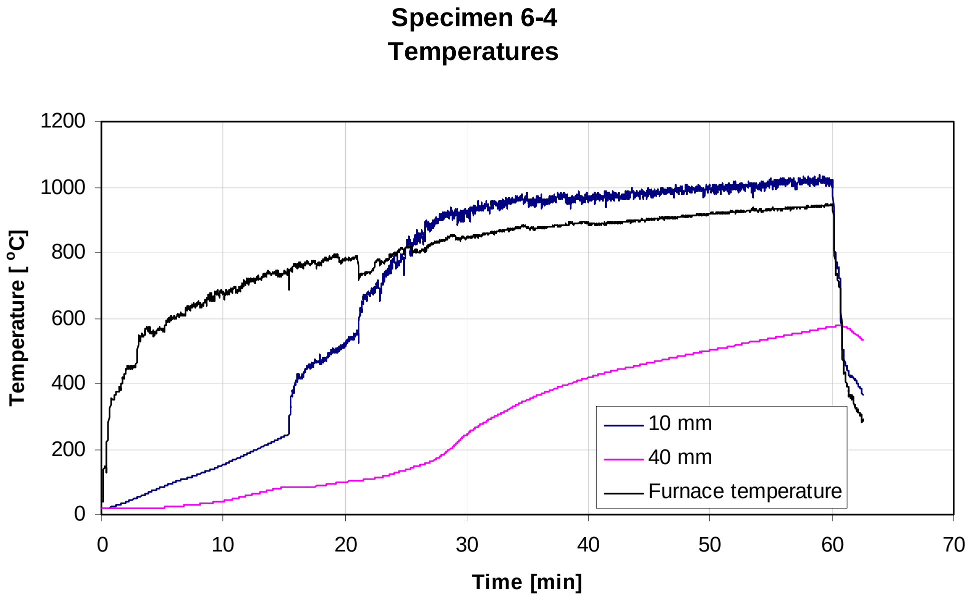


Figure A.54 Measured temperatures in furnace and in specimen 6-4.

Table A.31 Spalling measurements on specimen 6-4.

Position	0	100	200	300	400	500
0	4	7	6	10	8	5
100	6	15	22	13	11	2
200	5	16	23	31	15	6
300	14	13	26	37	18	18
400	9	15	26	26	18	19
500	3	16	28	21	18	8
600	1	16	15	18	15	4

Mean all	14
Mean inner	20
Max in diagram	37
Max measured	45

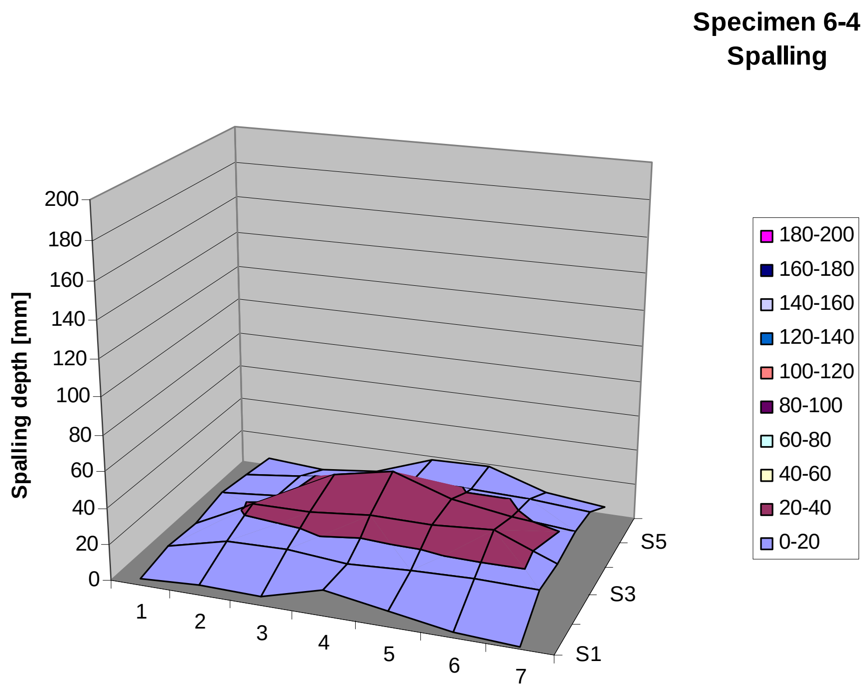


Figure A.55 Spalling measurements on specimen 6-4.

Table A.32 Oservations made on specimen 6-4

Time	Observation			
0,00	Start of test	Test date:	2005-12-06	
14,57	One explosion	Specimen:	6-4	
15,42	One loud explosion	Load level:	153	kN/bar
16,08	One small explosion	Weight loss:	11,4	kg
16,32	One explosion			
17,17	Two small explosions			
17,93	One small explosion			
21,12	One loud explosion, a piece from the back side disappears			
24,13	One small explosion			
24,82	One small explosion			
25,50	One small explosion, horizontal crack on front side			
49,92	Water on front side			
51,67	Water on top face			
60,00	Test terminates			

Figure A.56 Specimen 6-4 after test.

Specimen 6-6

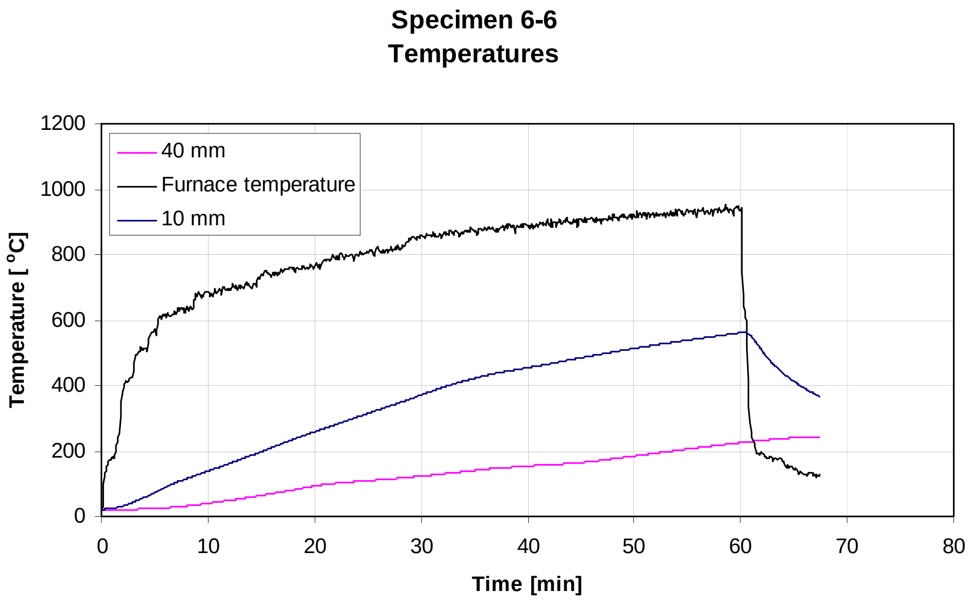


Figure A.57 Measured temperatures in furnace and in specimen 6-6.

Table A.33 Spalling measurements on specimen 6-6

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

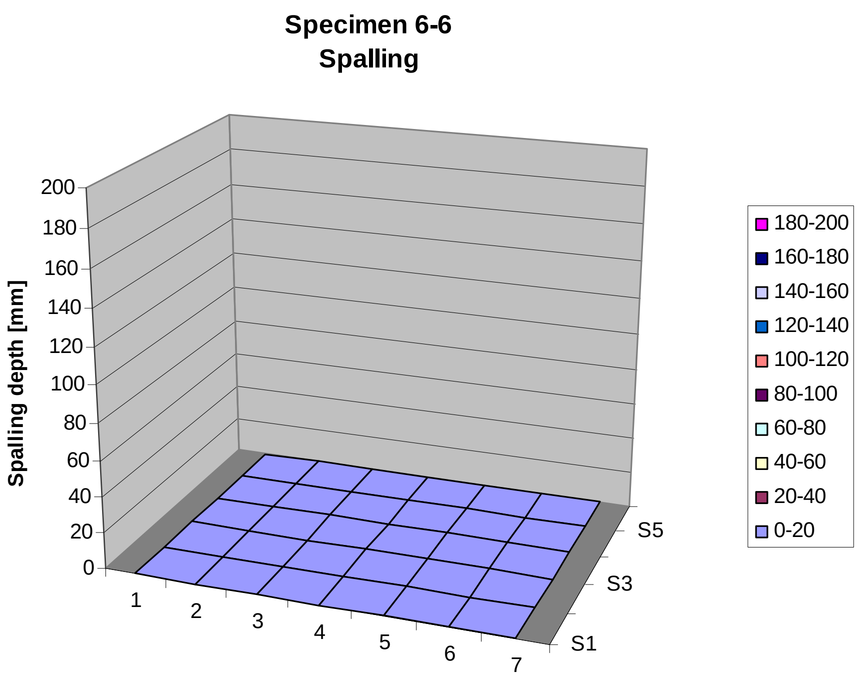


Figure A.58 Spalling measurements on specimen 6-6.

Table A.34 Observations made on specimen 6-6.

Time	Observation	Test date:	2005-09-09
0,00	Start of test	Specimen:	6-6
19,00	Cracks on sides		
23,00	Moisture		
60,00	Test terminated		

Figure A.59 Specimen 6-6 after test.

Concrete 7

Table A.35 Concrete admixture recipe 7.

Recipe	**7**
Water (kg/m^3)	212
CEM II 42,5R A-LL (kg/m^3)	410
Limestone filler, Limus 25 (kg/m^3)	122
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20 % torrhalt)	6,2
Sikament 20HE 50 (% of cement weight)	1,50
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	1,00
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	650
T50 (s)	2-3
Air (%)	1.7
Compressive strength, 28 days (MPa)	43.9

Specimen 7-3

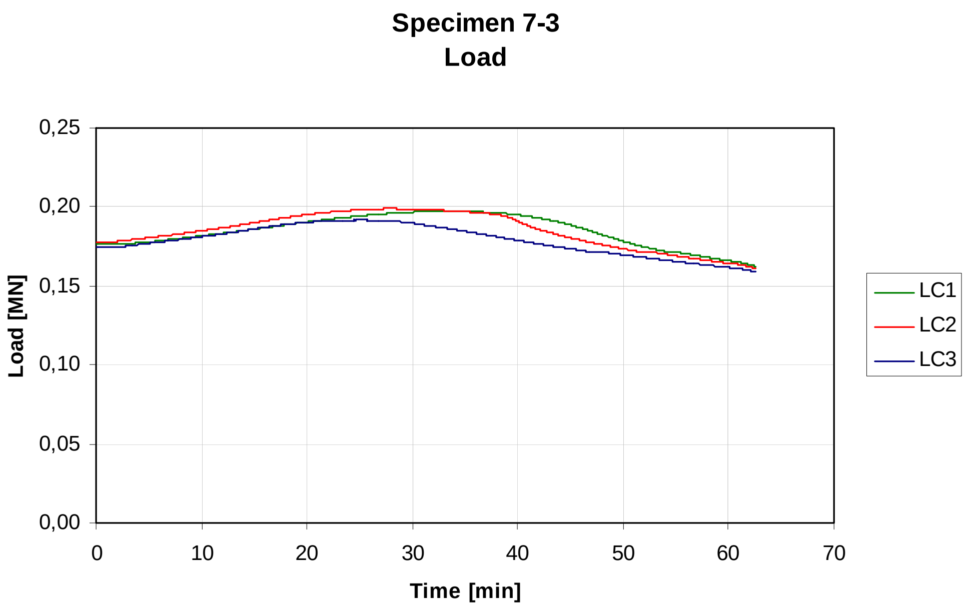


Figure A.60 Load measurements on specimen 7-3.

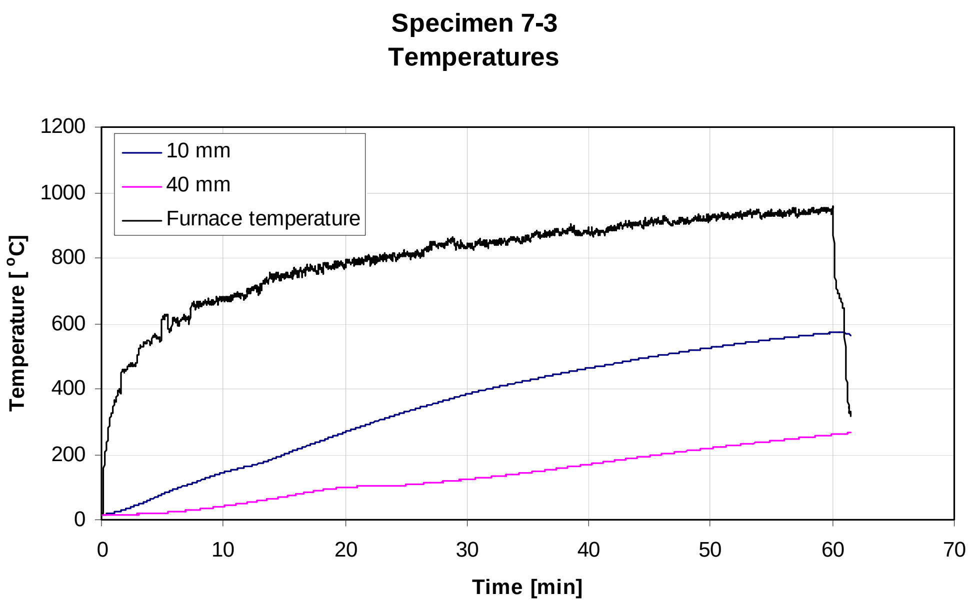


Figure A.61 Measured temperatures in furnace and in specimen 7-3.

Table A.36 Spalling measurements on specimen 7-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

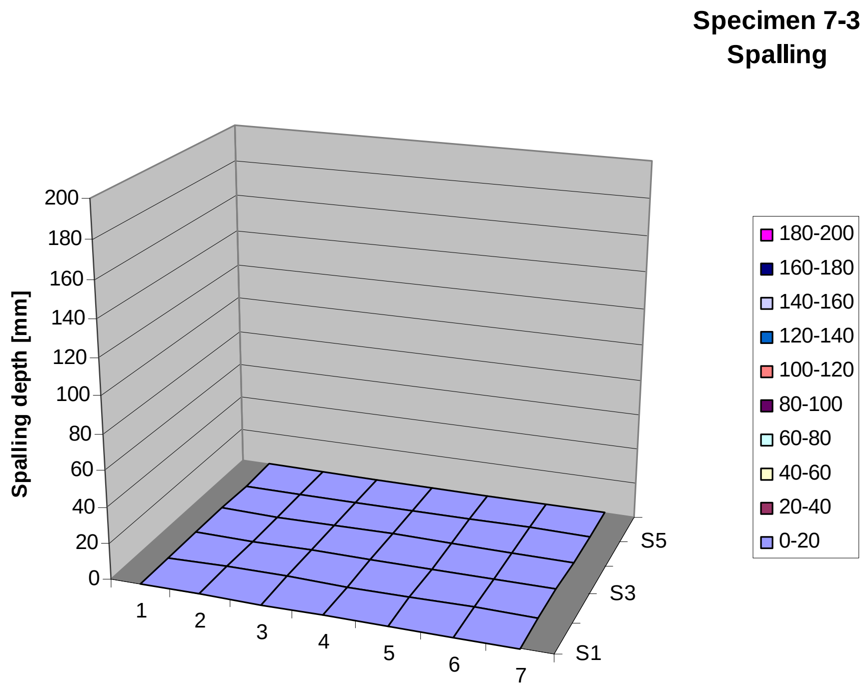


Figure A.62 Spalling measurements on specimen 7-3.

Table A.37 Observations made on specimen 7-3

Time	Observation			
0,00	Start of test	Test date:	2005-12-07	
36,00	Water on top face	Specimen:	7-3	
60,00	Test terminates	Load level:	177	kN/bar
		Weight loss:	4,7	kg

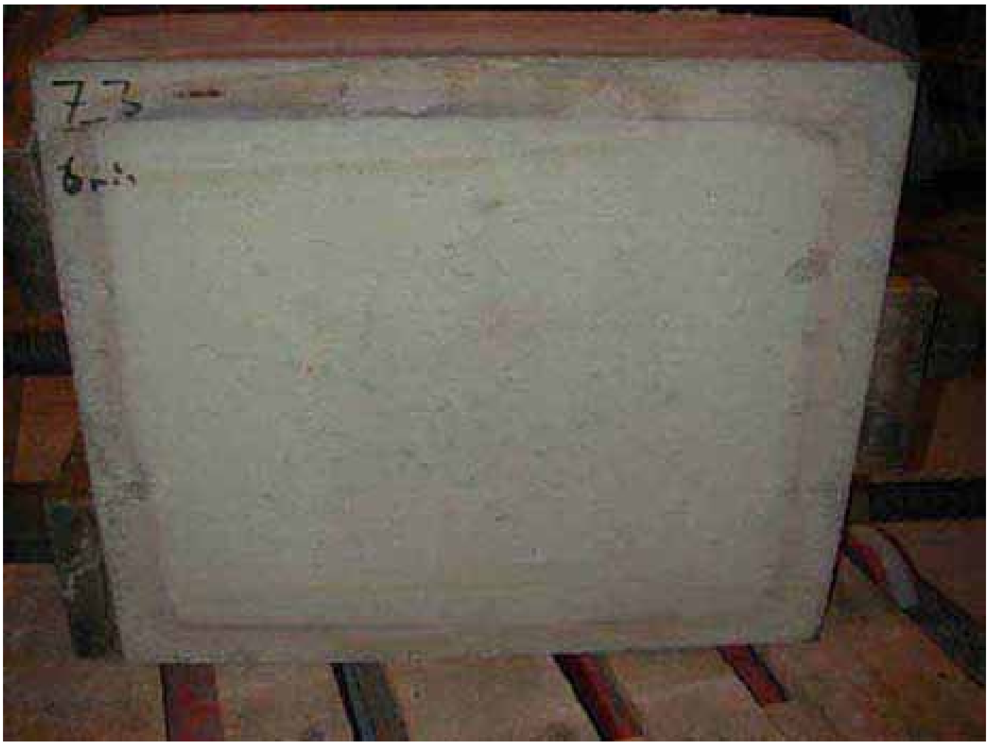


Figure A.63 Specimen 7-3 after test.

Specimen 7-5

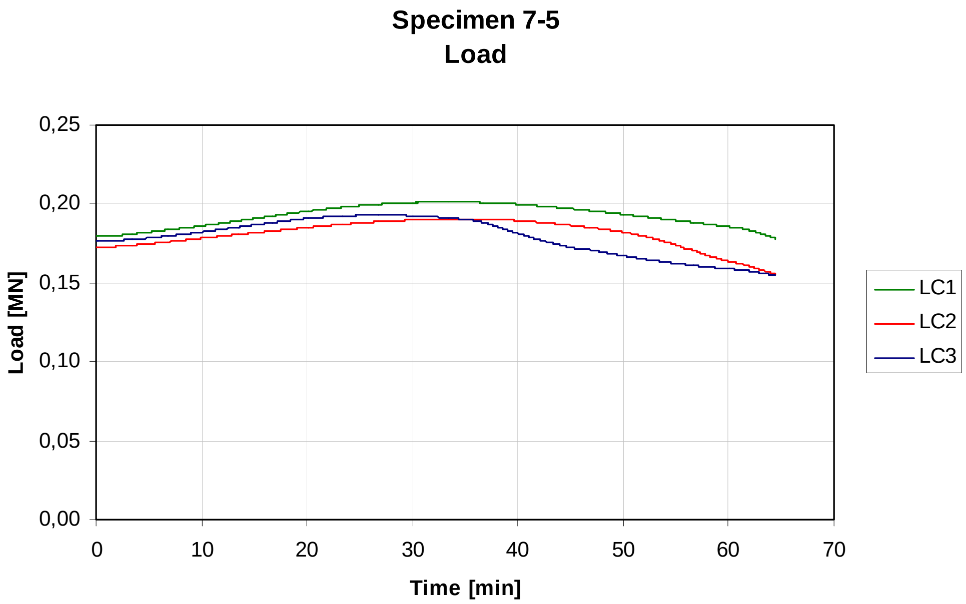


Figure A.64 Load measurements on specimen 7-5.

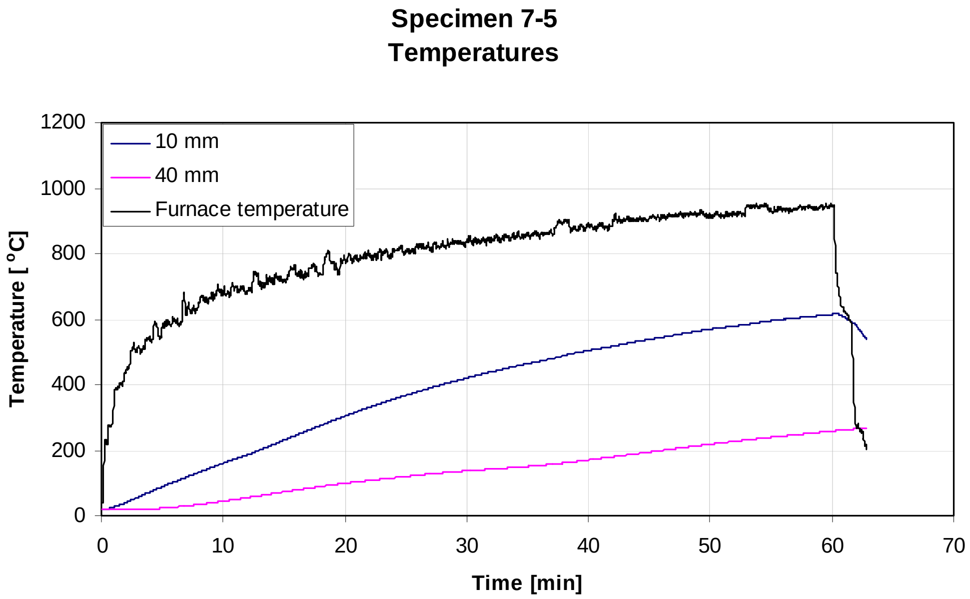


Figure A.65 Measured temperatures in furnace and in specimen 7-5.

Table A.38 Spalling measurements on specimen 7-5.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

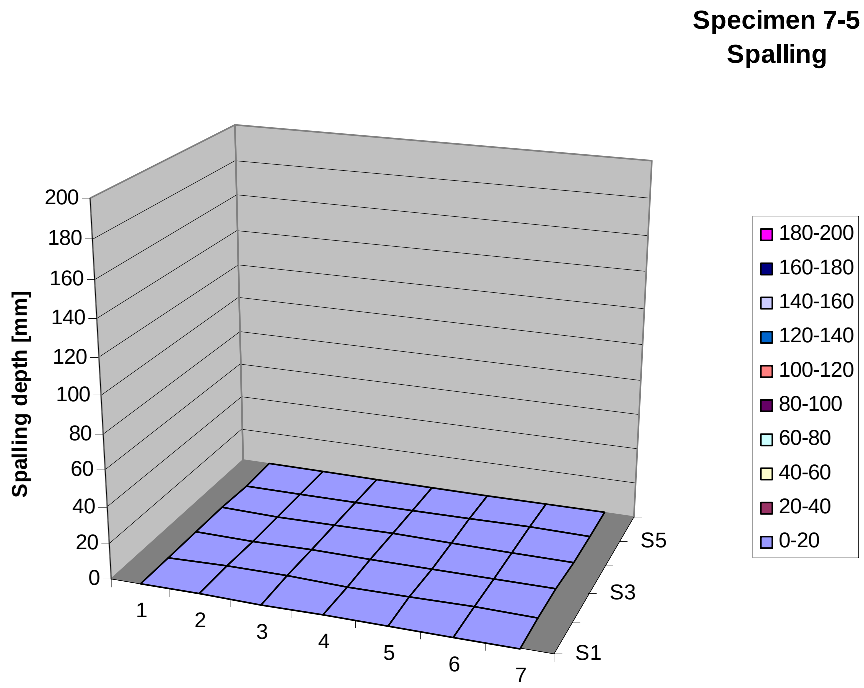


Figure A.66 Spalling measurements on specimen 7-5.

Table A.39 Observations made on specimen 7-5.

Time	Observation
0,00	Start of test
60,00	Test terminates

Test date:	2005-12-07	
Specimen:	7-5	
Load level:	177	kN/bar
Weight loss:	0,4	kg

Figure A.67 Specimen 7-5 after test.

Concrete 8

Table A.40 Concrete admixture recipe 8.

Recipe	8
Water (kg/m^3)	222
CEM II 42,5R A-LL (kg/m^3)	430
Limestone filler, Limus 25 (kg/m^3)	124
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,9
Sikament 20HE 50 (% of cement weight)	1,36
Fiber, Sika Crackstop, ϕ=18 μm, l=12 mm (kg/m^3)	1,50
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	630
T50 (s)	2-3
Air (%)	1.5
Compressive strength, 28 days (MPa)	45.0

Specimen 8-13

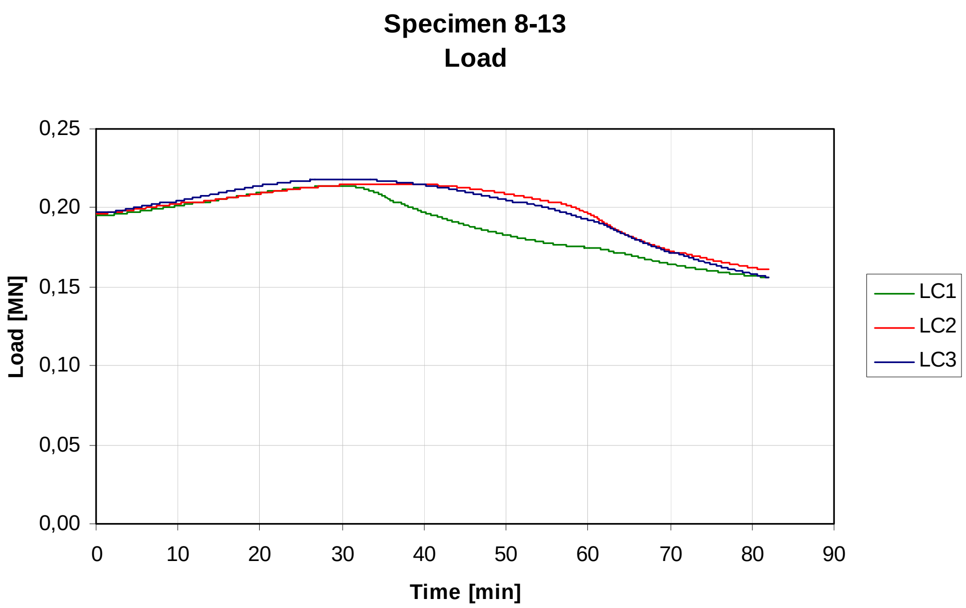


Figure A.68 Load measurements on specimen 8-13.

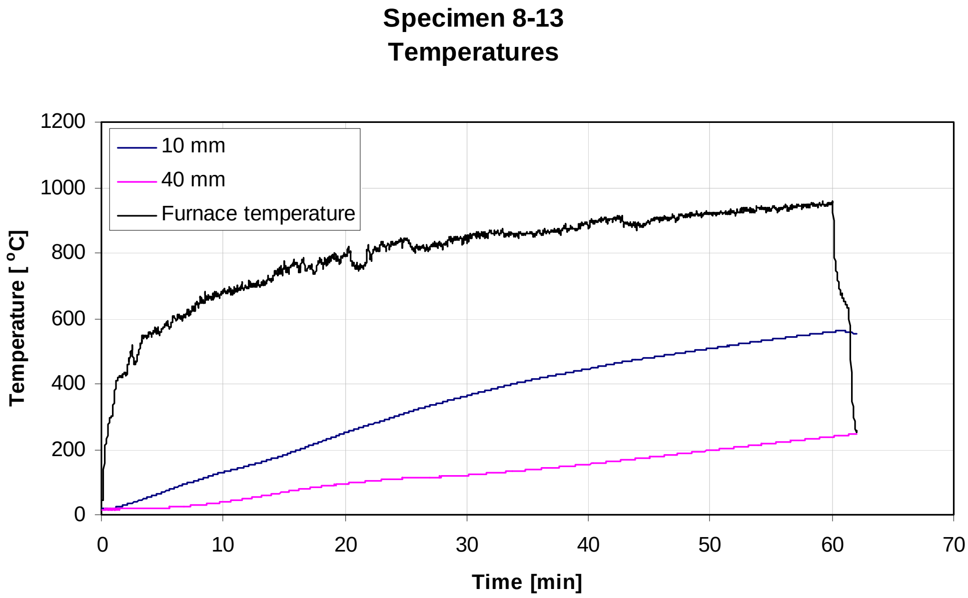


Figure A.69 Measured temperatures in furnace and in specimen 8-13.

Table A.41 Spalling measurements on specimen 8-13.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

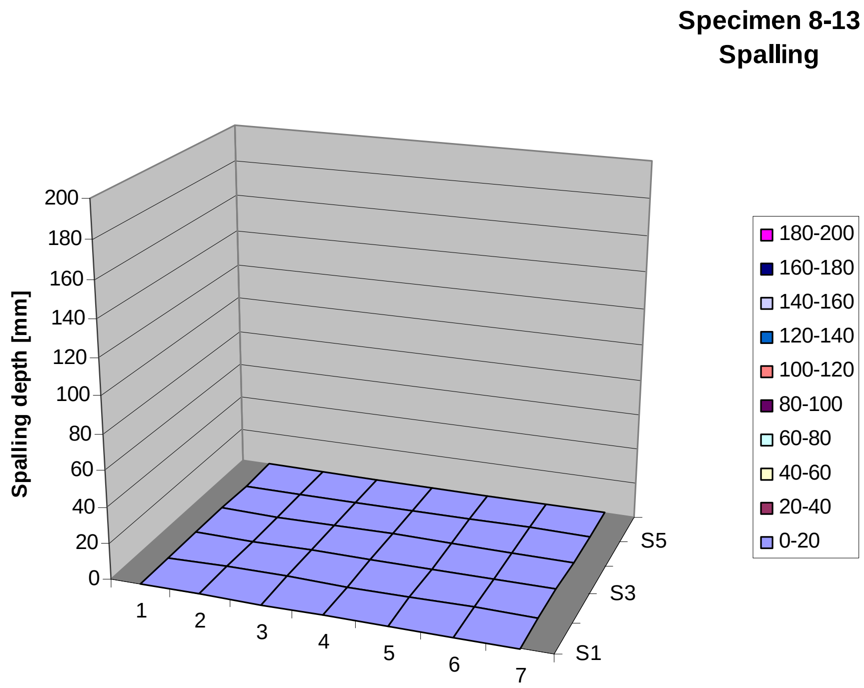


Figure A.70 Spalling measurements on specimen 8-13.

Table A.42 Observations made on specimen 8-13.

Time	Observation			
0,00	Start of test	Test date:	2005-12-12	
60,00	Test terminates	Specimen:	8-13	
		Load level:	196	kN/bar
		Weight loss:	3,4	kg

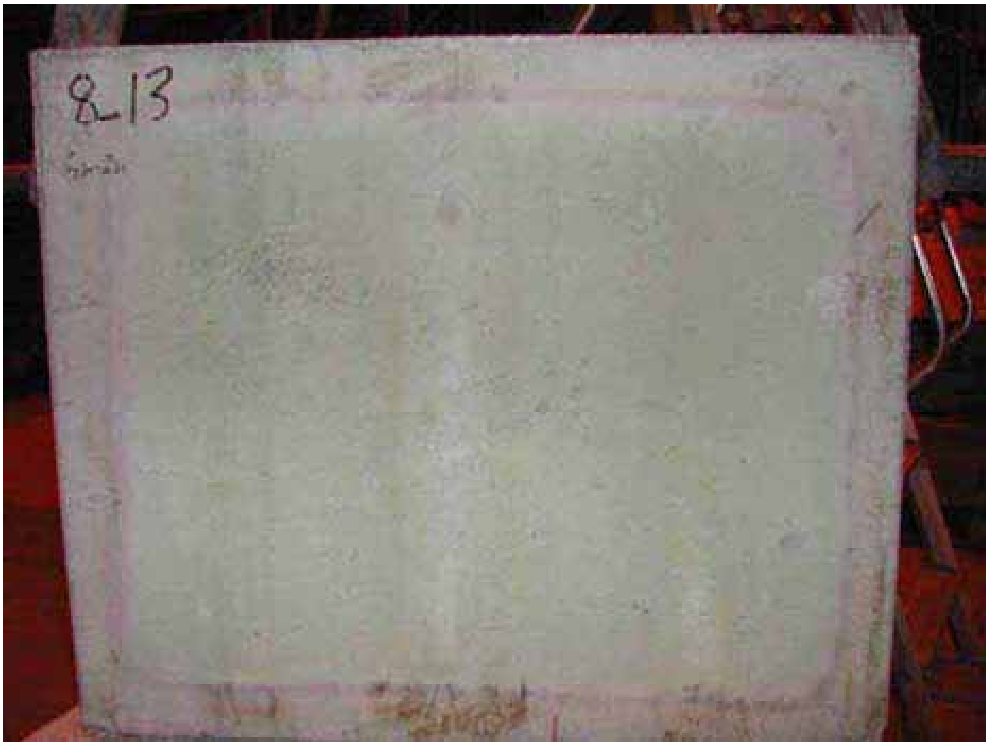


Figure A.71 Specimen 8-13 after test

Specimen 8-15

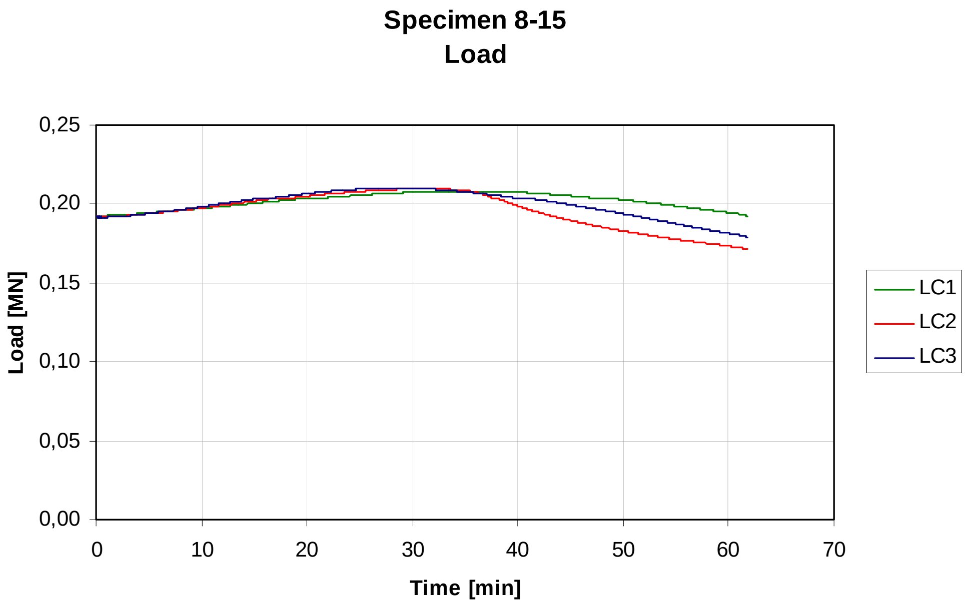


Figure A.72 Load measurements on specimen 8-15.

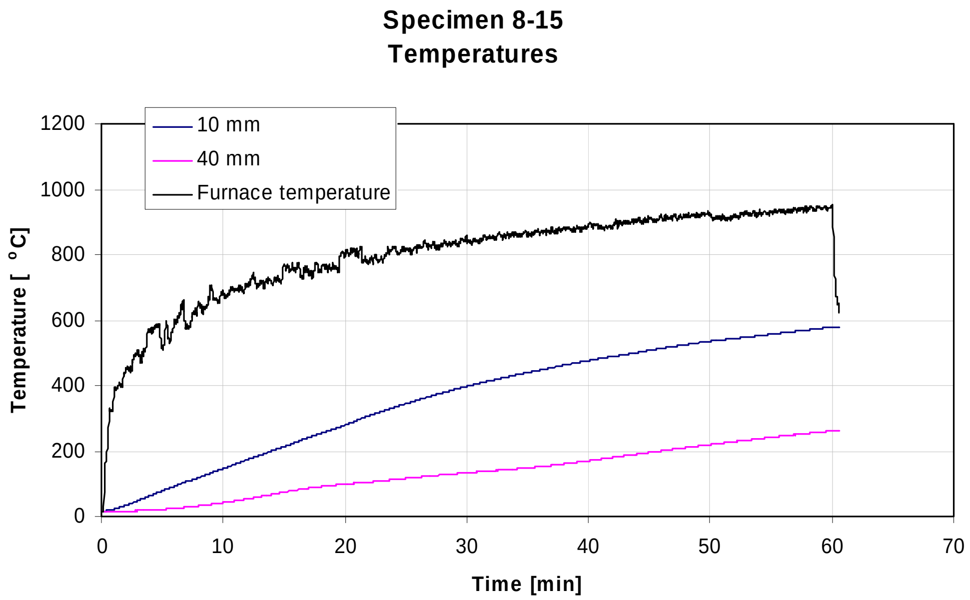


Figure A.73 Measured temperatures in furnace and in specimen 8-15.

Table A.43 Spalling measurements on specimen 8-15

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

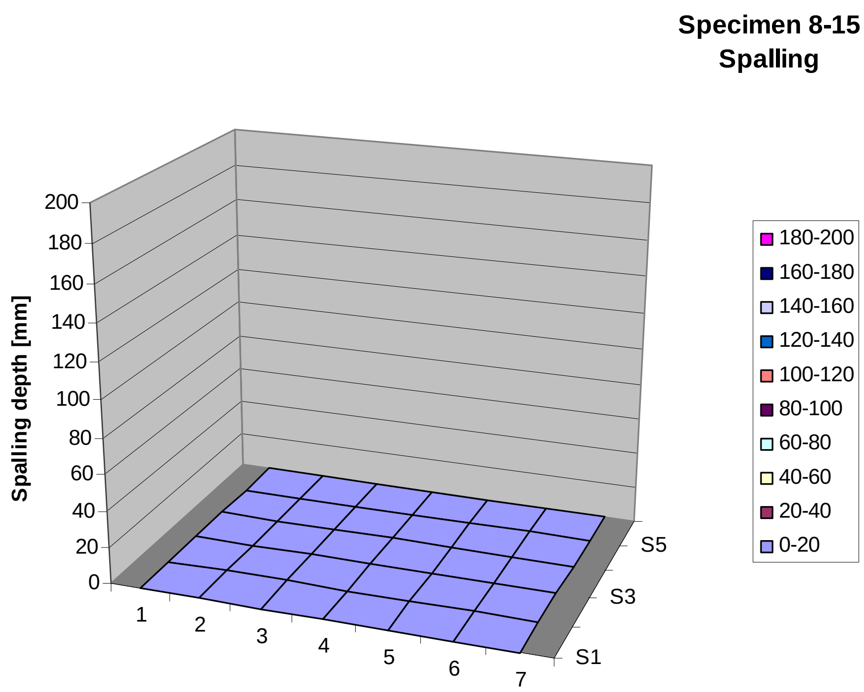


Figure A.74 Spalling measurements on specimen 8-15.

Table A.44 Observations made on specimen 8-15.

Time	Observation			
0,00	Start of test	Test date:	2005-12-12	
40,00	Water on top face	Specimen:	8-15	
60,00	Test terminates	Load level:	192	kN/bar
		Weight loss:	2,6	kg

Figure A.75 Specimen 8-15 after test.

Concrete 9

Table A.45 Concrete admixture recipe 9.

Recipe	**9**
Water (kg/m^3)	230
CEM II 42,5R A-LL (kg/m^3)	355
Limestone filler, Limus 25 (kg/m^3)	96
Water-powder ratio, w/p	0,51
Water-cement ratio, w/c	0,65
Sikament 20HE 50 (20% torrhalt)	4,14
Sikament 20HE 50 (% of cement weight)	1,17
Sika IgniFill (kg/m$_3$)	10,0
Gravel 0 – 8 mm (%)	65
Partly crushed 8 – 16 mm (%)	35
Slump flow (mm)	650
T50 (s)	1-2
Air (%)	1.7
Compressive strength, 28 days (MPa)	33.8

Specimen 9-3

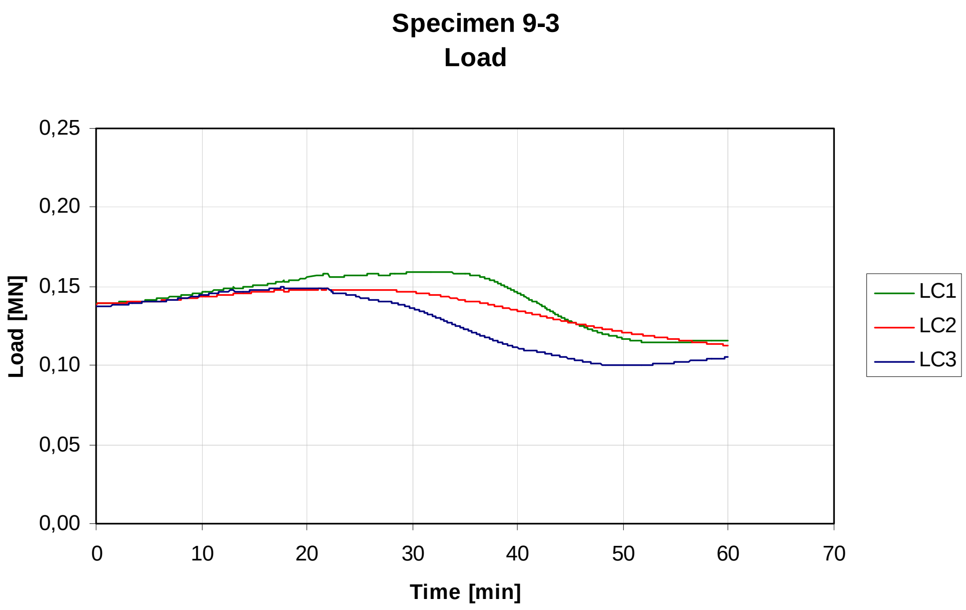


Figure A.76 Load measurements on specimen 9-3.

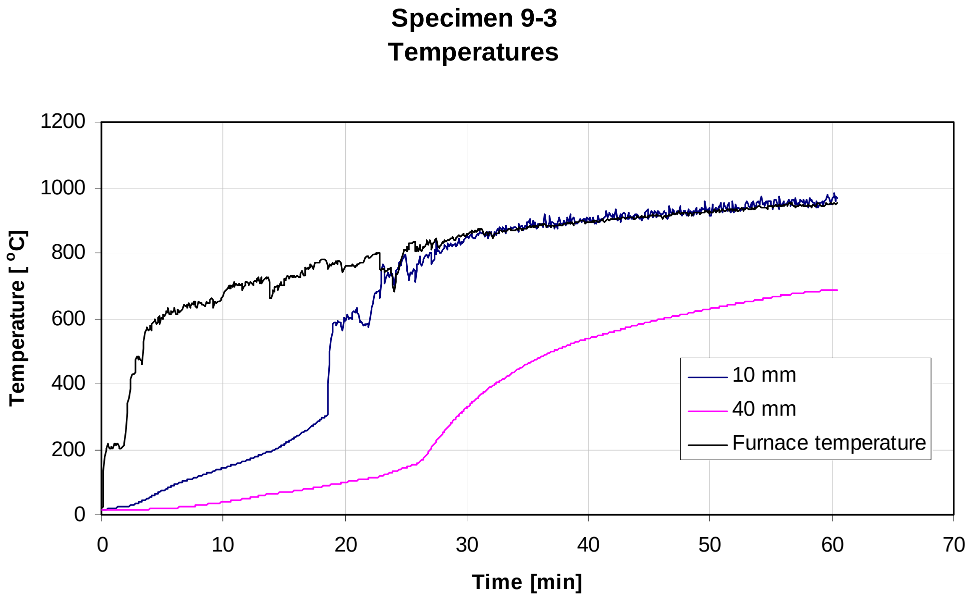


Figure A.77 Measured temperatures in furnace and in specimen 9-3.

Table A.46 Spalling measurements on specimen 9-3

Position	0	100	200	300	400	500
0	0	0	3	0	0	0
100	0	18	32	24	18	0
200	0	18	41	32	25	0
300	14	22	36	35	28	0
400	20	30	37	34	15	0
500	28	28	24	23	6	0
600	19	23	14	10	0	0

Mean all	16
Mean inner	26
Max in diagram	41
Max measured	43

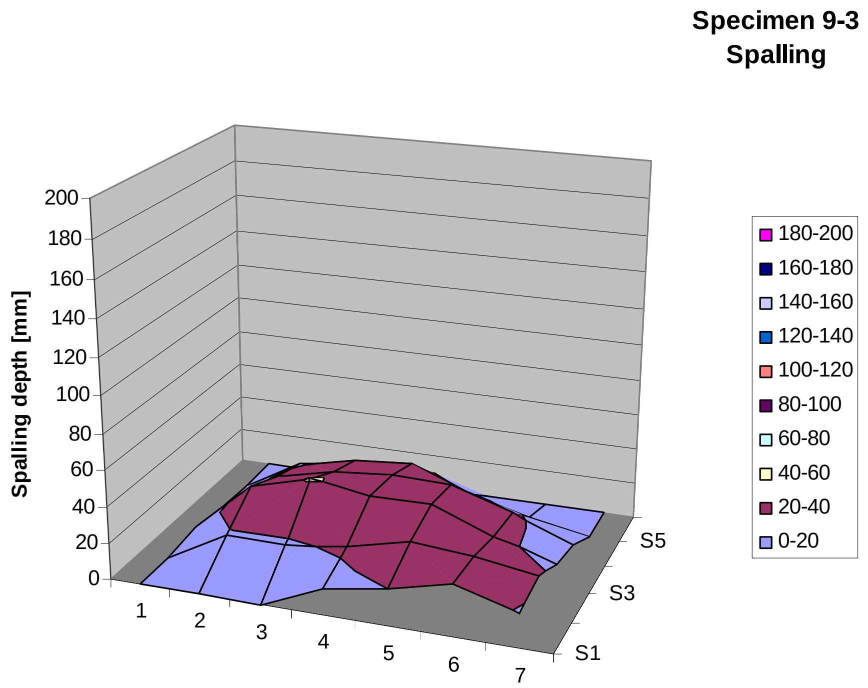


Figure A.78 Spalling measurements on specimen 9-3.

Table A.47 Observations made on specimen 9-3.

Time	Observation
0,00	Start of test
13,83	One explosion
15,00	Small explosions during 30 seconds
16,50	Small explosions during 30 seconds
18,50	One small explosion
19,75	One small explosion
22,00	One small explosion
22,83	One loud explosion
27,67	One explosion
60,50	Test terminates

Test date:	2005-12-13	
Specimen:	9-3	
Load level:	138	kN/bar
Weight loss:	12,0	kg

Figure A.79 Specimen 9-3 after test

Specimen 9-6

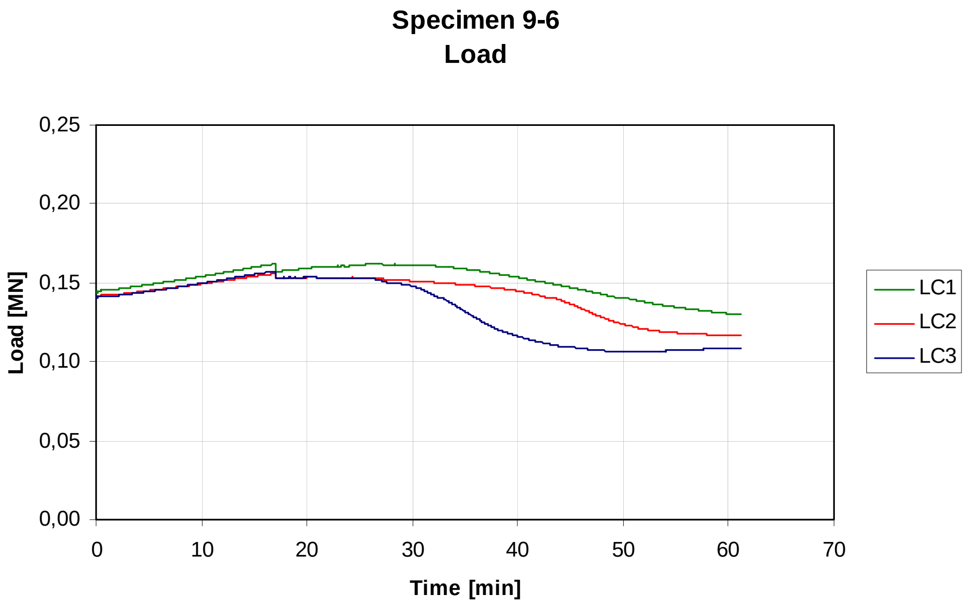


Figure A.80 Load measurements on specimen 9-6.

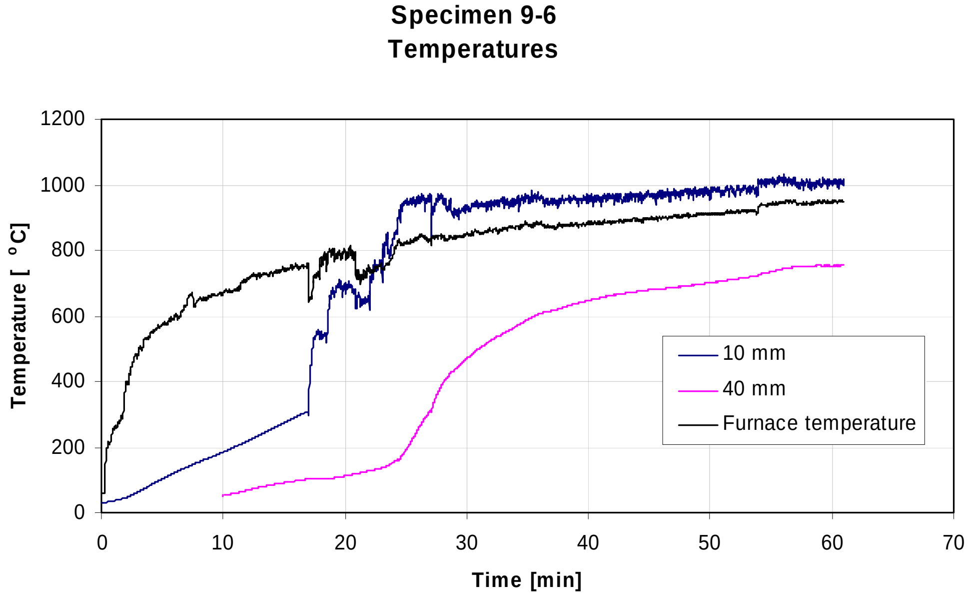


Figure A.81 Measured temperatures in furnace and in specimen 9-6.

Table A.48 Spalling measurements on specimen 9-6.

Position	0	100	200	300	400	500
0	0	9	4	13	0	0
100	16	25	27	38	26	0
200	22	22	51	53	31	2
300	17	15	47	40	24	5
400	12	16	29	24	10	4
500	9	13	15	16	14	3
600	9	14	9	0	4	0

Mean all	16
Mean inner	27
Max in diagram	53
Max measured	55

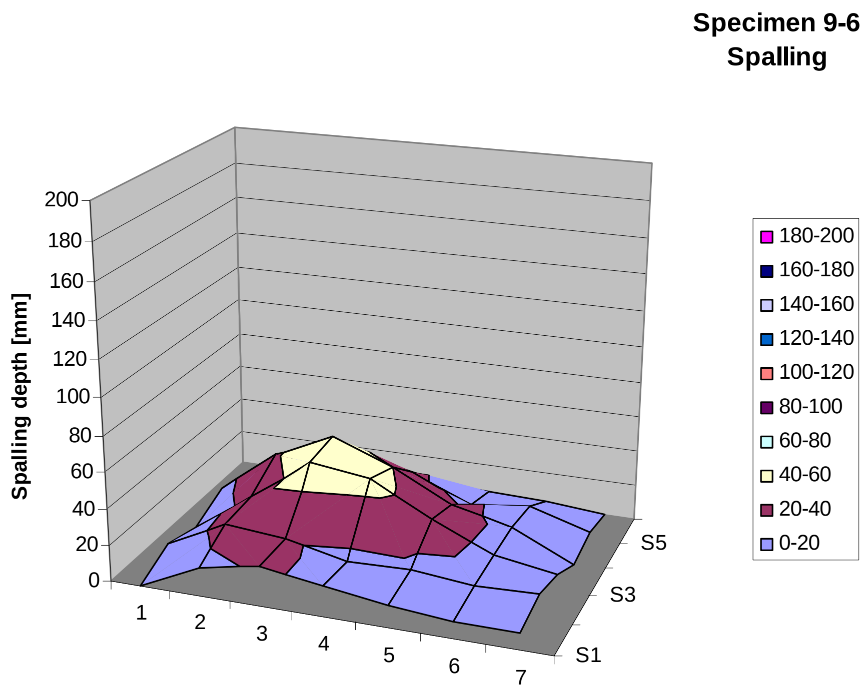


Figure A.82 Spalling measurements on specimen 9-6.

Table A.49 Observations made on specimen 9-6.

Time	Observation
0,00	Start of test
10,00	*Pole error*
17,00	One very loud explosion
18,00	Continuous small explosions
21,00	Two small explosions
23,00	Two small explosions
27,00	One small explosion
61,00	Test terminates

Test date:	2005-12-13	
Specimen:	9-6	
Load level:	142	kN/bar
Weight loss:	15	kg

Figure A.83 Specimen 9-6 after test.

Concrete 10

Table A.50 Concrete admixture recipe 10.

Recipe	**10**
Water (kg/m^3)	230
CEM II 42,5R A-LL (kg/m^3)	355
Limestone filler, Limus 25 (kg/m^3)	105
Water-powder ratio, w/p	0,50
Water-cement ratio, w/c	0,65
Sikament 20HE 50 (20% torrhalt)	4,50
Sikament 20HE 50 (% of cement weight)	1,27
Sika Stabilizer 100	4,00
Sika Stabilizer 100 (% of cement weight)	1,13
Gravel 0 – 8 mm (%)	65
Partly crushed 8 – 16 mm (%)	35
Slump flow (mm)	650
T50 (s)	<1
Air (%)	2.1
Compressive strength, 28 days (MPa)	36.6

<u>Specimen 10-1</u>

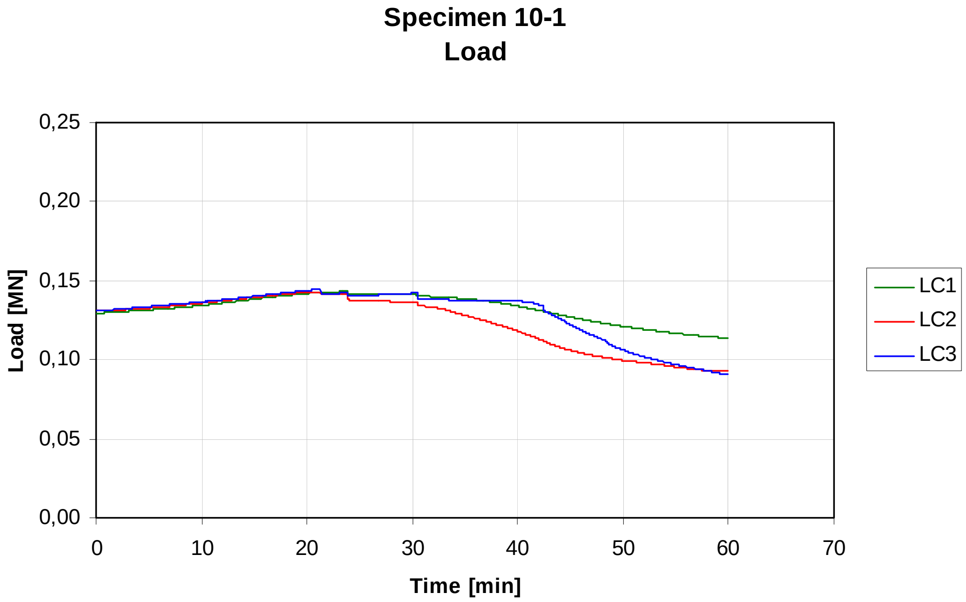


Figure A.84 Load measurements on specimen 10-1.

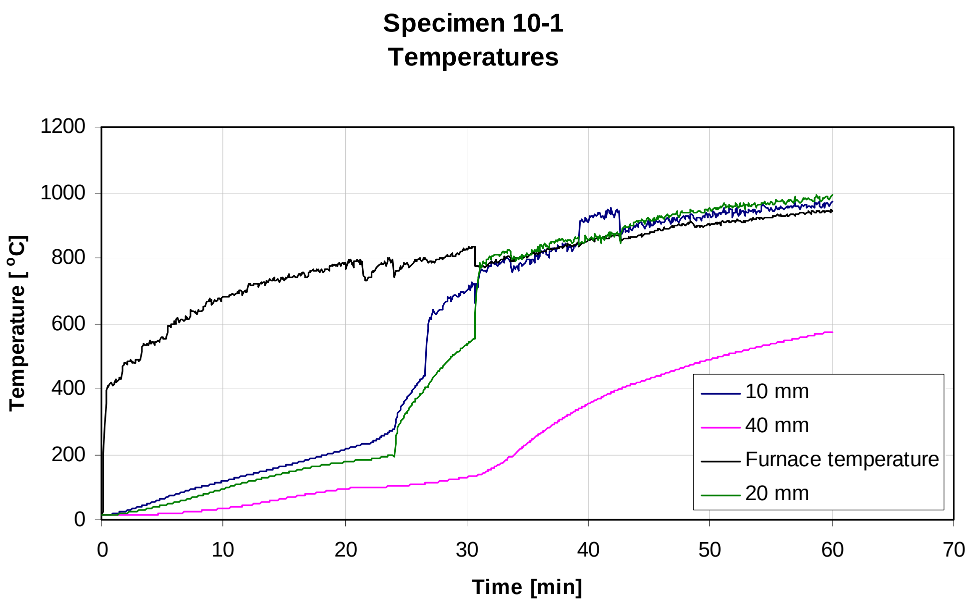


Figure A.85 Measured temperatures in furnace and in specimen 10-1.

Table A.51 Spalling measurements on specimen 10-1.

Position	0	100	200	300	400	500
0	0	6	23	9	0	0
100	7	20	23	25	5	0
200	37	31	24	34	10	0
300	58	46	45	33	11	0
400	47	43	30	22	15	0
500	33	31	28	25	13	4
600	0	5	0	0	0	0

Mean all	18
Mean inner	26
Max in diagram	58
Max measured	66

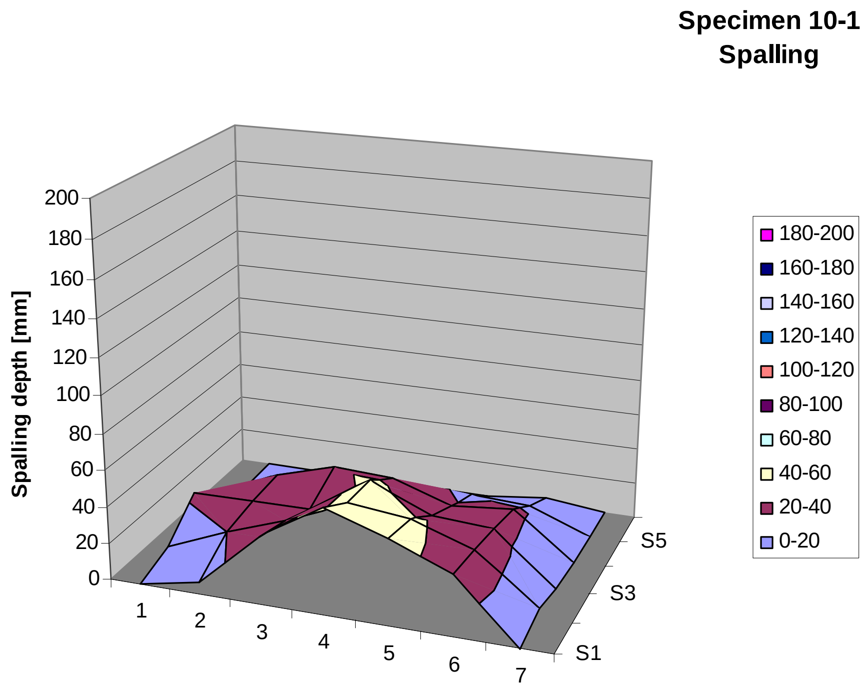


Figure A.86 Spalling measurements on specimen 10-1.

Table A.52 Observations made on specimen 10-1.

Time	Observation			
0,00	Start of test	Specimen:	10-1	
21,62	One explosion	Load level:	130	kN/bar
23,75	One small explosion	Weight loss:	15,0	kg
24,07	One explosion			
24,62	One small explosion			
25,30	One small explosion			
26,67	One small explosion			
30,68	One loud explosion, horizontal crack on front side			
32,07	One small explosion			
33,65	One explosion			
35,52	One small explosion			
42,58	One explosion			
43,80	One small explosion			
44,67	One small explosion			
48,73	One explosion			
60,00	Test terminates			

Test date: 2006-03-27

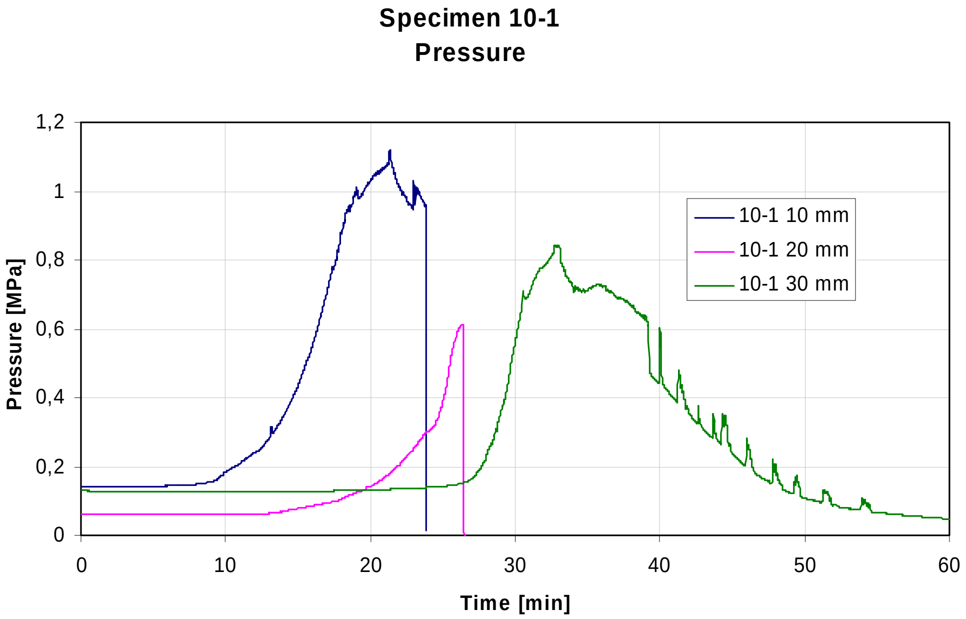


Figure A.87 Vapour pressure in specimen 10-1.

Figure A.88 Specimen 10-1 after test.

Specimen 10-2

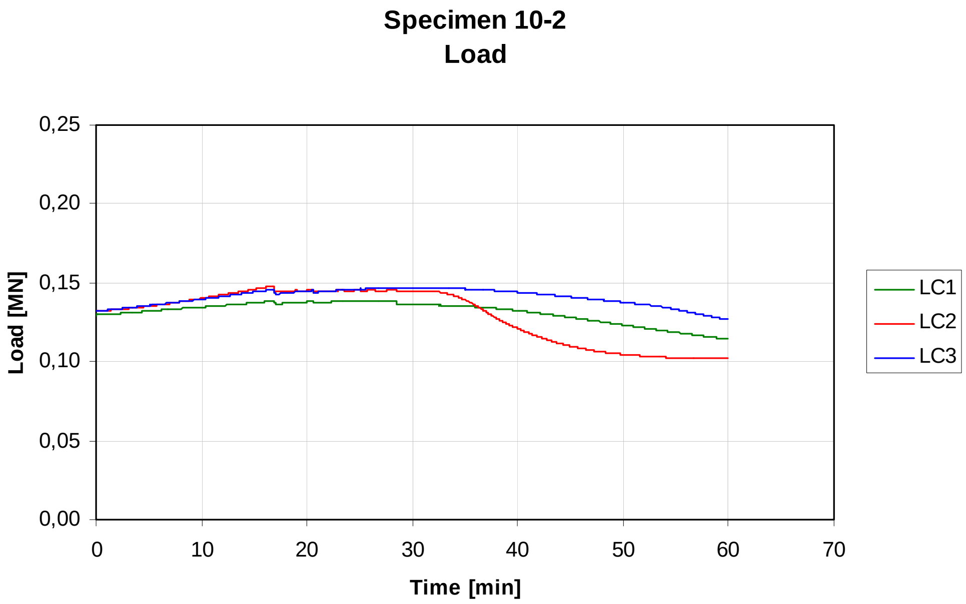


Figure A.89 Load measurements on specimen 10-2.

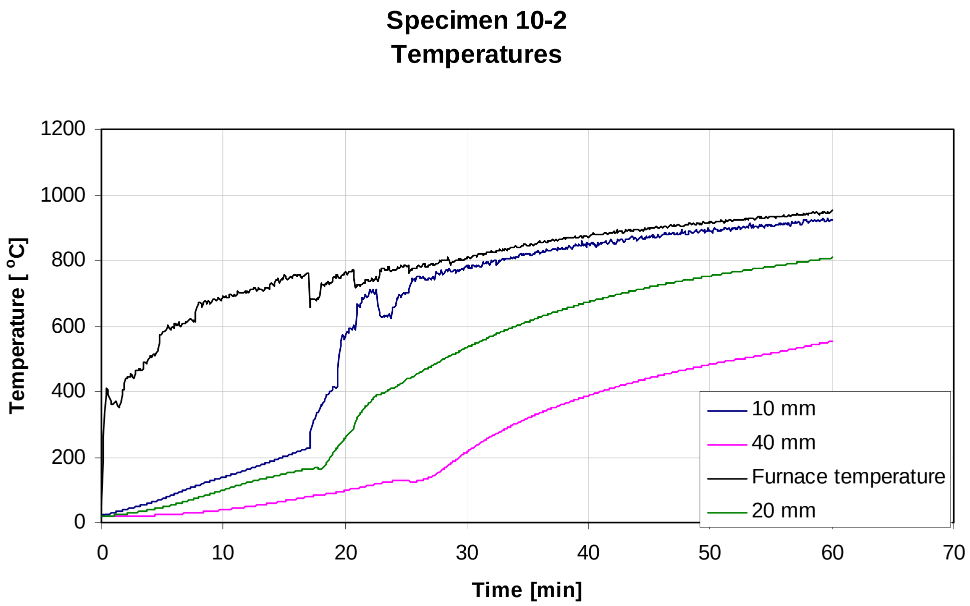


Figure A.90 Measured temperature in furnace and in specimen 10-2.

Table A.53 Spalling measurement on specimen 10-2.

Position	0	100	200	300	400	500
0	0	4	21	4	4	0
100	1	15	14	25	19	8
200	3	28	34	20	14	10
300	6	32	37	25	17	4
400	14	23	38	30	23	7
500	8	21	22	25	16	2
600	0	20	1	1	1	0

Mean all	14
Mean inner	24
Max in diagram	38
Max measured	38

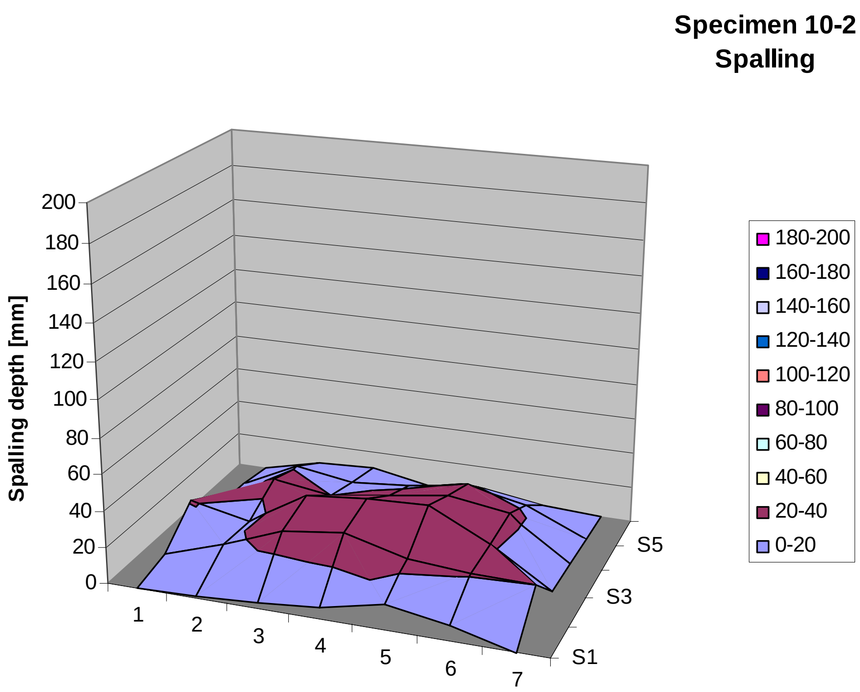


Figure A.91 Spalling measurement on specimen 10-2.

Table A.54 Observations made on specimen 10-2.

Time	Observation
0,00	Start of test
17,17	One loud explosion, horizontal cracks on sides
17,83	One small explosion
18,25	One small explosion
19,25	Two small explosions
19,42	One small explosion
20,78	Two explosions
22,28	One small explosion
22,82	One small explosion
23,02	One small explosion
23,25	One small explosion
23,75	Two small explosions
23,83	One small explosion
25,33	One explosion
26,67	One small explosion
28,67	One small explosion
30,03	Horizontal crack along the front side
60,00	Test terminates

Test date:	2006-03-27	
Specimen:	10-2	
Load level:	131	kN/bar
Weight loss:	12,3	kg

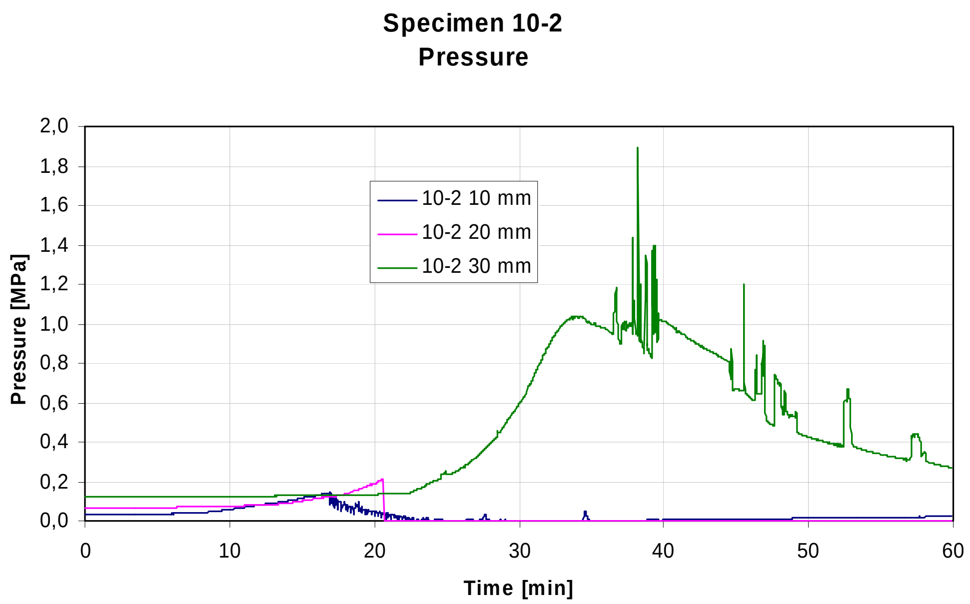


Figure A.92 Vapour pressure in specimen 10-2.

Figure A.93 Specimen 10-2 after test.

Specimen 10-3

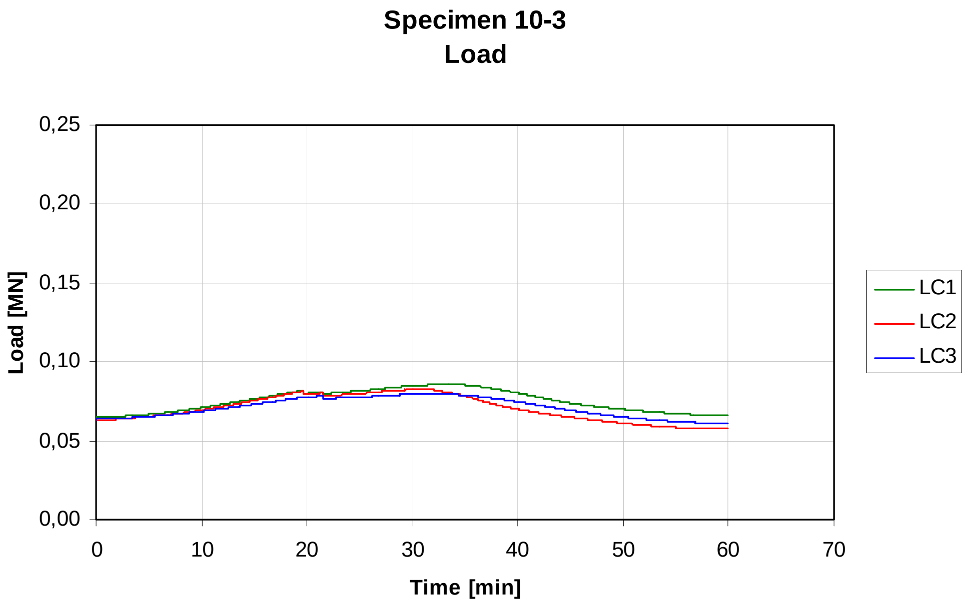


Figure A.94 Load measurements on specimen 10-3.

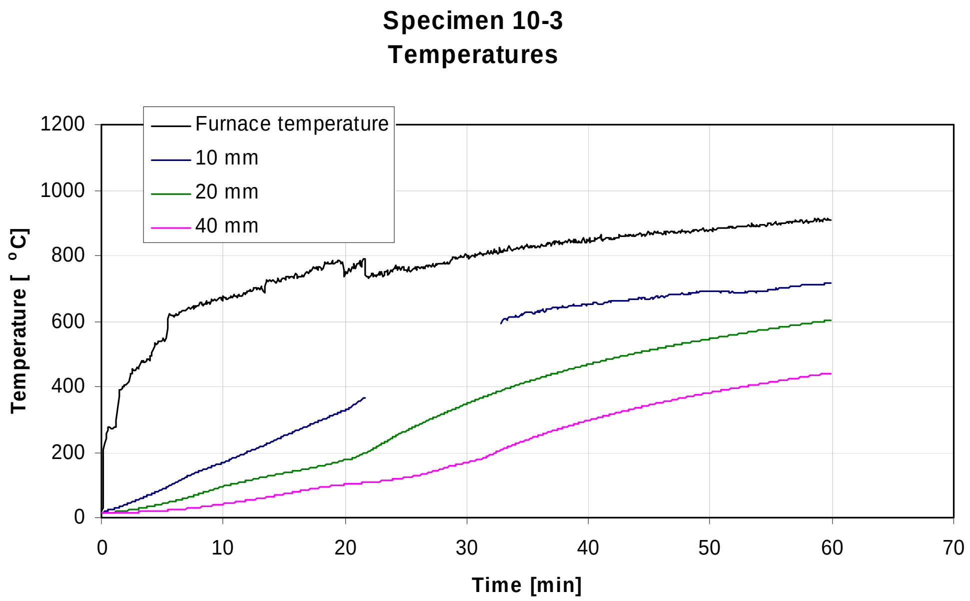


Figure A.95 Measured temperatures in furnace and in specimen 10-3.

Table A.55 Spalling measurements on specimen 10-3.

Position	0	100	200	300	400	500
0	10	6	6	15	9	0
100	8	20	29	24	22	0
200	9	16	23	23	25	6
300	2	9	17	17	21	0
400	4	19	20	6	12	0
500	10	23	20	8	0	0
600	0	13	0	1	0	0

Mean all	11
Mean inner	18
Max in diagram	29
Max measured	34

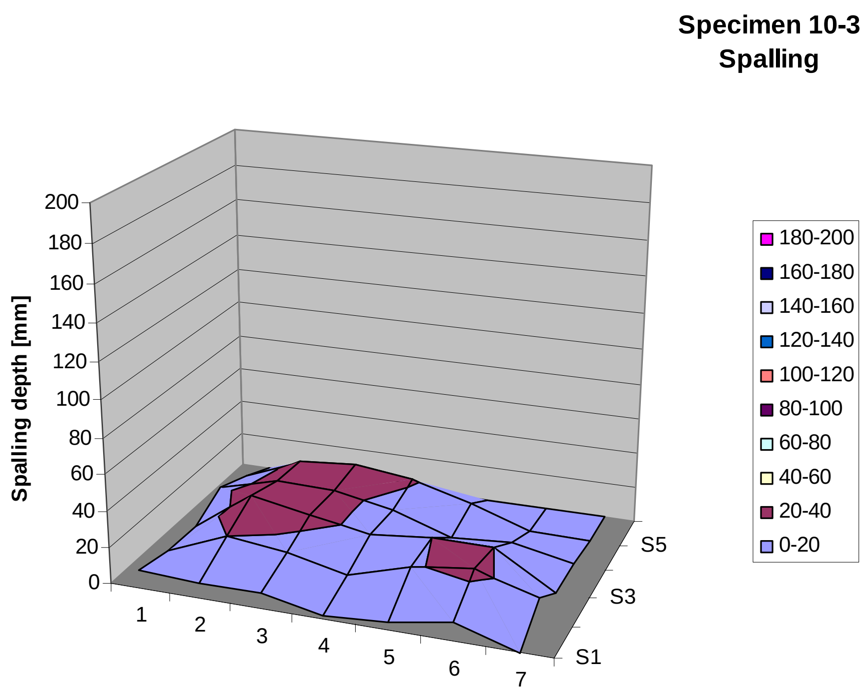


Figure A.96 Spalling measurements on specimen 10-3.

Table A.56 Observations made on specimen 10-3.

Time	Observation
0,00	Start of test
19,87	One explosion, small crack on back side
21,27	One small explosion
21,67	One explosion, horizontal crack along back side
23,35	One small explosion
24,32	One small explosion
24,97	One small explosion
60,00	Test terminates

Test date:	2006-03-28	
Specimen:	10-3	
Load level:	64	kN/bar
Weight loss:	7,8	kg

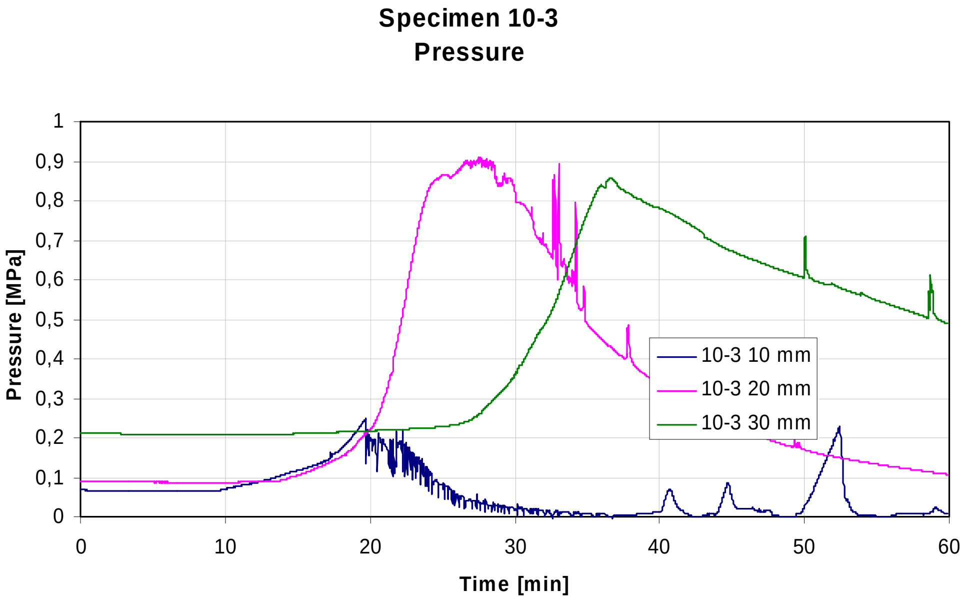


Figure A.97 Vapour pressure in specimen 10-3.

Figure A.98 Specimen 10-3 after test.

Specimen 10-4

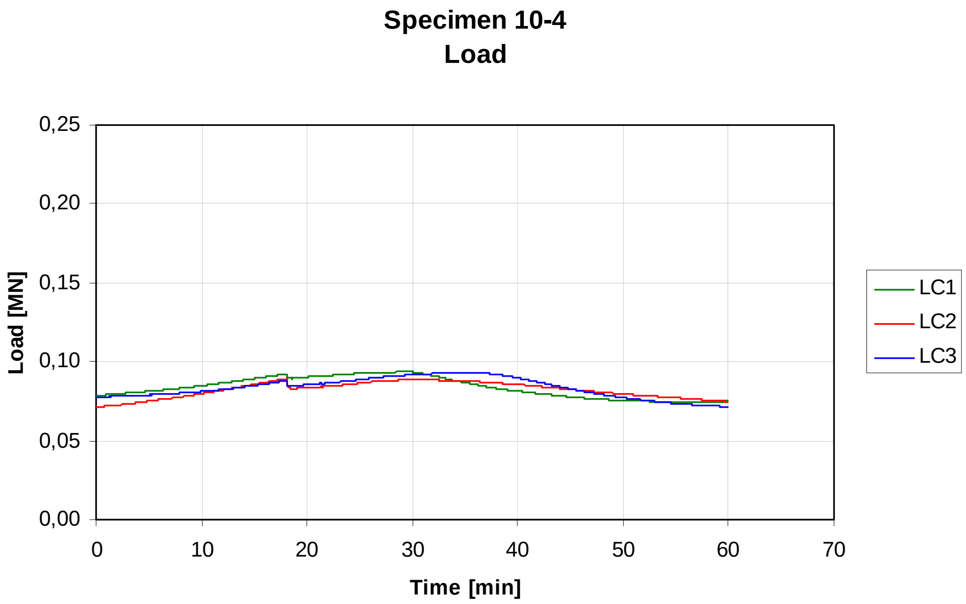


Figure A.99 Load measurements on specimen 10-3.

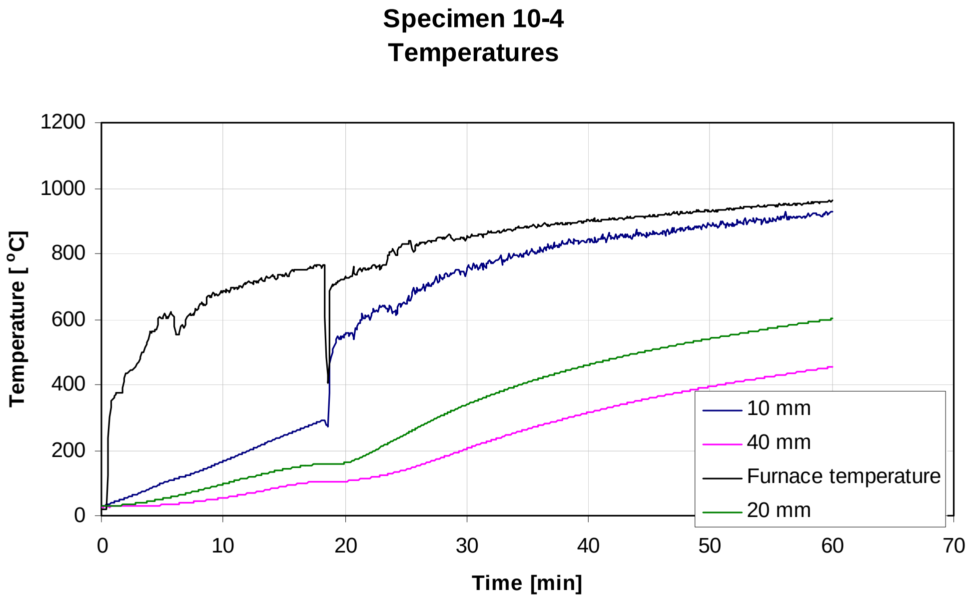


Figure A.100 Measured temperatures in furnace and in specimen 10-4.

Table A.57 Spalling measurements on specimen 10-4.

Position	0	100	200	300	400	500
0	11	15	9	2	5	0
100	9	16	30	29	26	7
200	15	26	24	30	19	6
300	7	24	23	21	15	3
400	16	11	14	16	12	0
500	0	1	0	0	0	0
600	0	0	0	0	0	0

Mean all	11
Mean inner	17
Max in diagram	30
Max measured	36

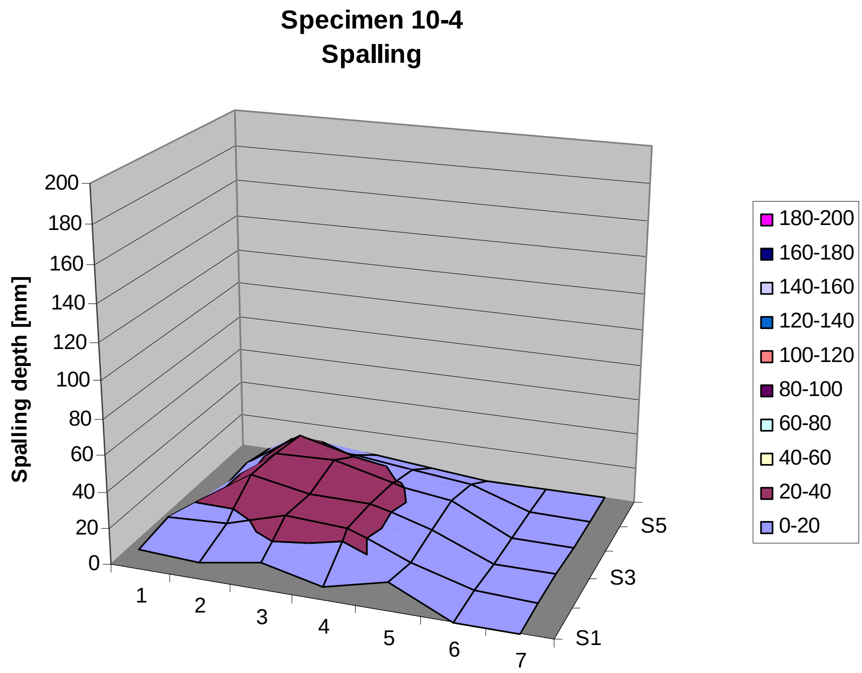


Figure A.101 Spalling measurements on specimen 10-4.

Table A.58 Observations made on specimens 10-4.

Time	Observation
0,00	Start of test
18,33	One explosion, burner blown out, horizontal crack on front side
20,12	Two small explosions
20,72	One small explosion
20,77	One small explosion
20,90	One small explosion
21,57	One explosion
22,08	One small explosion
22,47	One small explosion
22,83	One explosion
23,83	One small explosion
60,00	Test terminates

Test date:	2006-03-28	
Specimen:	10-4	
Load level:	76	kN/bar
Weight loss:	8,3	kg

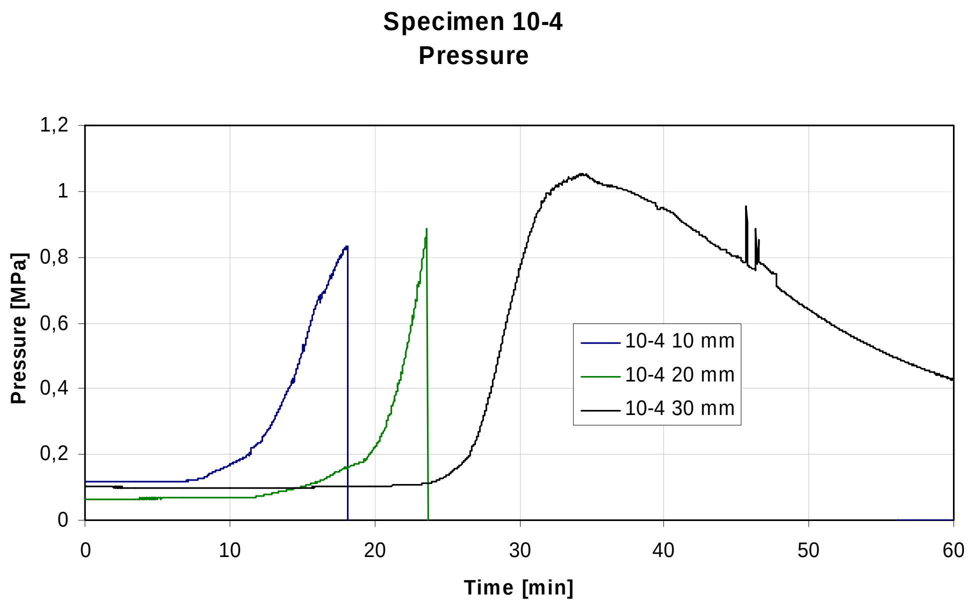


Figure A.102 Vapour pressure in specimen 10-4.

Figure A.103 Specimen 10-4 after test.

Specimen 10-5

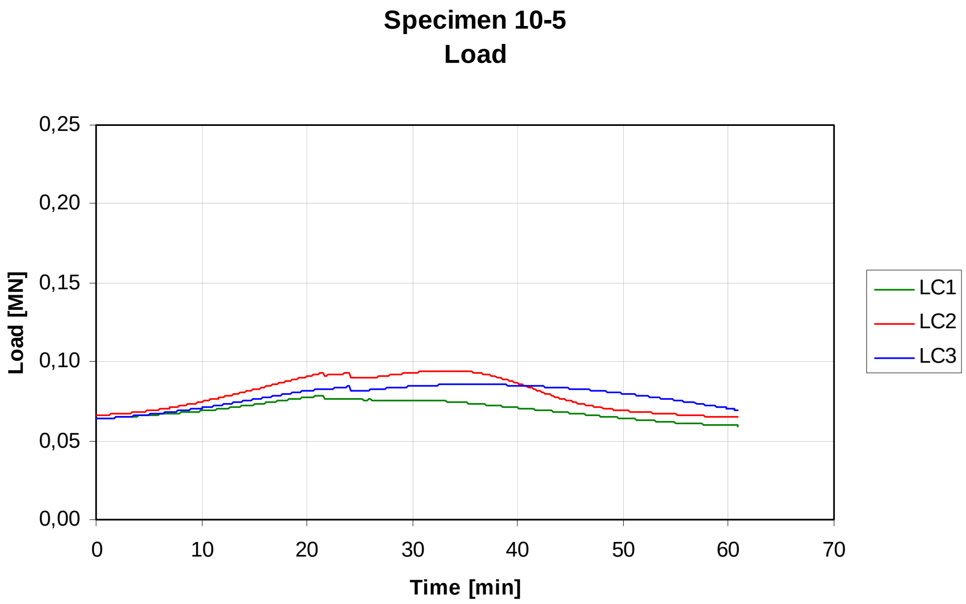


Figure A.104 Load measurement on specimen 10-5.

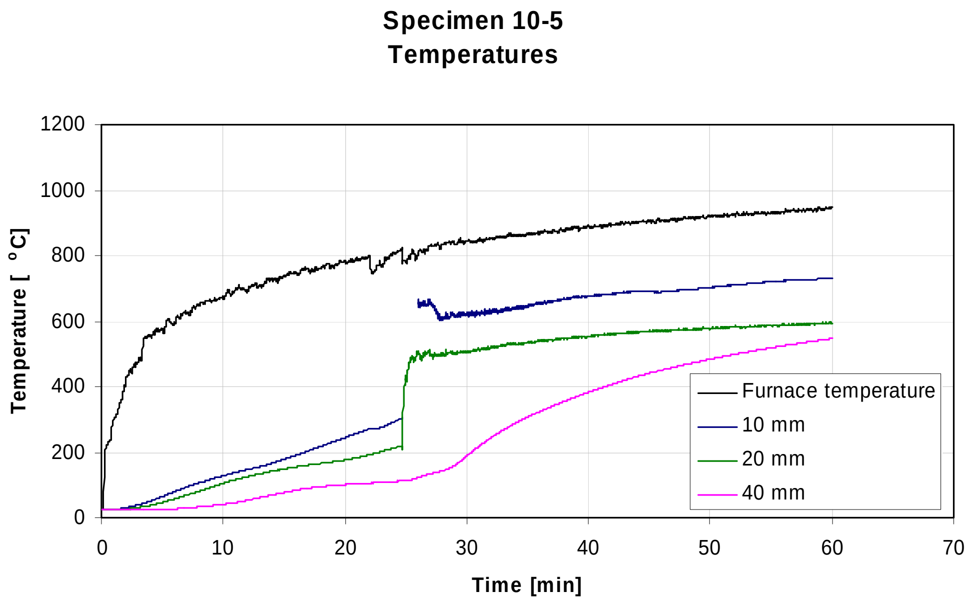


Figure A.105 Measured temperatures in furnace and in specimen 10-5.

Table A.59 Spalling measurement on specimen 10-5.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	2	5	4	0
200	1	7	34	24	10	0
300	3	20	36	24	15	0
400	13	24	28	31	14	0
500	7	32	19	28	24	0
600	0	0	0	0	0	0

Mean all	10
Mean inner	19
Max in diagram	36
Max measured	40

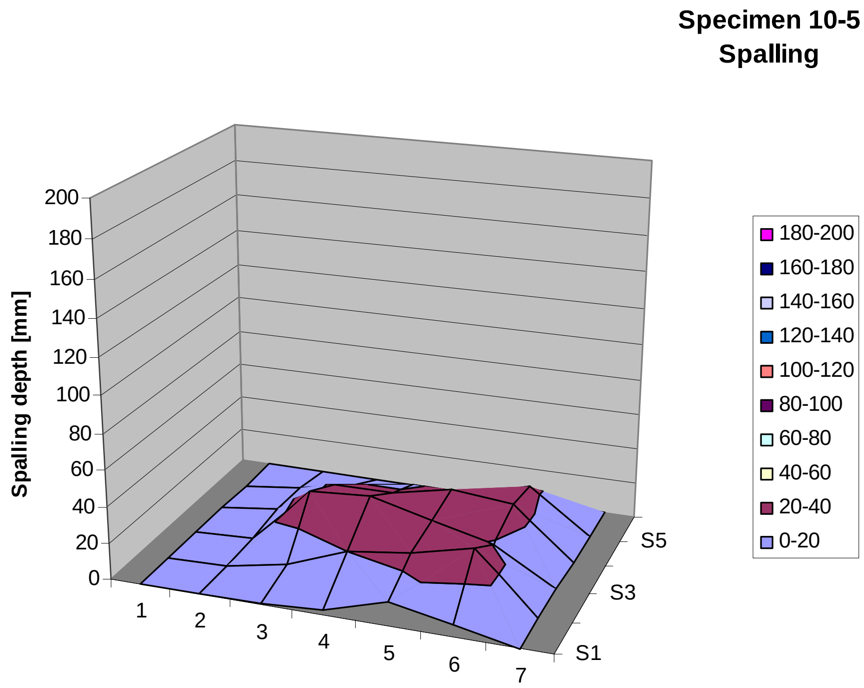


Figure A.106 Spalling measurement on specimen 10-5.

Table A.60 Observations made on specimen 10-5.

Time	Observation
0,00	Start of test
22,03	One explosion
22,83	One small explosion
23,32	One small explosion
23,55	One small explosion
23,78	One small explosion
24,73	One explosion
25,55	One small explosion
25,73	Two small explosions
25,92	One small explosion
26,52	One small explosion
60,00	Test terminates

Test date:	2006-07-04	
Specimen:	10-5	
Load level:	65	kN/bar
Weight loss:	9,7	kg

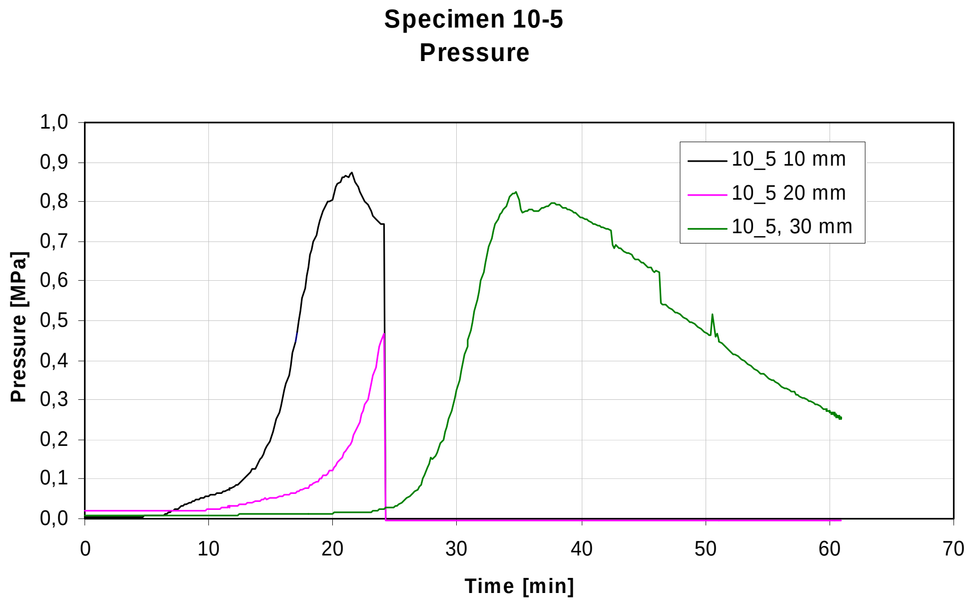


Figure A.107 Vapour pressure in specimen 10-5.

Figure A.108 Specimen 10-5 after test.

Specimen 10-6

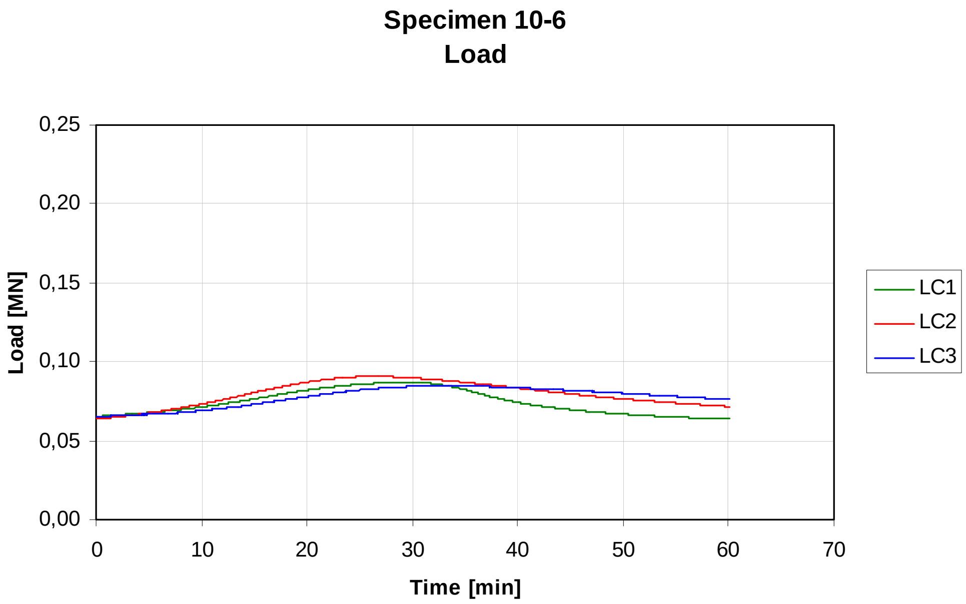


Figure A.109 Load measurements on specimen 10-6.

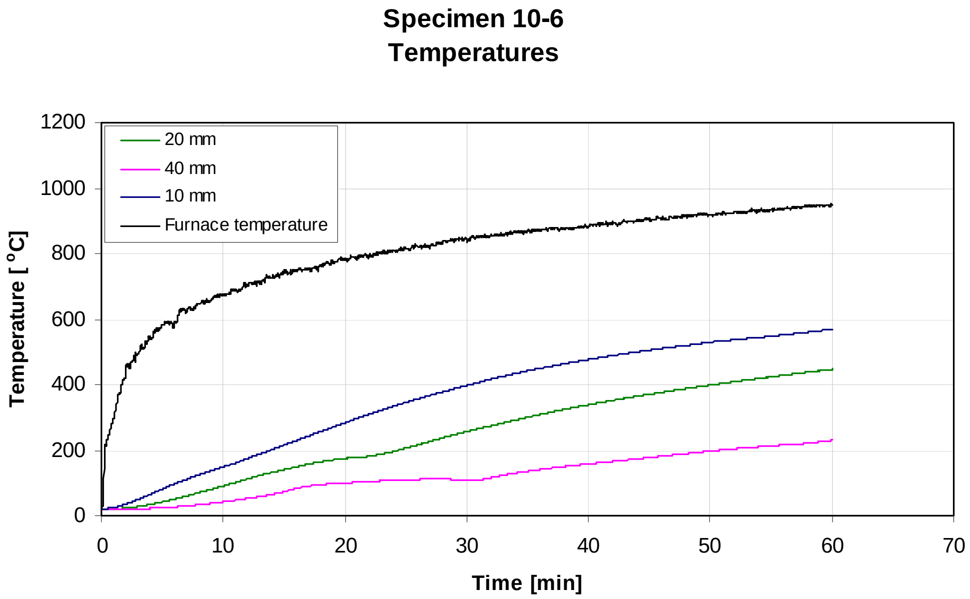


Figure A.110 Measured temperatures in furnace and in specimen 10-6.

Table A.61 Spalling measurements on specimen 10-6.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

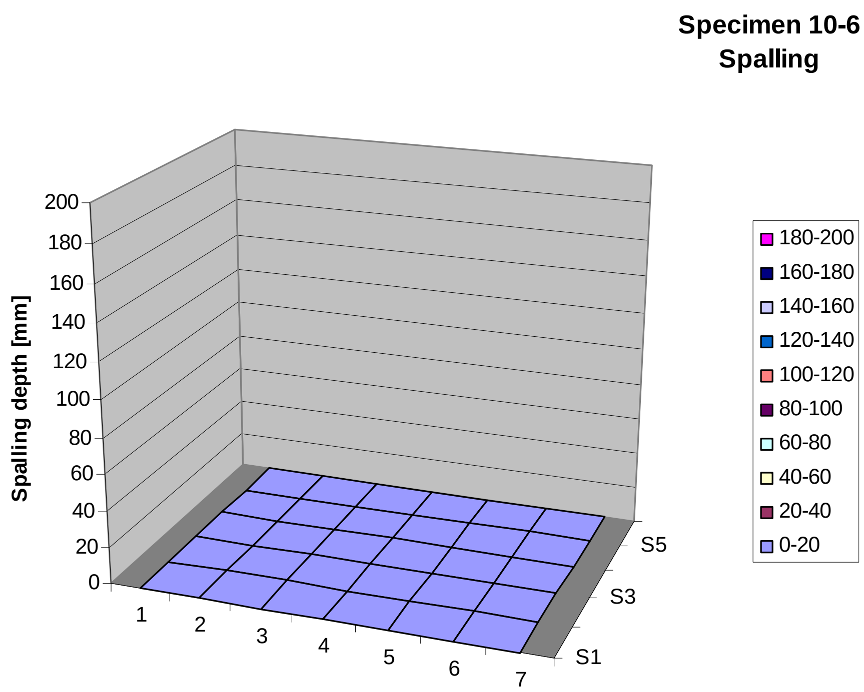


Figure A.111 Spalling measurements on specimen 10.6.

Table A.62 Observations made on specimen 10-6.

Time	Observation			
0,00	Start of test	Test date:	2006-06-30	
19,05	One explosion	Specimen:	10-6	
30,00	Water on top	Load level:	65	kN/bar
40,00	Water on front side	Weight loss:	2,4	kg
60,00	Test terminates			

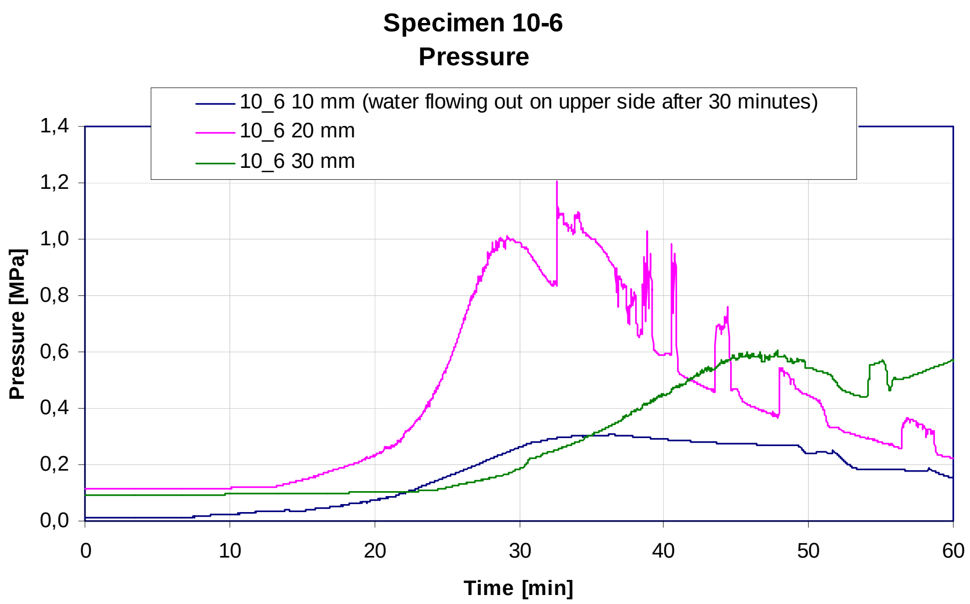


Figure A.112 Vapour pressure in specimen 10-6.

Figure A.113 Specimen 10-6 after test.

Specimen 10-12

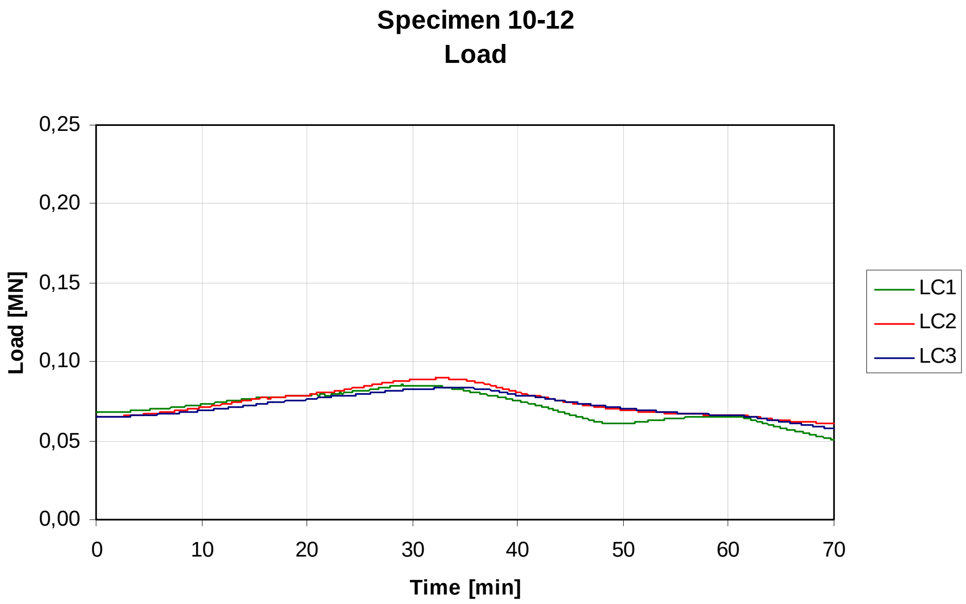


Figure A.114 Load measurements on specimen 10-12.

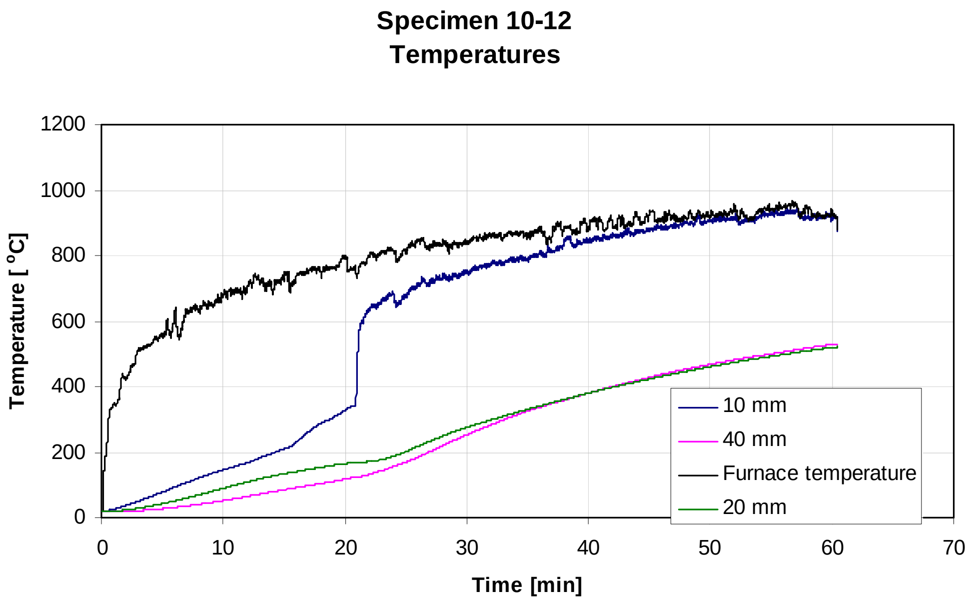


Figure A.115 Measured temperatures in furnace and in specimen 10-12.

Table A.63 Spalling measurements on specimen 10-12.

Position	0	100	200	300	400	500
0	23	4	1	7	0	0
100	26	28	23	21	12	4
200	46	26	23	21	13	0
300	56	23	27	10	7	0
400	30	24	21	0	0	0
500	17	18	3	0	0	0
600	0	0	0	0	0	0

Mean all	12
Mean inner	15
Max in diagram	56
Max measured	56

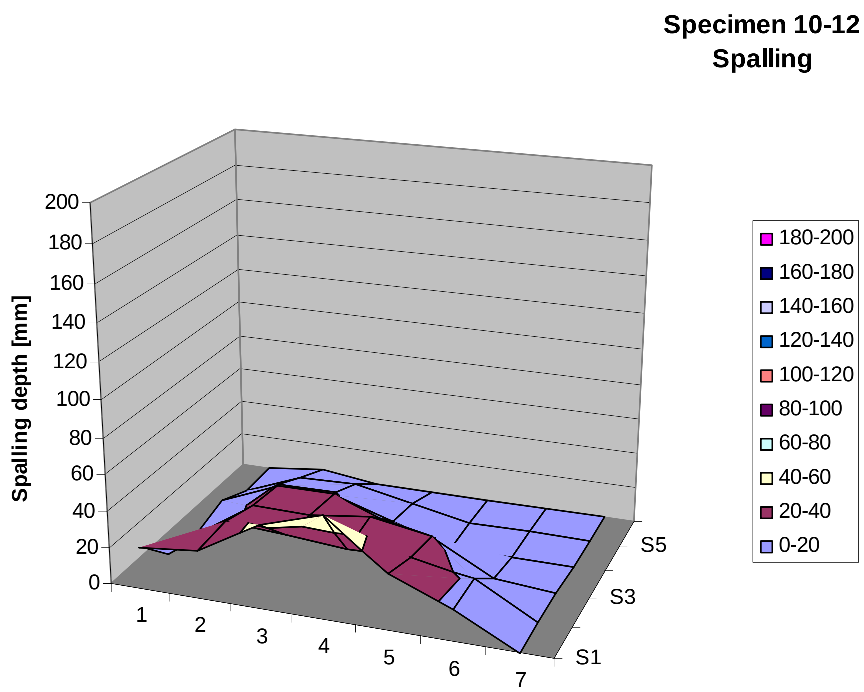


Figure A.116 Spalling measurements on specimen 10-12.

Table A.64 Observations made on specimen 10-12.

Time	Observation		
0,00	Start of test	Test date:	2005-10-13
15,45	One loud explosion	Specimen	10-12
15,70	One small explosion	Load level:	66 kN/bar
16,43	One small explosion		
16,62	One small explosion		
16,90	One small explosion		
16,93	One small explosion		
17,40	One small explosion		
17,62	One explosion		
17,98	One explosion		
18,02	One explosion		
18,47	One small explosion		
20,13	One loud explosion		
20,90	One loud explosion		
22,20	One small explosion		
23,97	One small explosion		
24,18	One loud explosion, opening on back side		
27,83	Water on front side		
28,33	One small explosion		
32,80	One small explosion		
34,55	One small explosion		
36,30	One small explosion		
60,00	Test terminated		

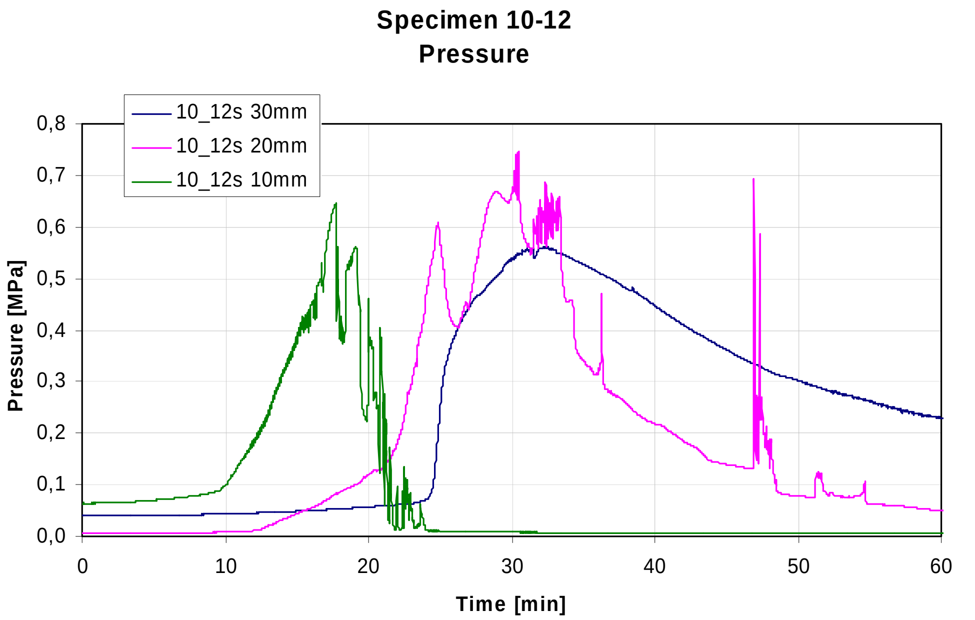


Figure A.117 Vapour pressure in specimen 10-12.

Figure A.118 Specimen 10-12 after test.

Specimen 10-14

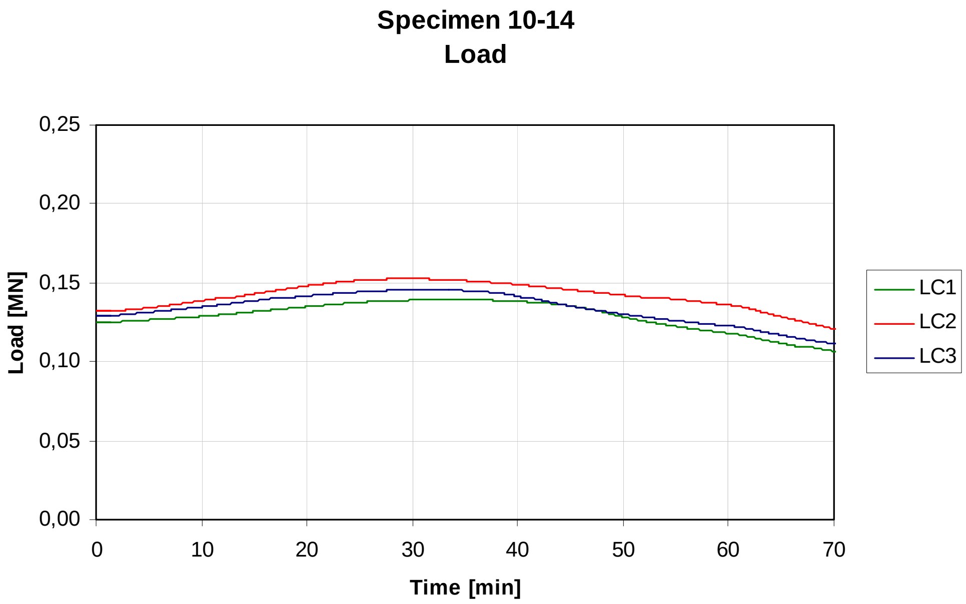


Figure A.119 Load measurements on specimen 10-14.

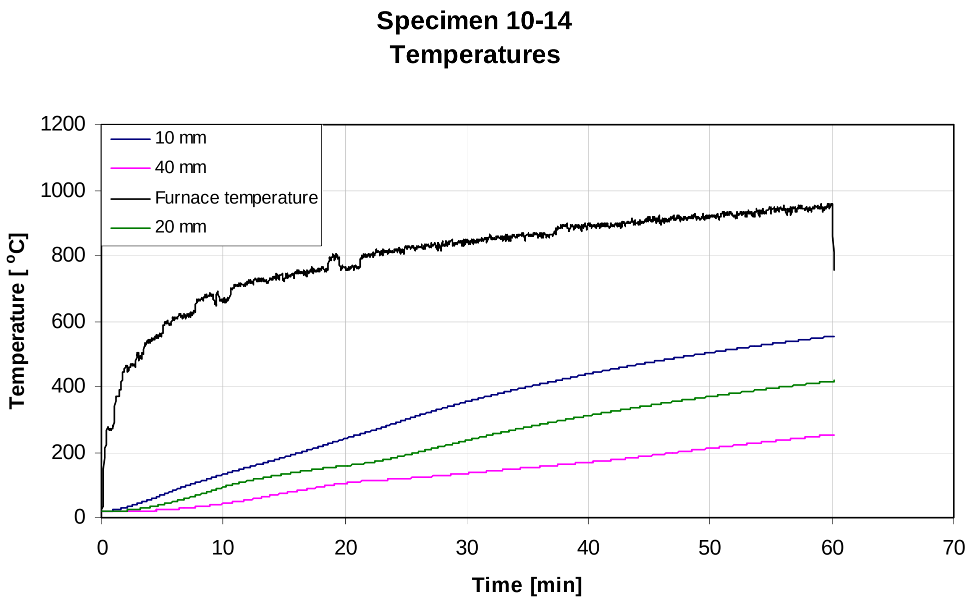


Figure A.120 Measured temperatures in furnace and in specimen 10-14.

Table A.65 Spalling measurements on specimen 10-14.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

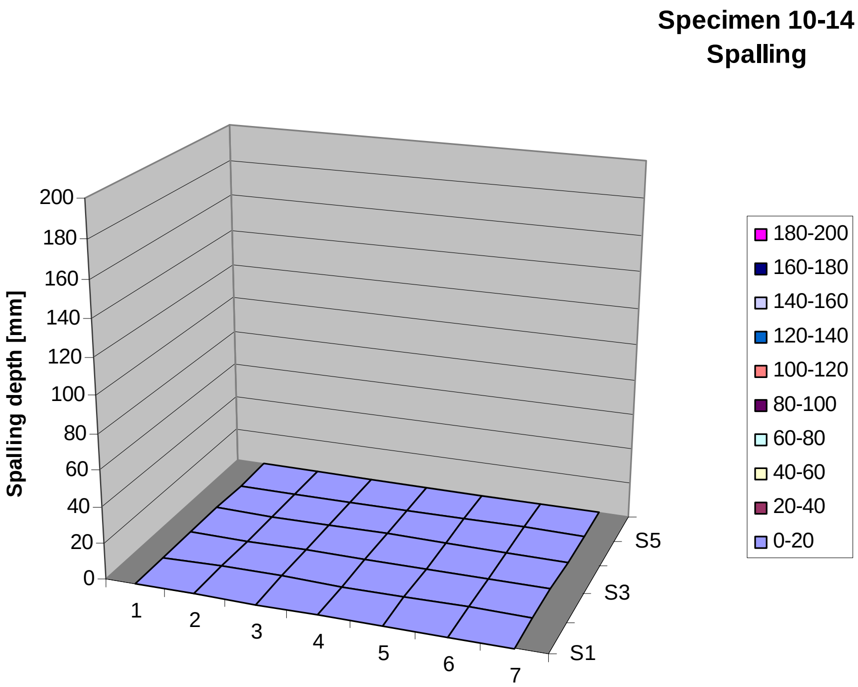


Figure A.121 Spalling measurements on specimen 10-14.

Table A.66 Observations made on specimen 10-14

Time	Observation			
0,00	Start of test	Test date:	2005-10-07	
60,00	Test terminated	Specimen:	10-14	
		Load level:	129	kN/bar

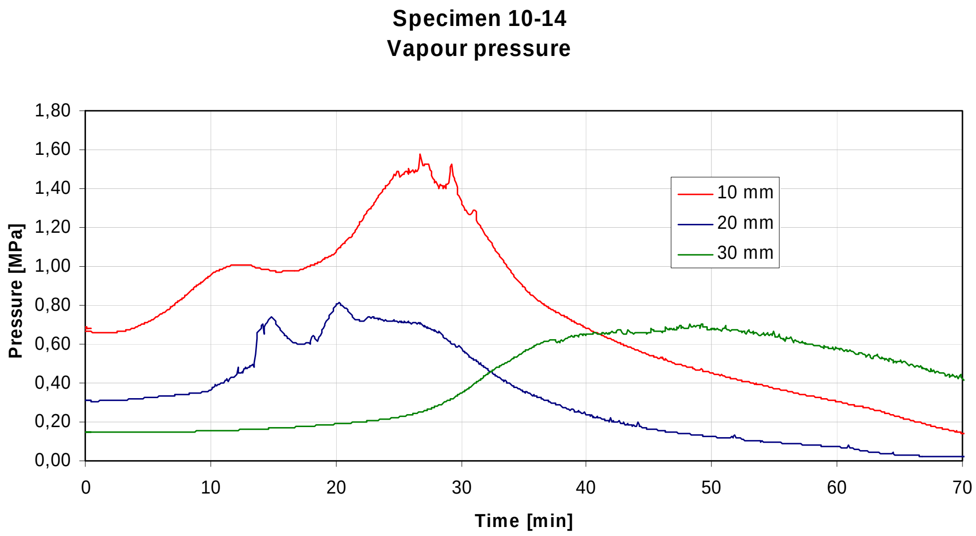


Figure A.122 Vapour pressure in specimen 10-14.

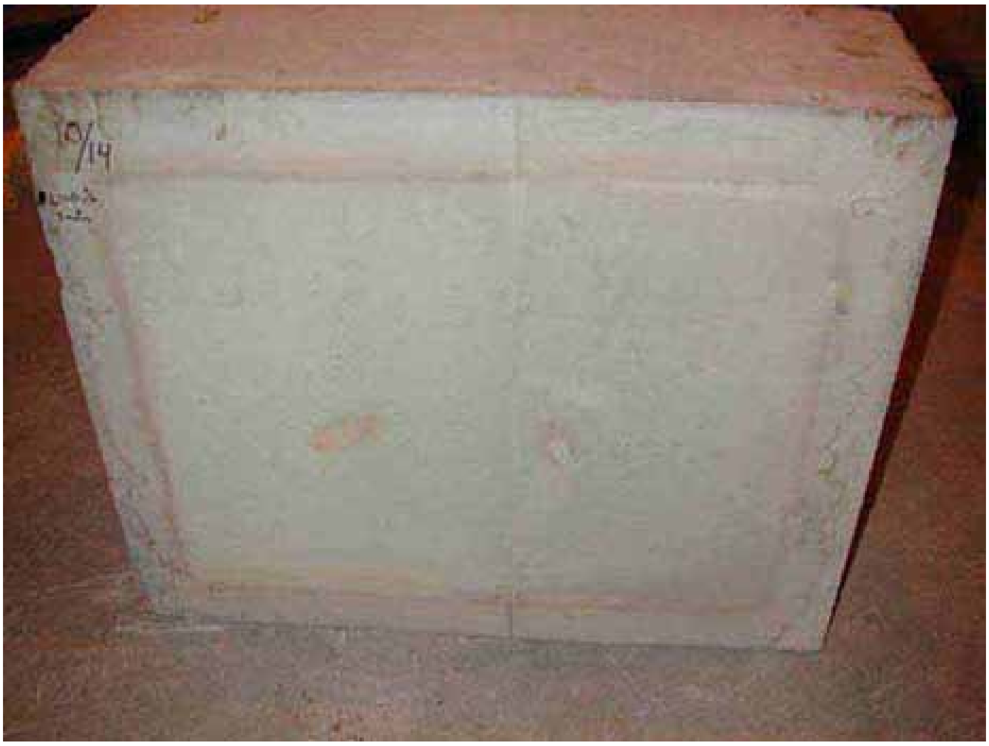


Figure A.123 Specimen 10-14 after test.

Specimen 10-16

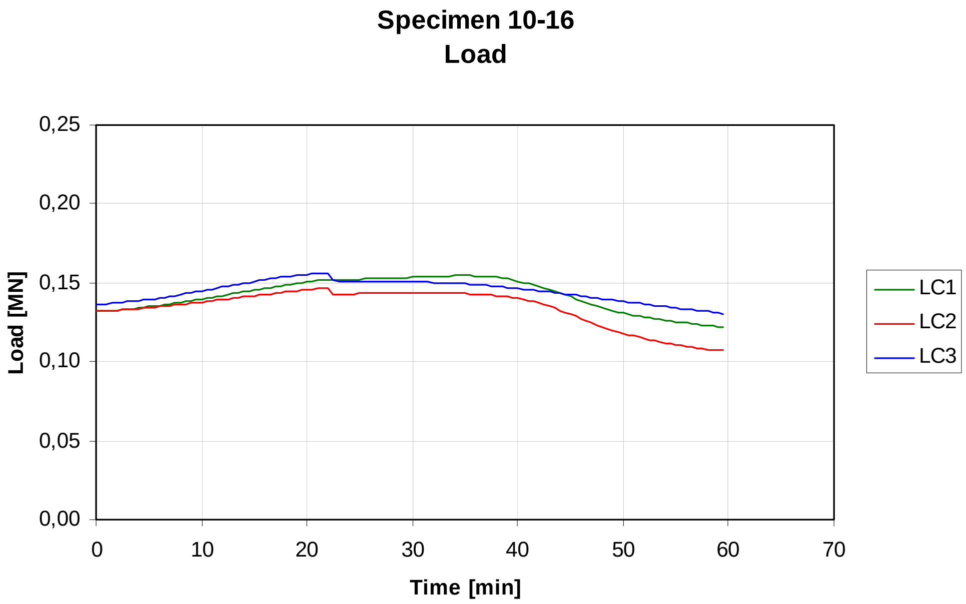


Figure A.124 Load measurements on specimen 10-16.

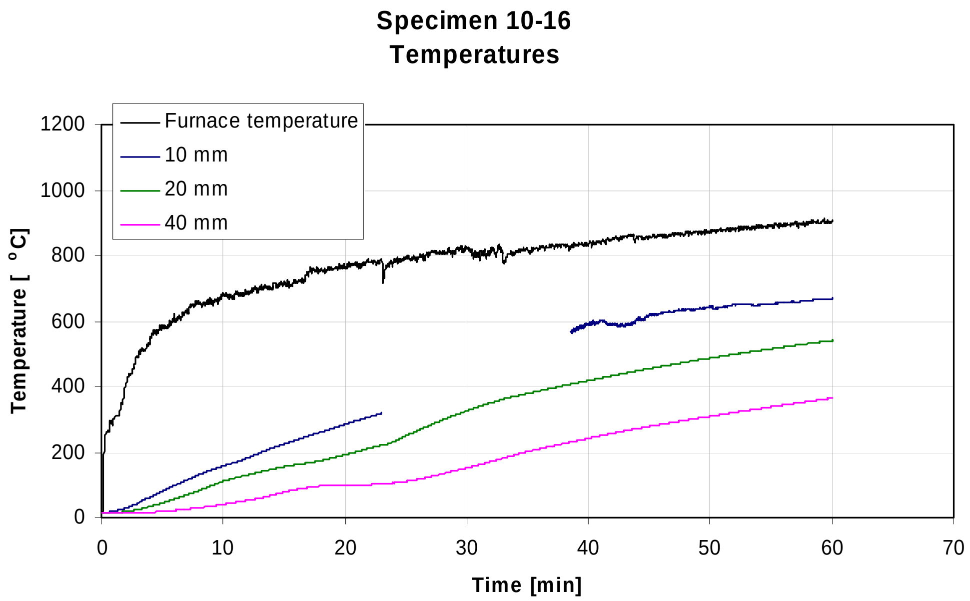


Figure A.125 Measured temperatures in furnace and in specimen 10-16.

Table A.67 Spalling measurements on specimen 10-16.

Position	0	100	200	300	400	500
0	16	8	3	0	0	0
100	21	23	20	0	0	0
200	13	21	20	2	0	0
300	8	19	23	7	0	0
400	12	18	20	9	0	0
500	9	13	20	5	0	0
600	0	0	7	0	0	0

Mean all	8
Mean inner	11
Max in diagram	23
Max measured	29

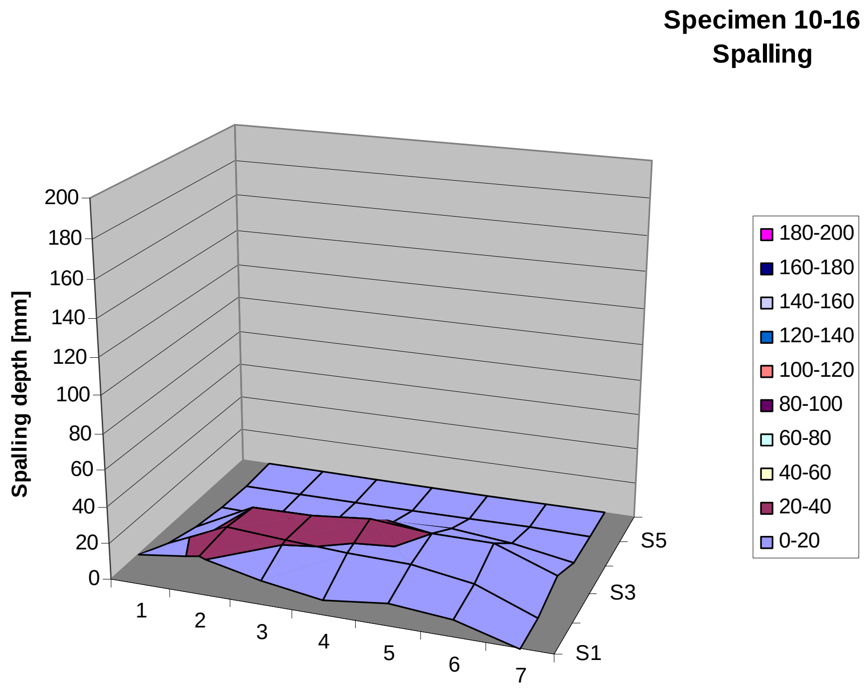


Figure A.126 Spalling measurements on specimen 10-16.

Table A.68 Observations made on specimen 10-16.

Time	Observation
0,00	Start of test
23,10	One loud explosion, horizontal crack on side
60,00	Test terminates

Test date:	2006-04-10	
Specimen:	10-16	
Load level:	133	kN/bar
Weight loss:	6,8	kg

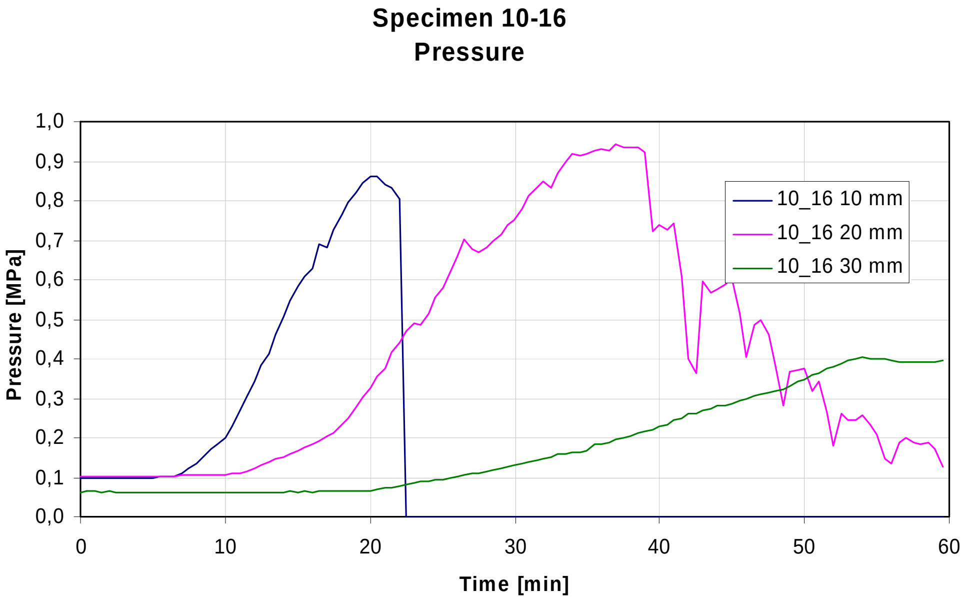


Figure A.127 Vapour pressure in specimen 10-16.

Figure A.128 Specimen 10-16 after test.

Specimen 10-17

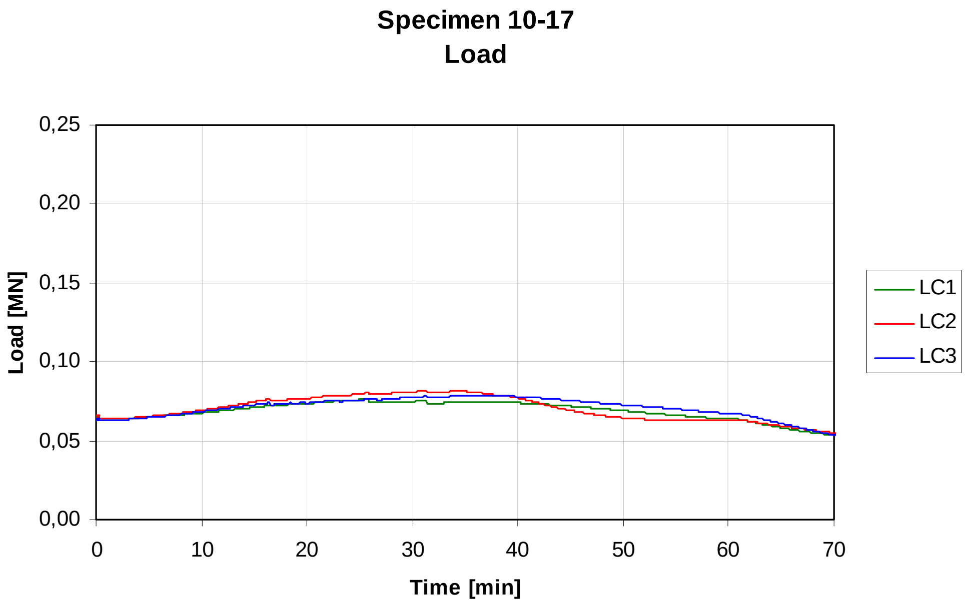


Figure A.129 Load measurements on specimen 10-17.

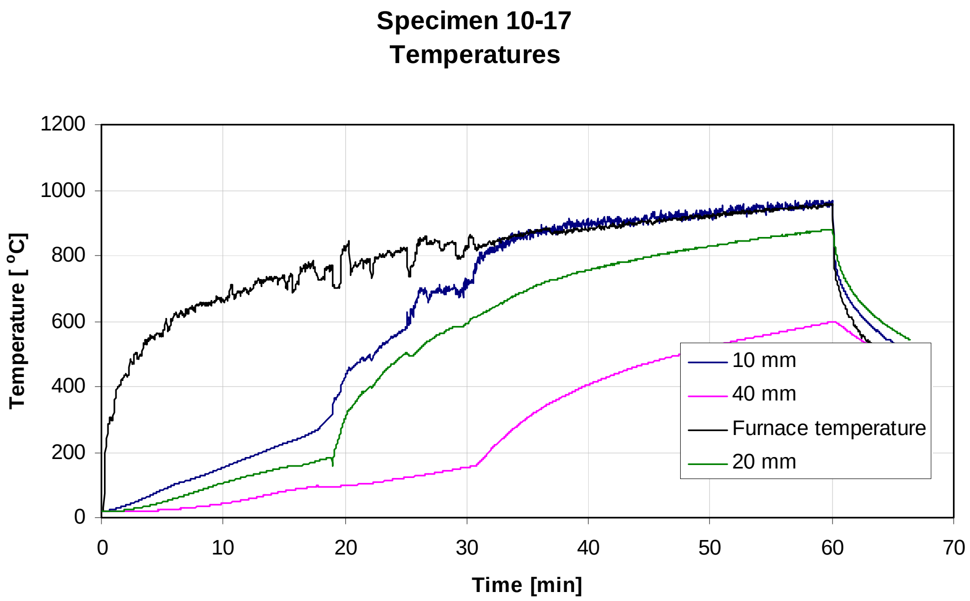


Figure A.130 Measured temperatures in furnace and in specimen 10-17.

Table A.69 Spalling measurements on specimen 10-17.

Position	0	100	200	300	400	500
0	0	0	0	0	1	0
100	3	13	13	17	29	0
200	11	29	27	19	34	3
300	12	32	38	17	37	25
400	1	25	23	17	33	33
500	3	16	20	22	43	29
600	0	0	4	2	6	0

Mean all	15
Mean inner	25
Max in diagram	43
Max measured	43

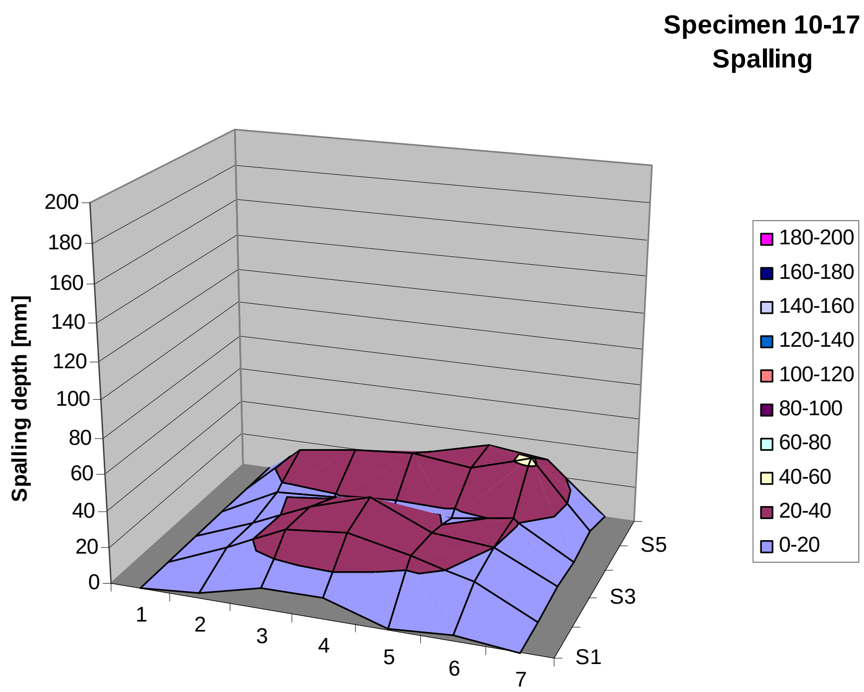


Figure A.131 Spalling measurements on specimen 10-17.

Table A.70 Observations made on specimen 10-17.

Time	Observation		
0,00	Start of test	Test date:	2005-10-10
15,68	One loud explosion	Specimen:	10-17
16,42	One small explosion	Load level:	65 kN/bar
17,00	Two small explosions		
17,75	One loud explosion		
18,77	One small explosion		
18,97	One explosion		
21,40	One explosion		
22,30	One explosion		
23,57	One small explosion		
23,95	One small explosion		
25,07	One loud explosion		
25,87	One small explosion		
26,77	One small explosion		
27,87	Two small explosions		
30,62	One loud explosion, horizontal cracks on both sides		
30,72	One loud explosion		
60,00	Test terminated		

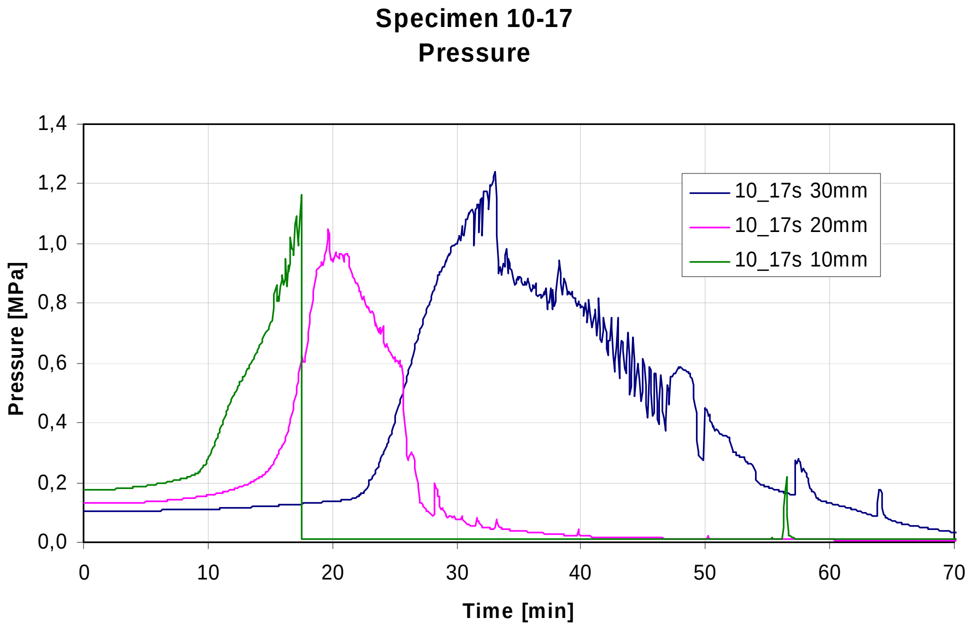


Figure A.132 Vapour pressure in specimen 10-17.

Figure A.133 Specimen 10-17 after test.

Specimen 10-18

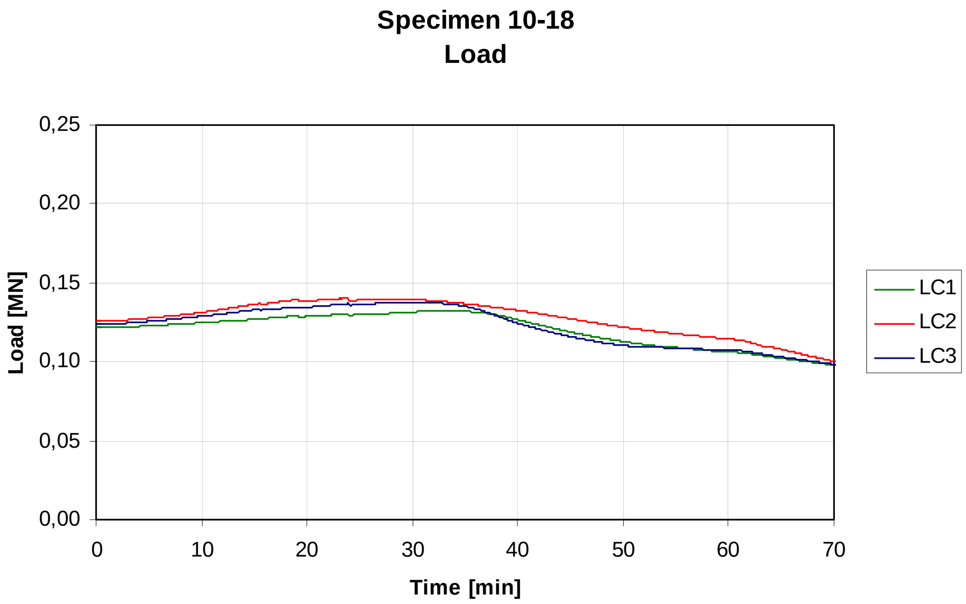


Figure A.134 Load measurements on specimen 10-18.

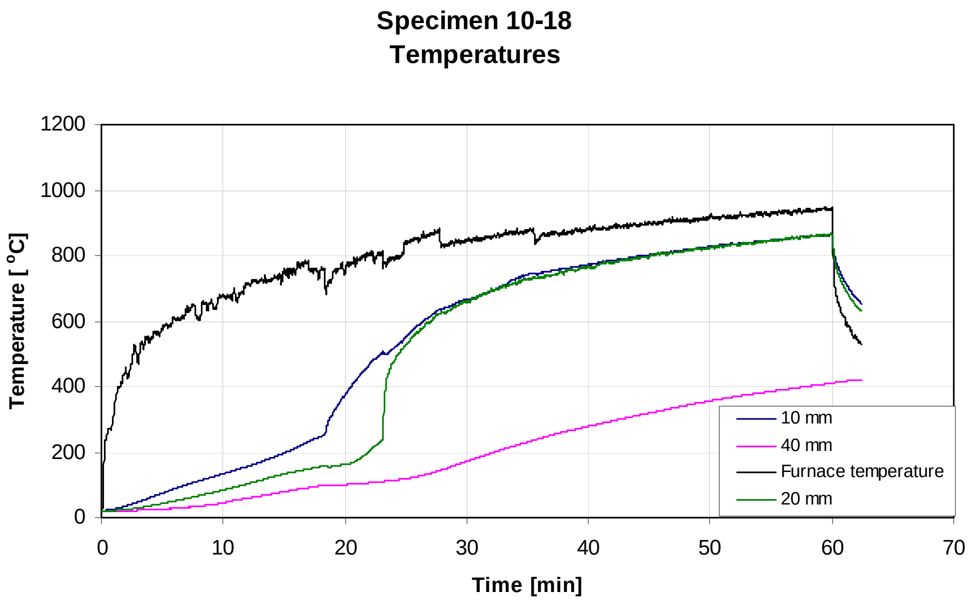


Figure A.135 Measured temperatures in furnace and in specimen 10-18.

Table A.71 Spalling measurements on specimen 10-18.

Position	0	100	200	300	400	500
0	0	9	0	3	7	0
100	0	16	29	27	14	5
200	0	17	30	16	20	4
300	0	21	21	24	26	4
400	0	14	27	26	24	5
500	0	11	23	19	20	0
600	0	0	0	0	0	0

Mean all	11
Mean inner	21
Max in diagram	30
Max measured	30

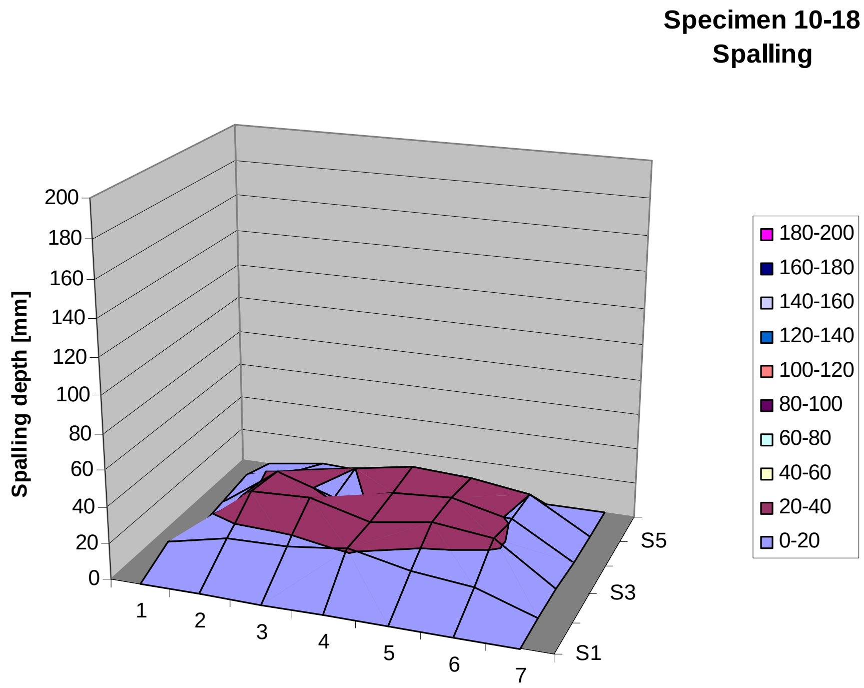


Figure A.136 Spalling measurements on specimen 10-18.

Table A.72 Observations made on specimen 10-18.

Time	Observation			
0,00	Start of test	Test date:	2005-10-05	
14,77	One explosion	Specimen:	10-18	
16,30	One explosion	Load level:	124	kN/bar
16,87	One explosion			
18,38	Two loud explosions			
19,83	One small explosion			
20,82	One small explosion			
22,42	One small explosion			
23,15	One loud explosion			
26,07	One explosion			
47,00	Moisture on front side			
60,00	Test terminated			

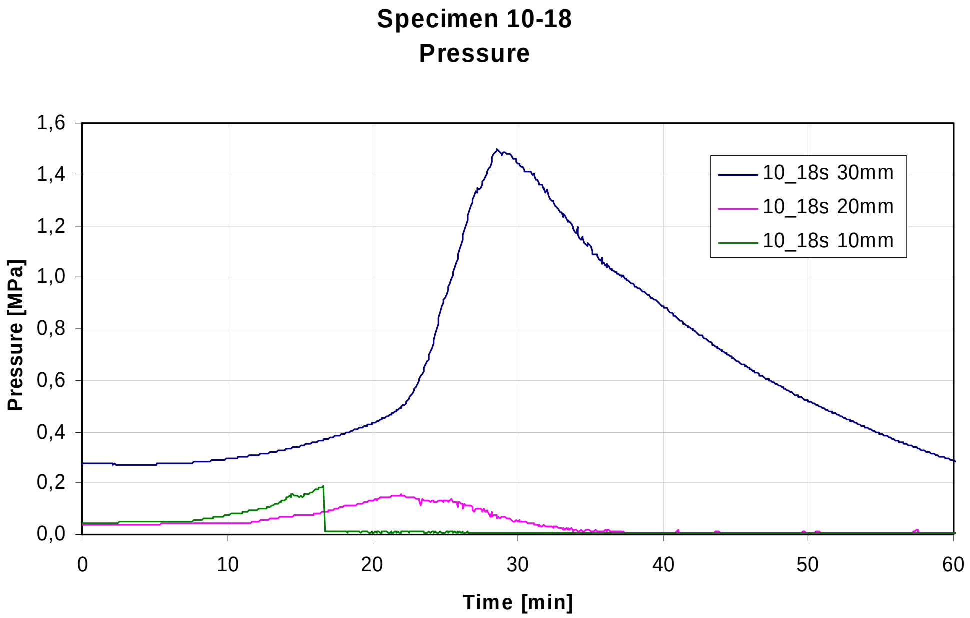


Figure A.137 Vapour pressure in specimen 10-18.

Figure A.138 Specimen 10-18 after test.

Specimen 10-21

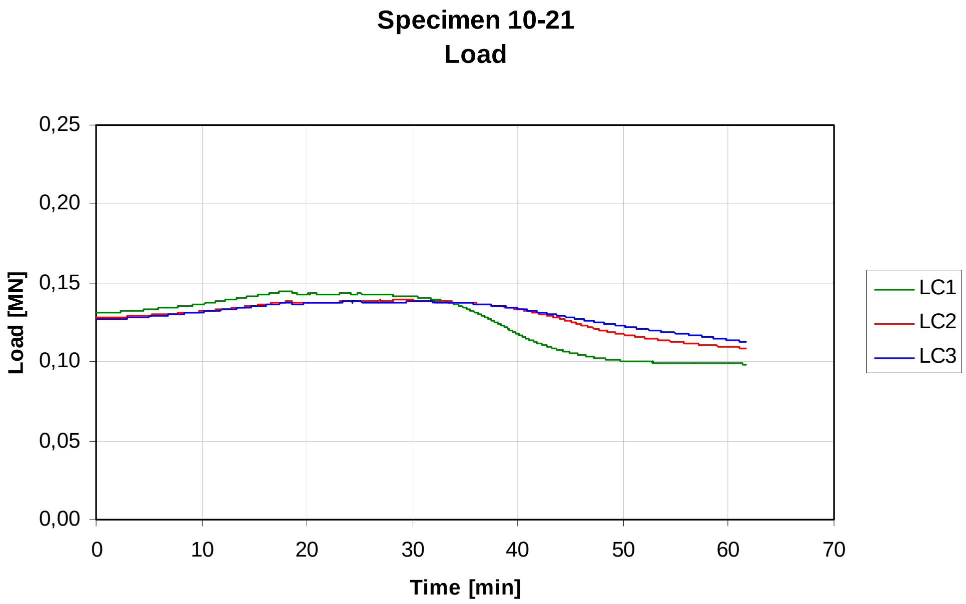


Figure A.139 Load measurements on specimen 10-21.

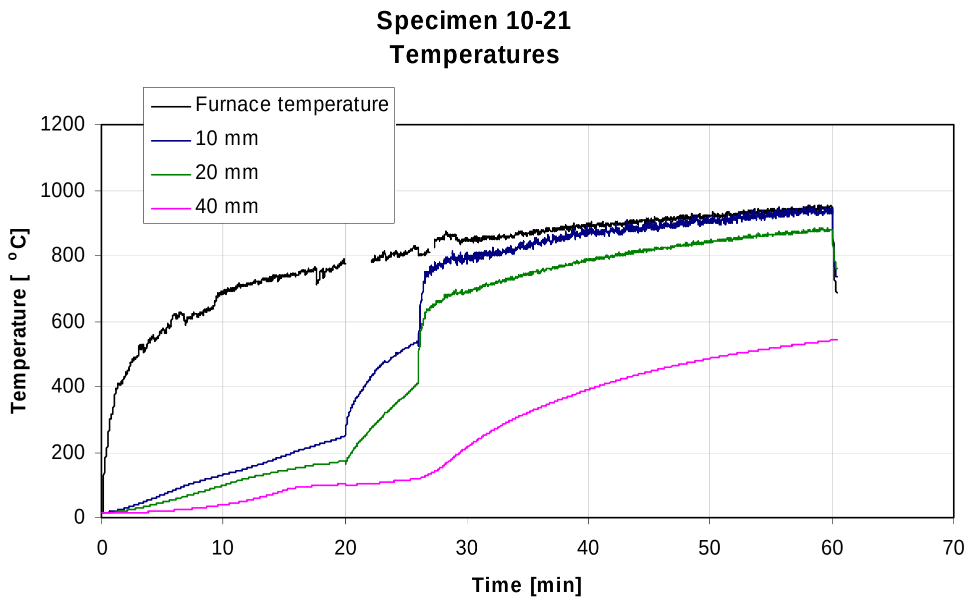


Figure A.140 Measured temperatures in furnace and in specimen 10-21.

Table A.73 Spalling measurements on specimen 10-21.

Position	0	100	200	300	400	500
0	4	5	4	0	0	0
100	8	16	23	18	0	0
200	15	27	31	18	0	0
300	5	18	34	27	12	0
400	6	12	37	23	15	0
500	0	3	23	32	14	0
600	0	0	2	0	1	0

Mean all	10
Mean inner	19
Max in diagram	37
Max measured	38

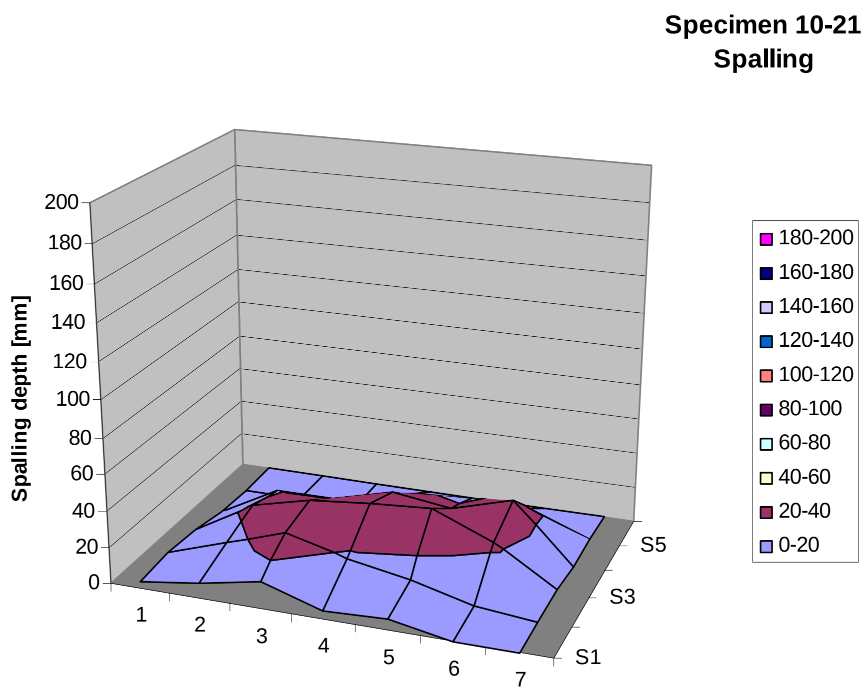


Figure A.141 Spalling measurements on specimen 10-21.

Table A.74 Observations made on specimen 10-21.

Time	Observation			
0,00	Start of test	Test date:	2005-12-29	
17,67	One loud explosion	Specimen:	10-21	
18,22	One loud explosion	Load level:	129	kN/bar
18,73	Two small explosions	Weight loss:	10,0	kg
18,97	One small explosion			
19,30	One small explosion			
19,45	One small explosion			
19,98	One small explosion			
20,00	One loud explosion			
21,67	TC in furnace breaks and changed			
23,33	One small explosion			
24,28	One loud explosion			
24,77	One small explosion			
26,08	One explosion			
37,33	Some water on front and back side, at lower corners			
60,00	Test terminates			

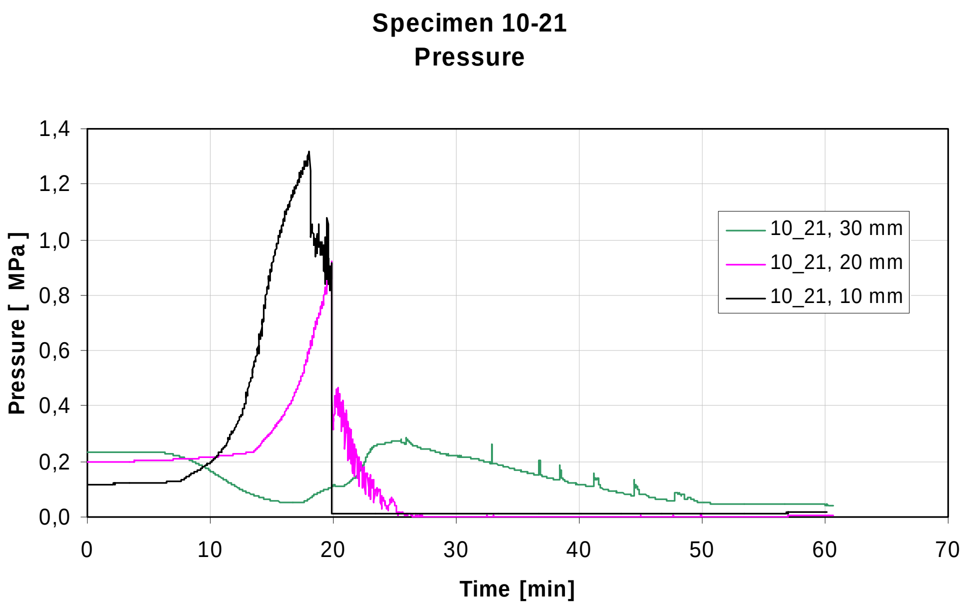


Figure A.142 Vapour pressure in specimen 10-21.

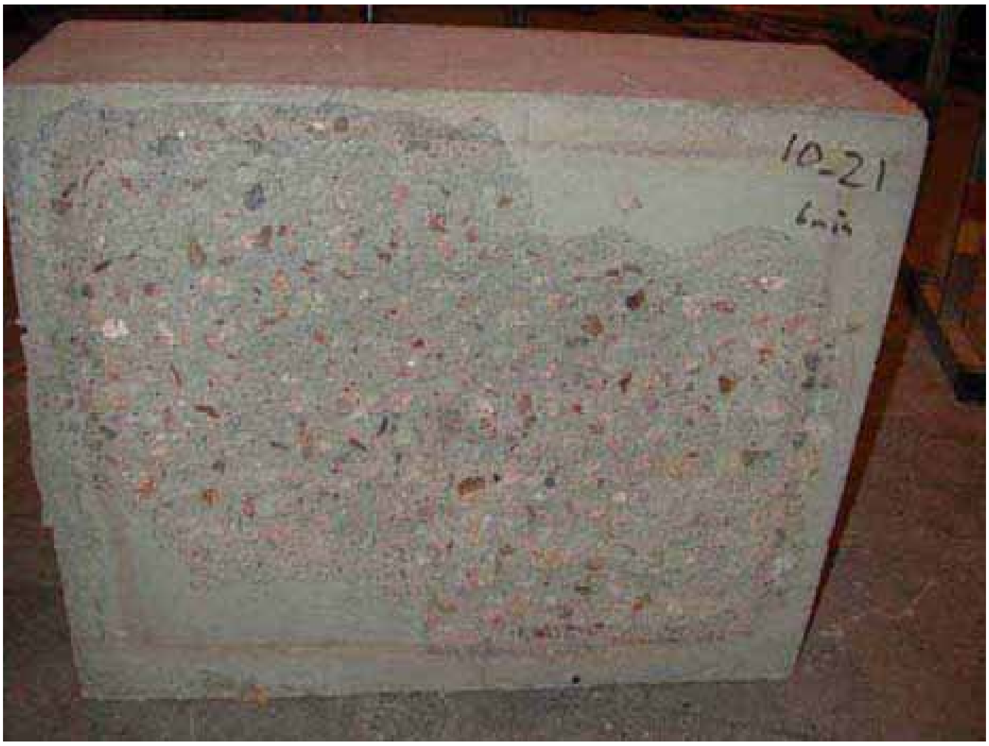


Figure A.143 Specimen 10-21 after test.

Specimen 10-22

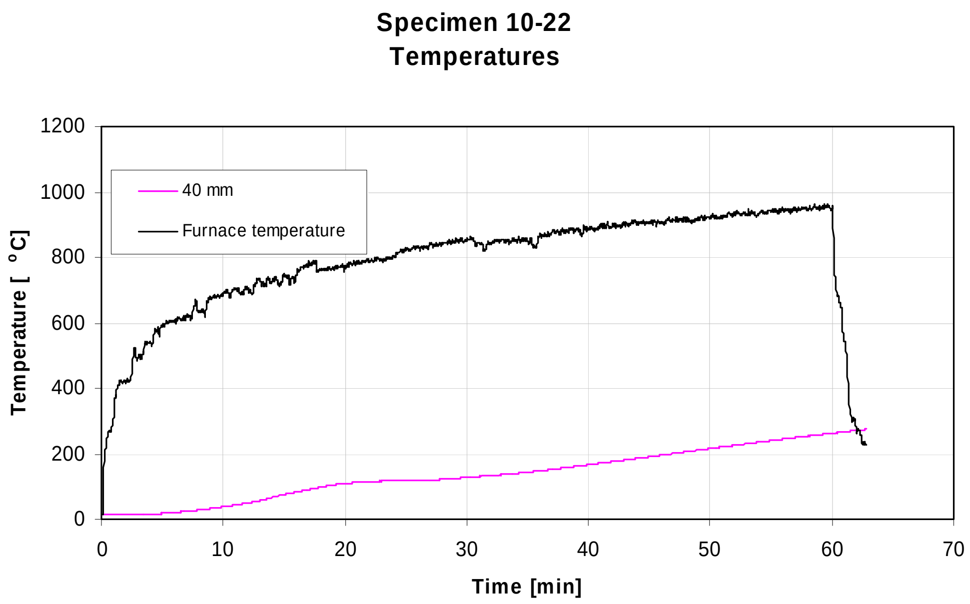


Figure A.144 Measured temperature in furnace and in specimen 10-22.

Table A.75 Spalling measurements on specimen 10-22

Position	0	100	200	300	400	500
0	0	3	6	1	0	0
100	1	20	17	12	0	0
200	0	4	5	9	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	2
Mean inner	3
Max in diagram	20
Max measured	24

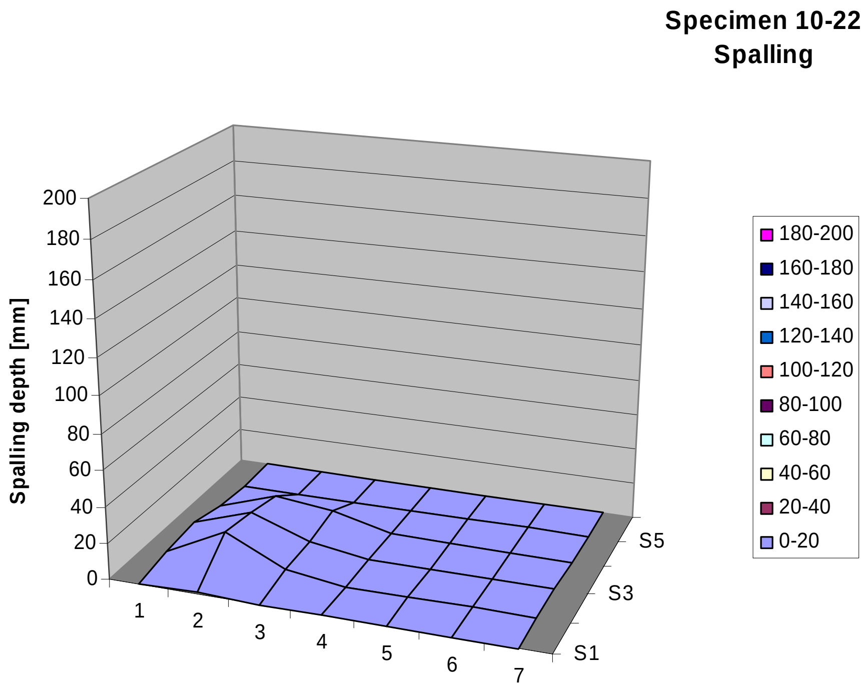


Figure A.145 Spalling measurements on specimen 10-22.

Table A.76 Observations made on specimen 10-22.

Time	Observation
0,00	Start of test
15,40	One loud explosion
17,62	One small explosion
19,50	Vertical crack on both front and back side
22,00	Water at pipes
24,83	Water on front and back sides
60,00	Test terminates

Test date:	2005-12-27	
Specimen:	10-22	
Load level:	0	kN/bar
Weight loss:	7,4	kg

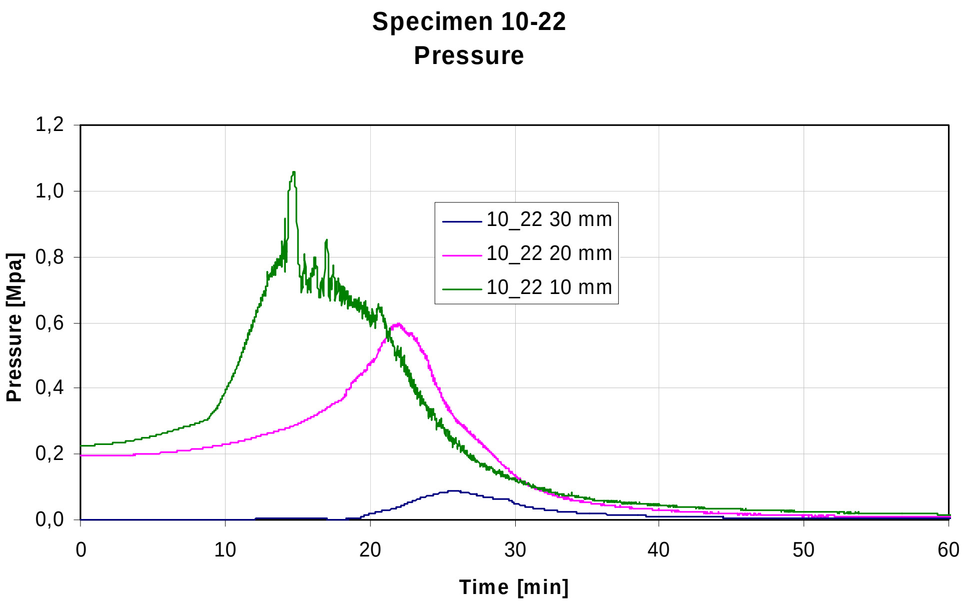


Figure A.146 Vapour pressure in specimen 10-22.

Figure A.147 Specimen 10-22 after test.

Specimen 10-23

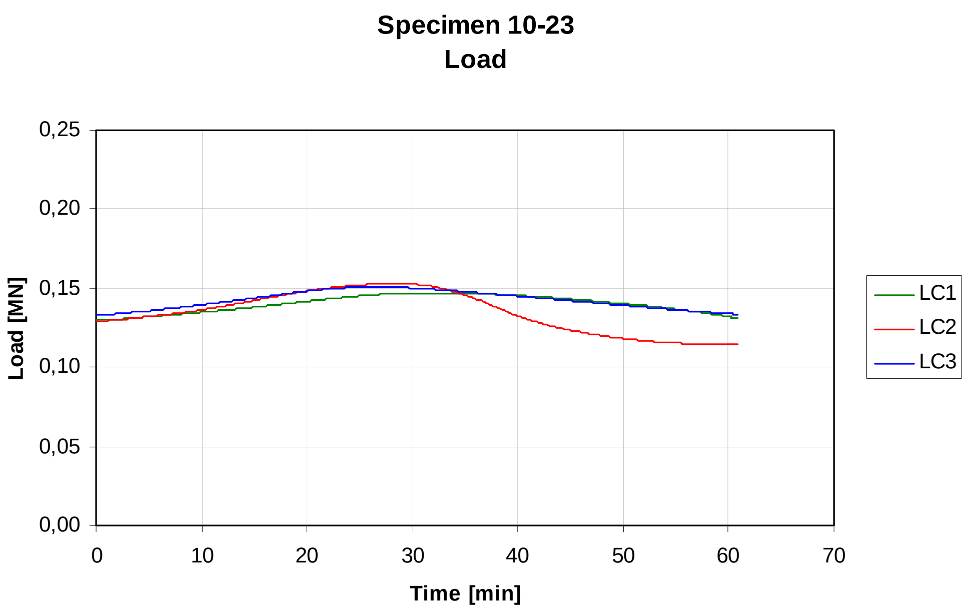


Figure A.148 Load measurements on specimen 10-23.

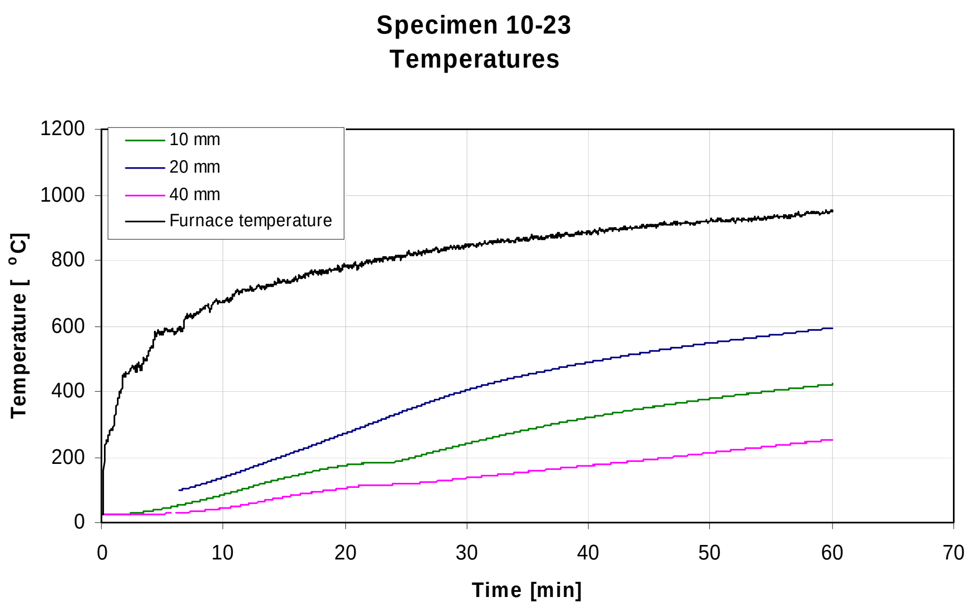


Figure A.149 Measured temperature in furnace and in specimen 10-23.

Table A.77 Spalling measurements on specimen 10-23

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

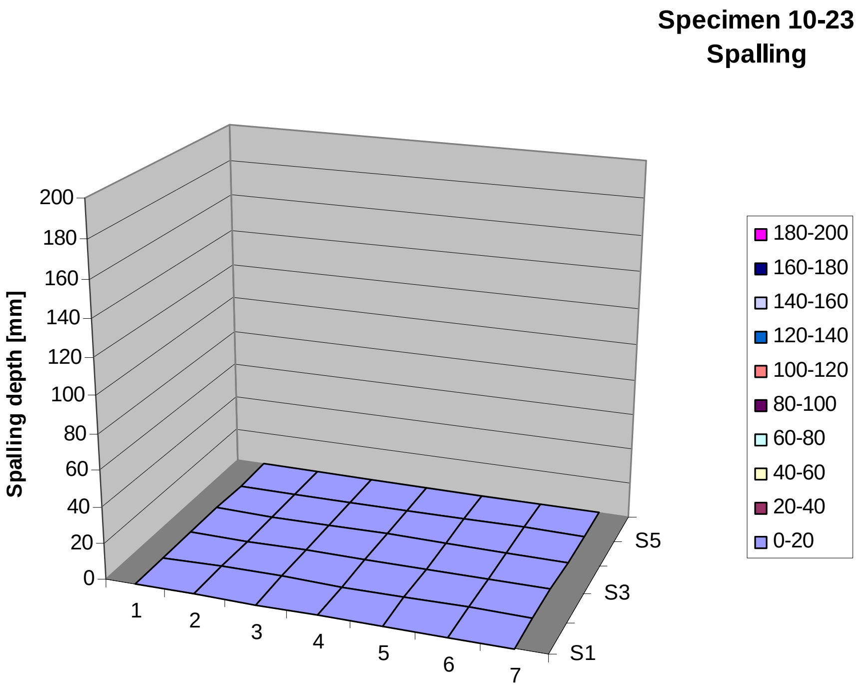


Figure A.150 Spalling measurements on specimen 10-23.

Table A.78 Observations made on specimen 10-23.

Time	Observation			
0,00	Start of test	Test date:	2006-07-05	
60,00	Test terminates	Specimen:	10-23	
		Load level:	131	kN/bar
		Weight loss:	2,2	kg

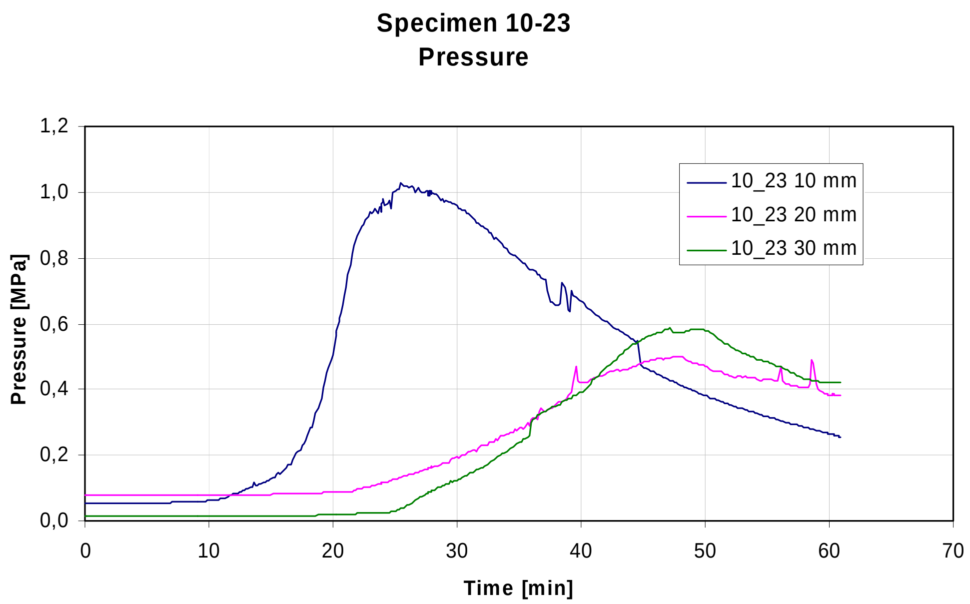


Figure A.151 Vapour pressure in specimen 10-23.

Figure A.152 Specimen 10-23 after test.

Specimen 10-24

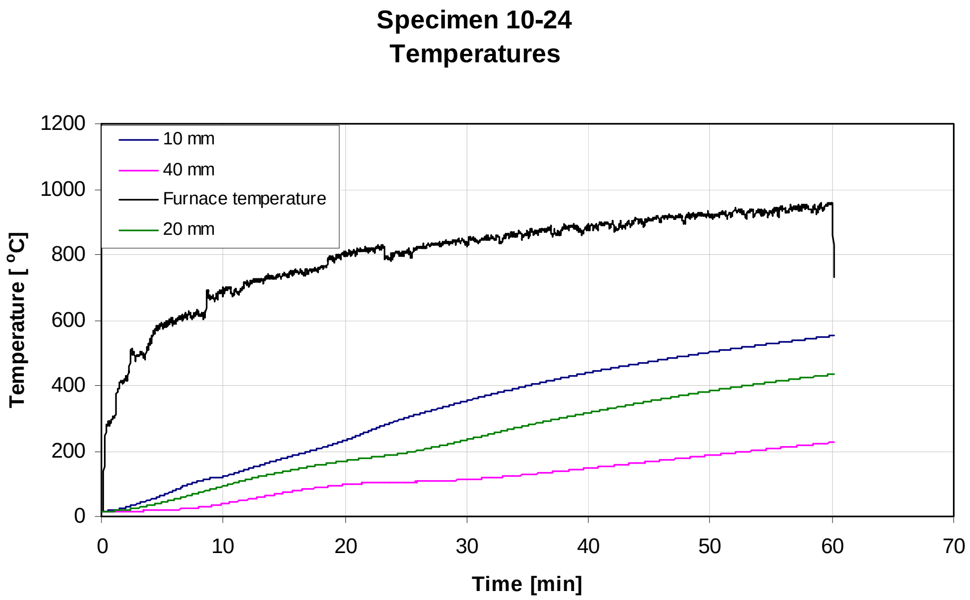


Figure A.153 Measured temperatures in furnace and in specimen 10-24.

Table A.79 Spalling measurements on specimen 10-24.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

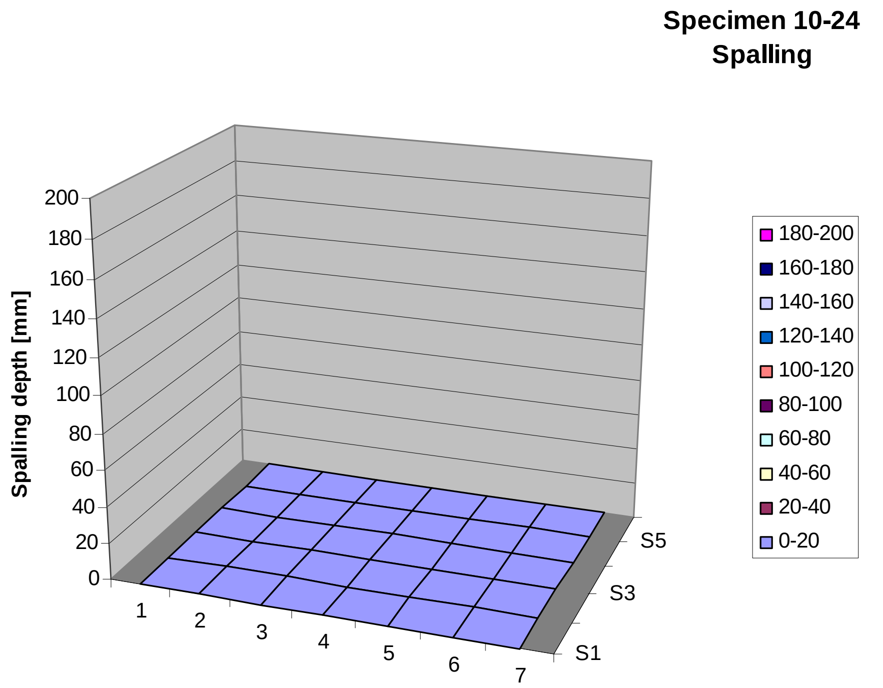


Figure A.154 Spalling measurements on specimen 10-24.

Table A.80 Observations made on specimen 10-24.

Time	Observation			
0,00	Start of test	Test date:	2005-12-28	
20,00	Water on back side, crack on front side	Specimen:	10-24	
24,33	Water on front side	Load level:	0	kN/bar
60,00	Test terminates	Weight loss:	6,0	kg

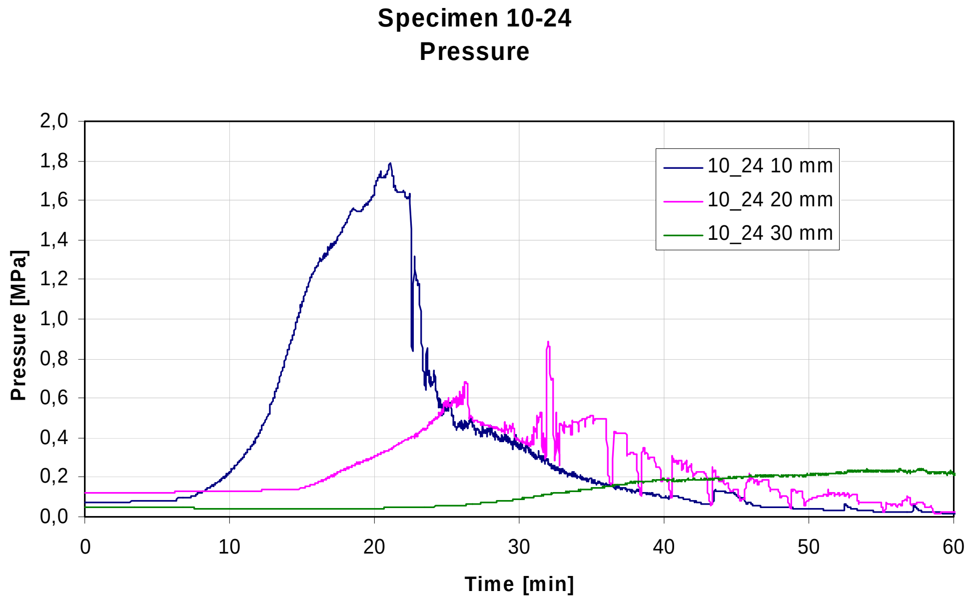


Figure A.155 Vapour pressure in specimen 10-24.

Figure A.156 Specimen 10-24 after test.

Specimen 10-25

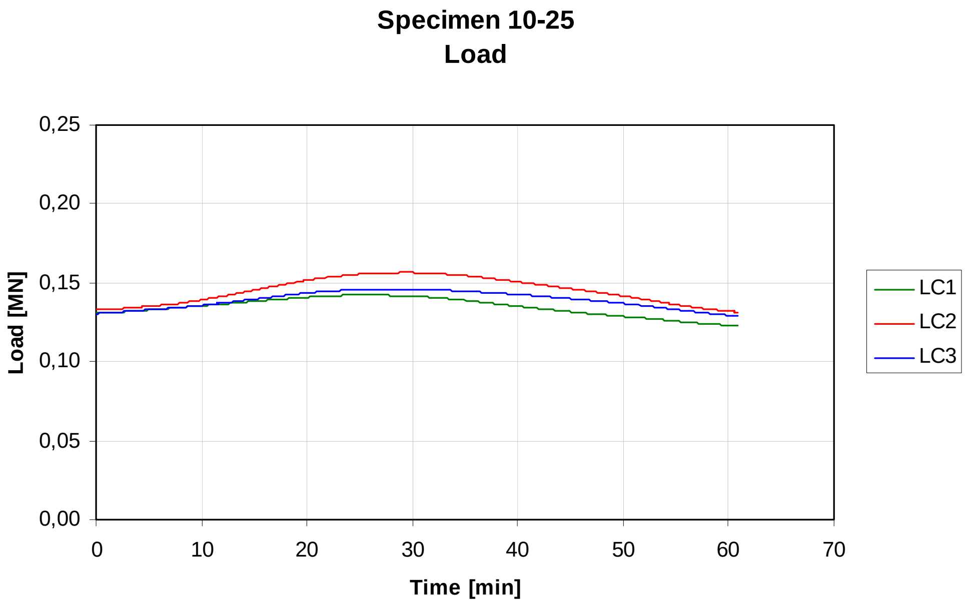


Figure A.157 Load measurements on specimen 10-25.

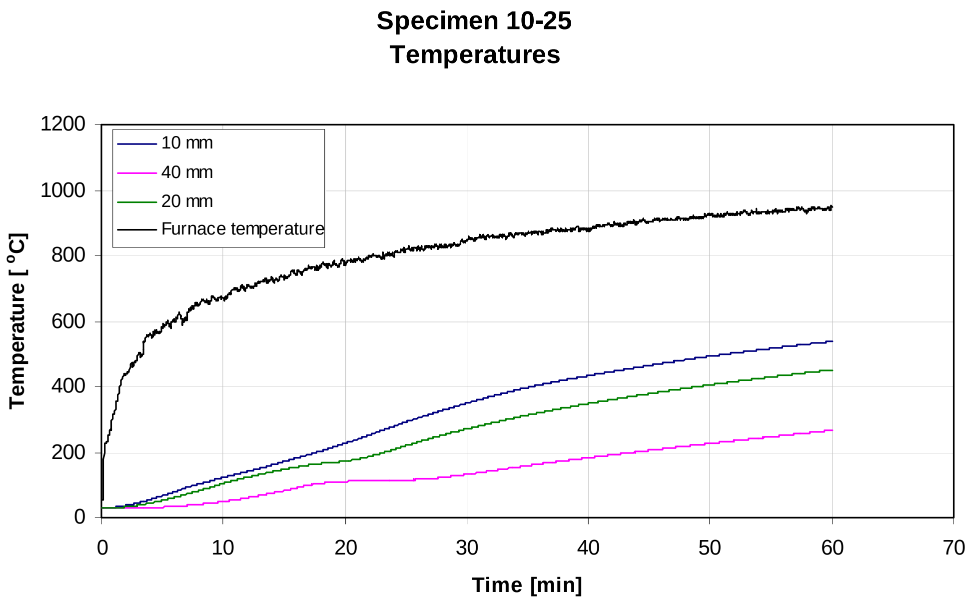


Figure A.158 Measured temperatures in furnace and in specimen 10-25.

Table A.81 Spalling measurements on specimen 10-25.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

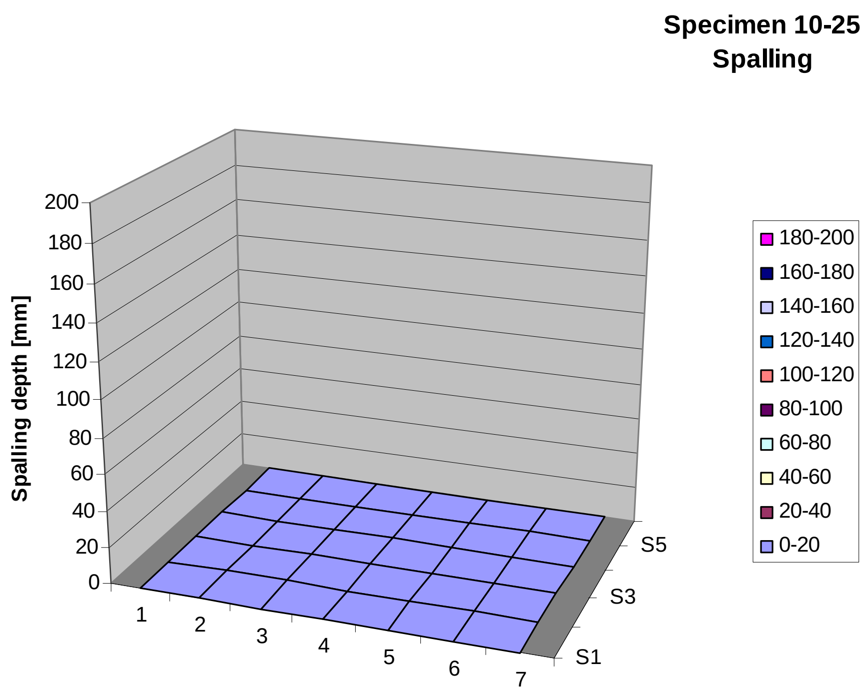


Figure A.159 Spalling measurements on specimen 10-25.

Table A.82 Observations made on specimen 10-25.

Time	Observation			
0,00	Start of test	Test date:	2006-07-05	
60,00	Test terminates	Specimen:	10-25	
		Load level:	132	kN/bar
		Weight loss:	1,9	kg

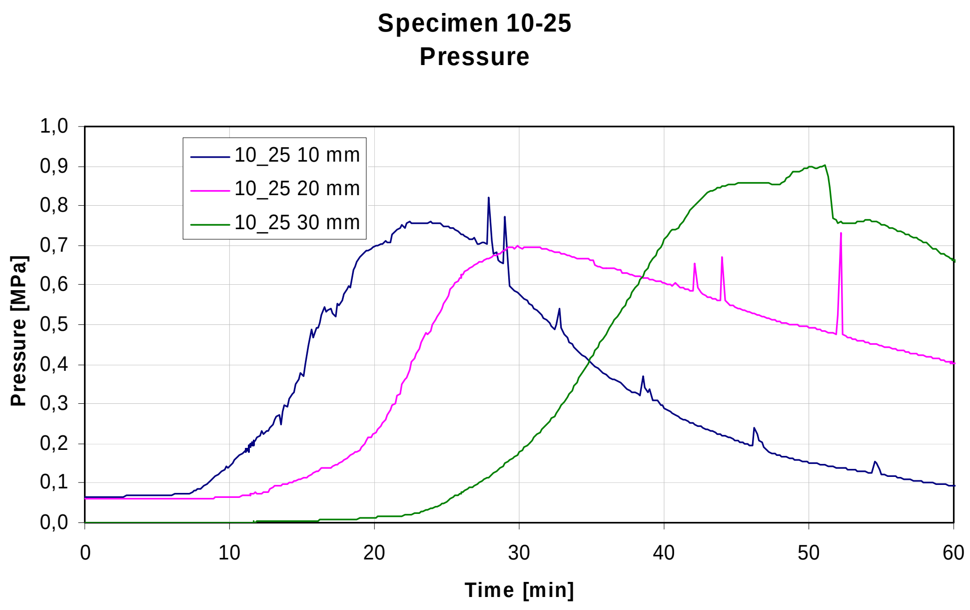


Figure A.160 Vapour pressure in specimen 10-25.

Figure A.161 Specimen 10-25 after test.

Specimen 10-26

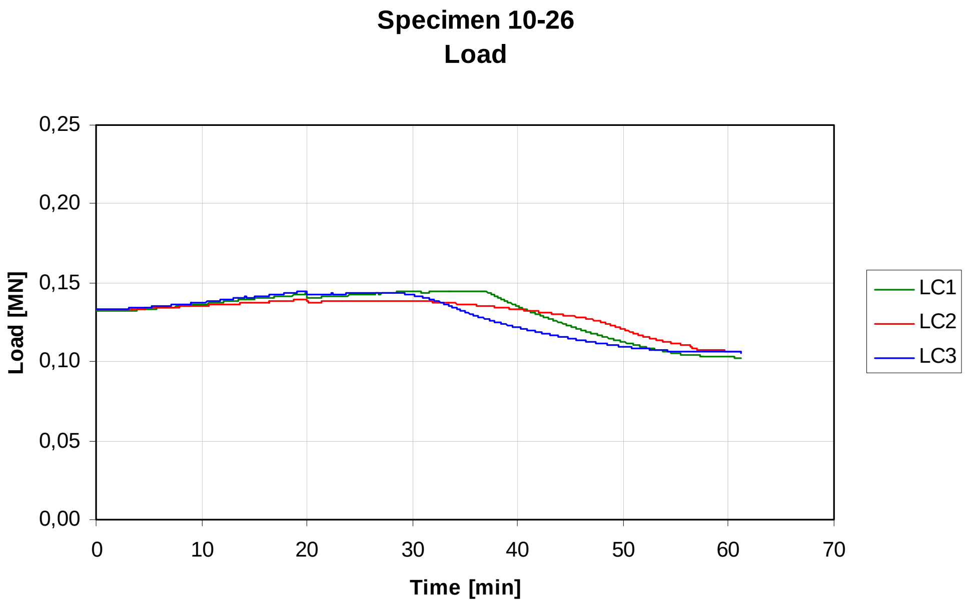


Figure A.162 Load measurements on specimen 10-26.

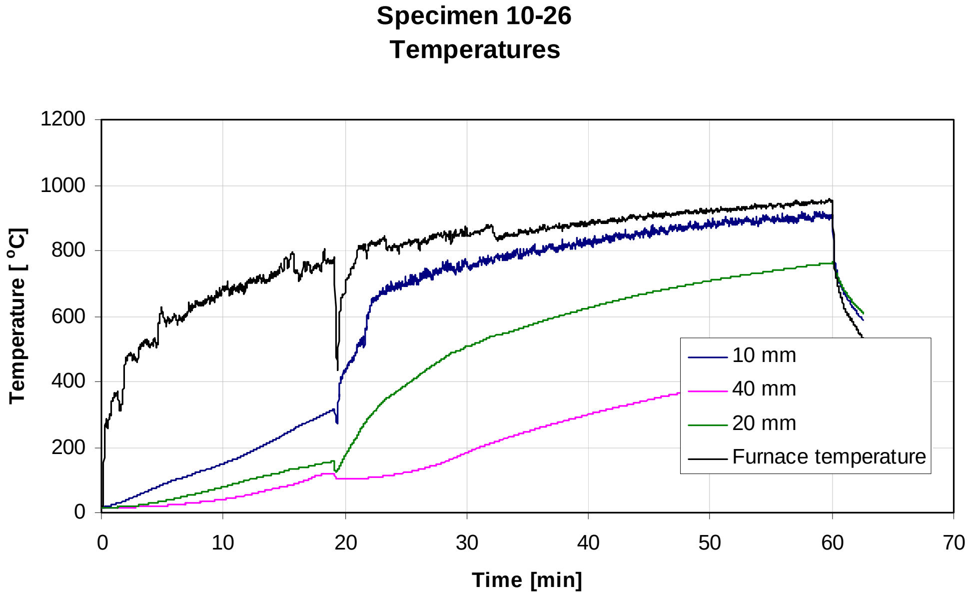


Figure A.163 Measured temperatures in furnace and in specimen 10-26.

Table A.83 Spalling measurements on specimen 10-26.

Position	0	100	200	300	400	500
0	0	5	1	0	4	0
100	25	24	28	13	15	0
200	29	18	19	22	13	0
300	27	23	13	23	16	0
400	34	27	25	20	16	0
500	19	27	18	15	9	0
600	0	5	4	6	3	0

Mean all	13
Mean inner	19
Max in diagram	34
Max measured	43

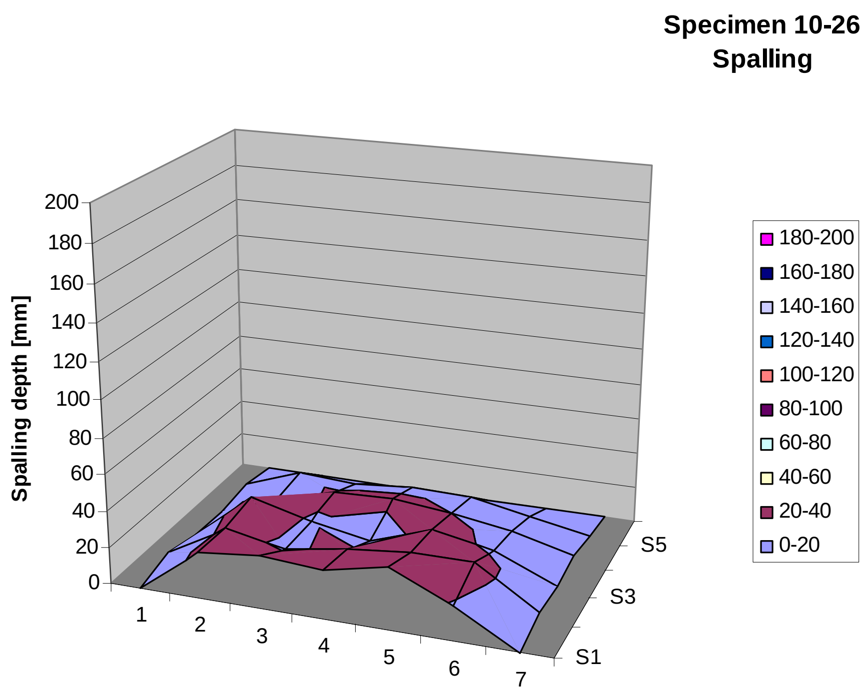


Figure A.164 Spalling measurements on specimen 10-26.

Table A.84 Observations made on specimen 10-26.

Time	Observation
0,00	Start of test
13,37	One loud explosion
14,23	Some small explosions
14,82	One explosion
16,33	One explosion
16,92	One small explosion
17,53	One small explosion
18,50	One small explosion
19,50	One very loud explosion, blow out burner
21,10	Horizontal cracks on front side
21,57	One small explosion
21,77	Two explosions
22,18	One small explosion
22,32	One explosion
22,45	One small explosion
23,75	One small explosion
24,30	One explosion
25,15	One small explosion
25,95	One small explosion
28,75	One small explosion
29,20	One small explosion
30,15	One explosion
31,72	One very small explosion
32,38	One explosion
60,00	Test terminates

Test date:	2005-12-30	
Specimen:	10-26	
Load level:	133	kN/bar
Weight loss:	11,9	kg

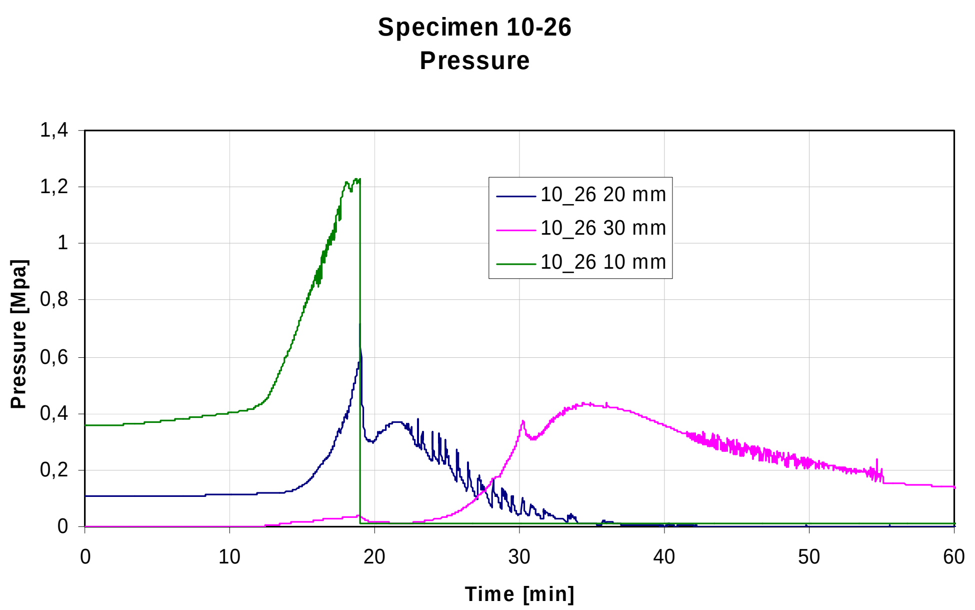


Figure A.165 Vapour pressure in specimen 10-26.

Figure A.166 Specimen 10-26 after test

Concrete 11

Table A.85 Concrete admixture recipe 11.

Recipe	**11**
Water (kg/m^3)	236
CEM II 42,5R A-LL (kg/m^3)	365
Limestone filler, Limus 25 (kg/m^3)	109
Water-powder ratio, w/p	0,50
Water-cement ratio, w/c	0,65
Sikament 20HE 50 (20% torrhalt)	4,93
Sikament 20HE 50 (% of cement weight)	1,35
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	0,50
Gravel 0 – 8 mm (%)	65
Partly crushed 8 – 16 mm (%)	35
Slump flow (mm)	650
T50 (s)	2
Air (%)	1.9
Compressive strength, 28 days (MPa)	40.3

Specimen 11-5

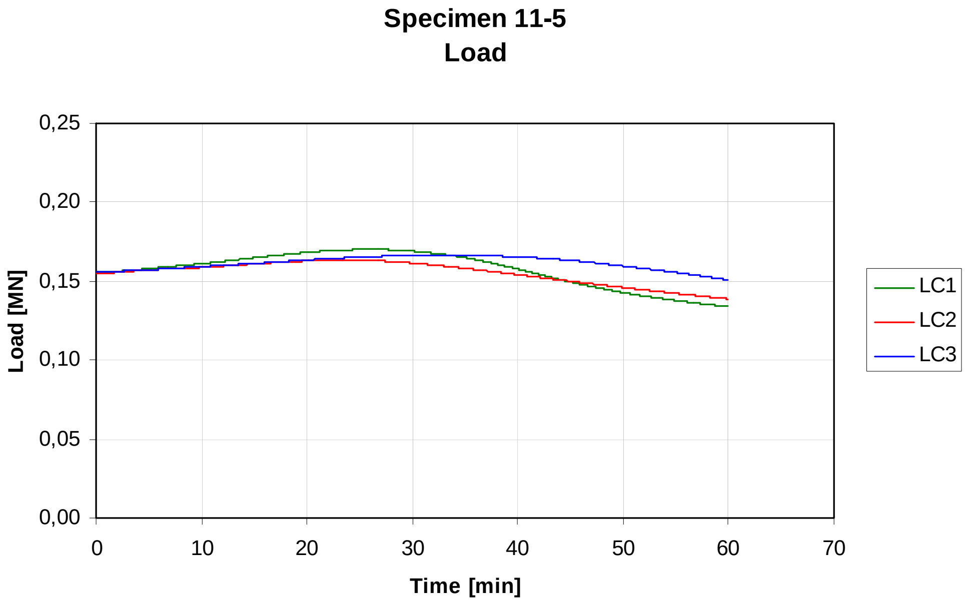


Figure A.167 Load measurements on specimen 11-5.

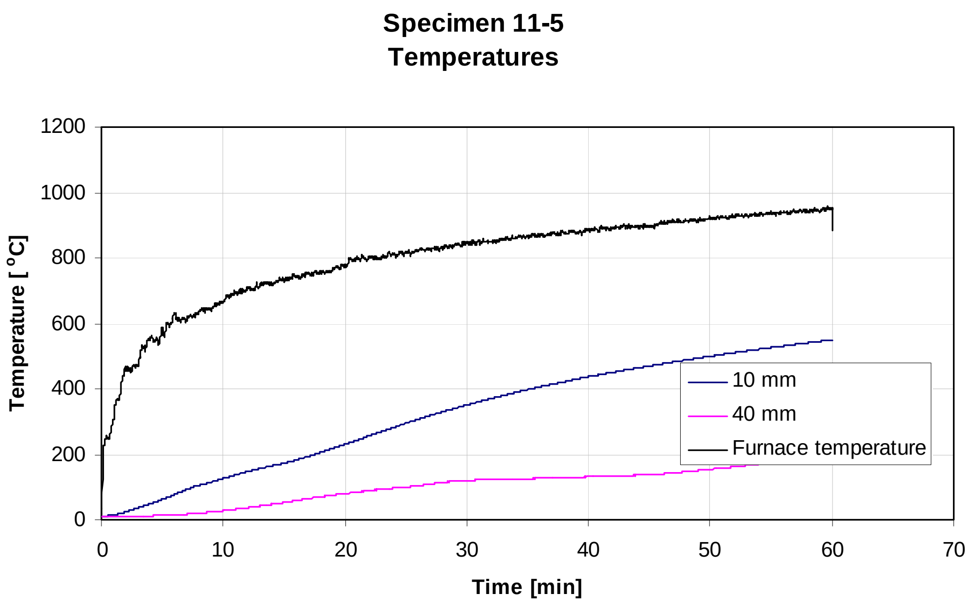


Figure A.168 Measured temperatures in furnace and in specimen 11-5.

Table A.86 Spalling measurements on specimen 11-5.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0

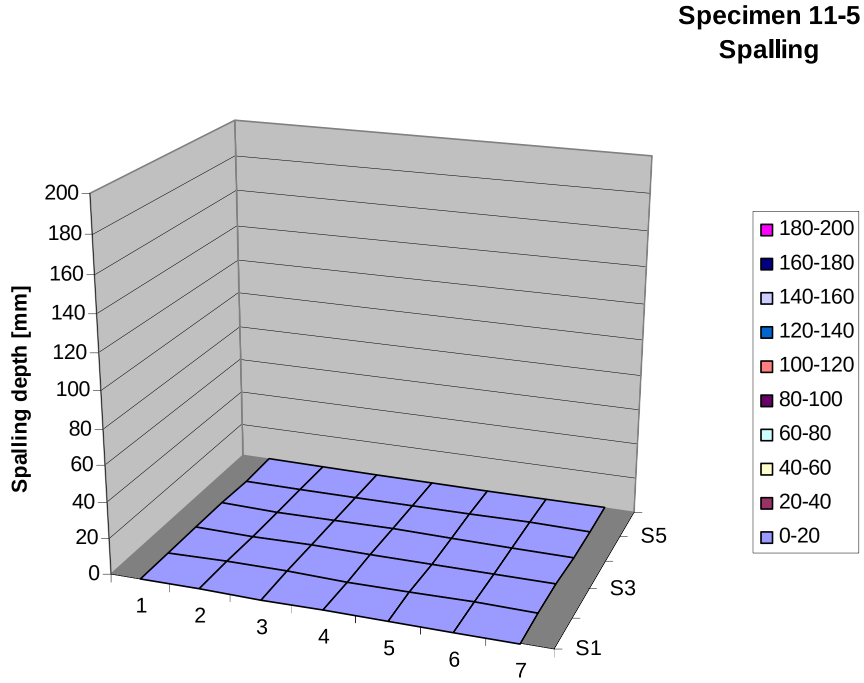


Figure A.169 Spalling measurements on specimen 11-5.

Table A.87 Observations made on specimen 11-5.

Time	Observation			
		Test date:	2006-03-10	
0,00	Start of test	Specimen:	11-5	
34,00	Water on back side	Load level:	155	kN/bar
60,00	Test terminates	Weight loss:	1,8	kg

Figure A.170 Specimen 11-5 after test.

Specimen 11-7

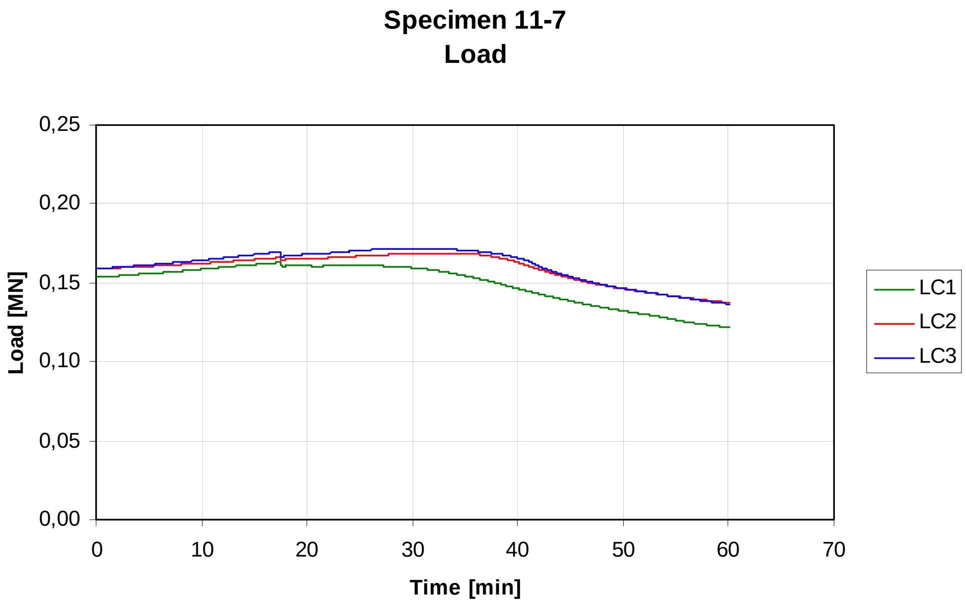


Figure A.171 Load measurements on specimen 11-7.

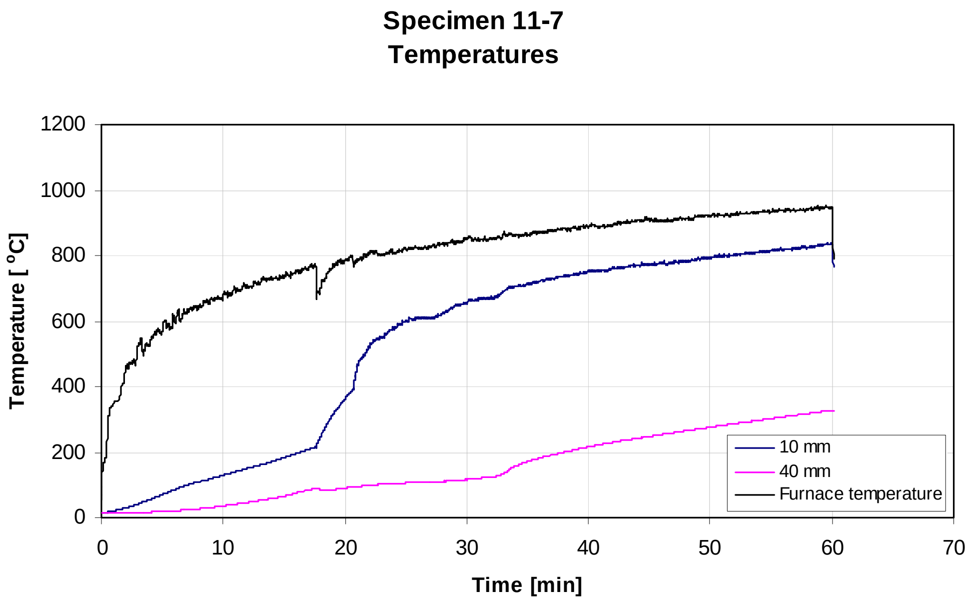


Figure A.172 Measured temperatures in furnace and in specimen 11-7.

Table A.88 Spalling measurements on specimen 11-7.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	2	12	4	0	0	0
200	3	9	12	11	3	0
300	4	15	13	18	17	0
400	7	14	26	21	19	2
500	2	19	28	21	15	2
600	1	5	1	1	2	0

Mean all	7
Mean inner	14
Max in diagram	28
Max measured	33

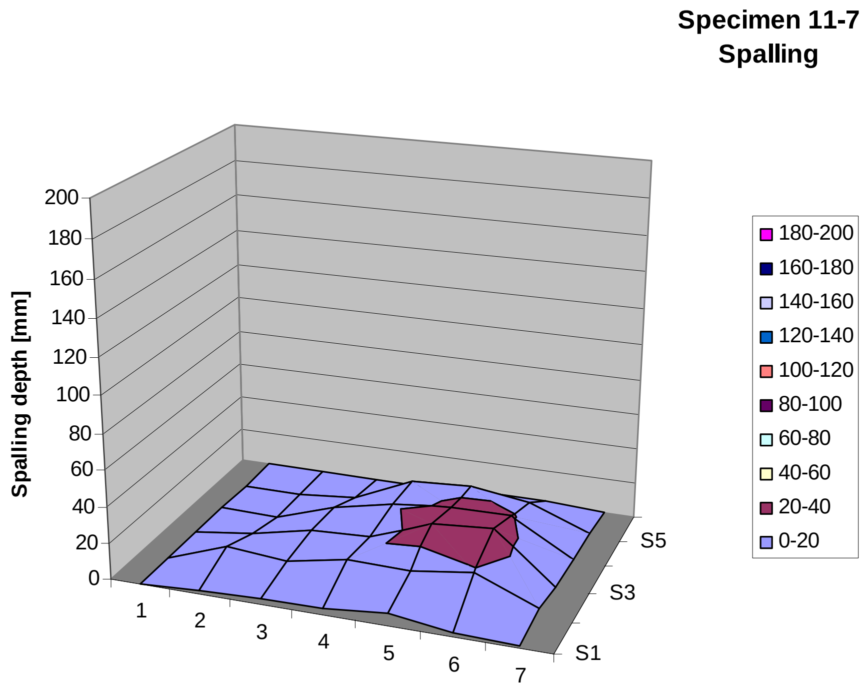


Figure A.173 Spalling measurements on specimen 11-7.

Table A.89 Observations made on specimen 11-7.

Time	Observation
0,00	Start of test
17,67	One loud explosion
19,22	One small explosion
19,88	One small explosion
20,67	One explosion
20,93	One small explosion
21,33	One small explosion
36,00	Water on top face, small cracks on back side
60,00	Test terminates

Test date:	2006-03-11	
Specimen:	11-7	
Load level:	157	kN/bar
Weight loss:	8,0	kg

Figure A.174 Specimen 11-7 after test.

Concrete 12

Table A.90 Concrete admixture recipe 12.

Recipe	**12**
Water (kg/m^3)	212
CEM II 42,5R A-LL (kg/m^3)	300
Limestone filler, Limus 25 (kg/m^3)	87
Water-powder ratio, w/p	0,55
Water-cement ratio, w/c	0,71
Sikament 20HE 50 (20% torrhalt)	4,1
Sikament 20HE 50 (% of cement weight)	1,37
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	680
T50 (s)	1-2
Air (%)	2.3
Compressive strength, 28 days (MPa)	34.5

Specimen 12-1

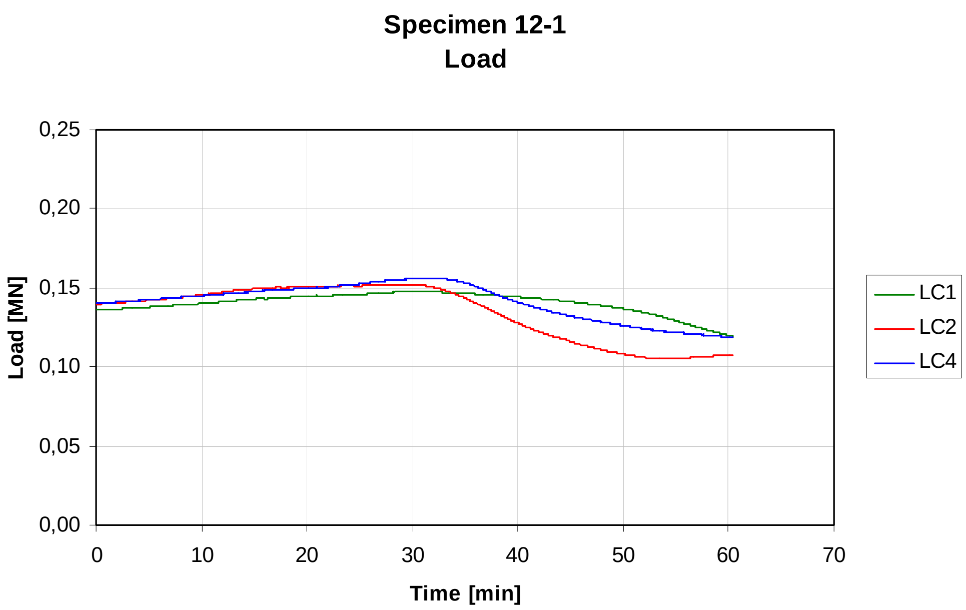


Figure A.175 Load measurements on specimen 12-1.

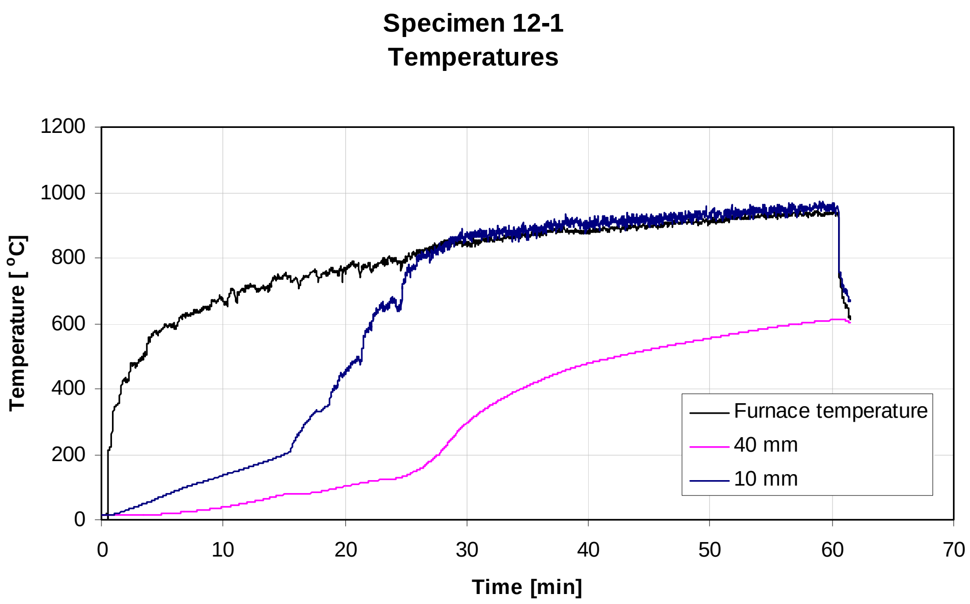


Figure A.176 Measured temperatures in furnace and in specimen 12-1.

Table A.91 Spalling measurements on specimen 12-1.

Position	0	100	200	300	400	500
0	0	3	3	0	1	1
100	1	22	26	20	20	1
200	3	22	29	30	23	1
300	1	28	36	30	22	2
400	2	24	34	28	19	2
500	1	20	23	20	12	1
600	1	0	1	2	3	0

Mean all	12
Mean inner	24
Max in diagram	36
Max measured	43

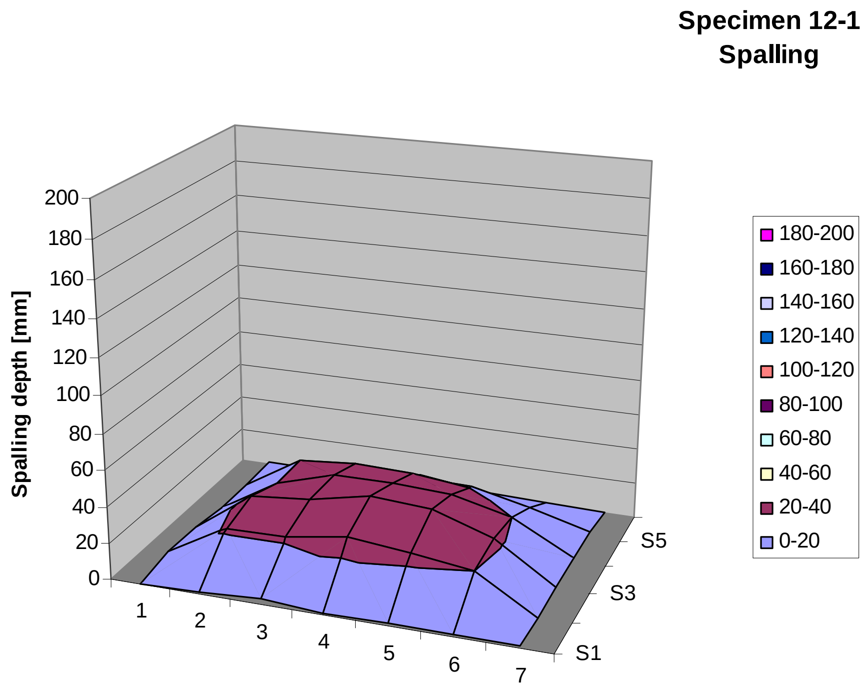


Figure A.177 Spalling measurements on specimen 12-1.

Table A.92 Observations made on specimen 12-1

Time	Observation			
0,00	Start of test	Test date:	2006-03-07	
10,00	One small explosion	Specimen:	12-1	
10,95	One explosion	Load level:	139	kN/bar
12,70	One small explosion	Weight loss:	11,1	kg
13,67	One explosion			
14,17	One small explosion			
14,30	One small explosion			
14,65	One small explosion			
15,17	One small explosion			
15,52	One explosion			
16,12	Three fast explosion			
16,90	One explosion			
17,67	One explosion			
17,80	One small explosion			
18,45	One small explosion			
18,75	One small explosion			
19,28	One small explosion			
19,43	One small explosion			
19,68	One explosion			
20,00	One small explosion			
20,75	One small explosion			
21,17	One explosion			
22,08	One small explosion			
23,22	One small explosion			
24,17	One small explosion			
24,62	One explosion			
29,00	Water on top face and back side			
60,00	Test terminates			

Figure A.178 Specimen 12-1 after test.

Specimen 12-2

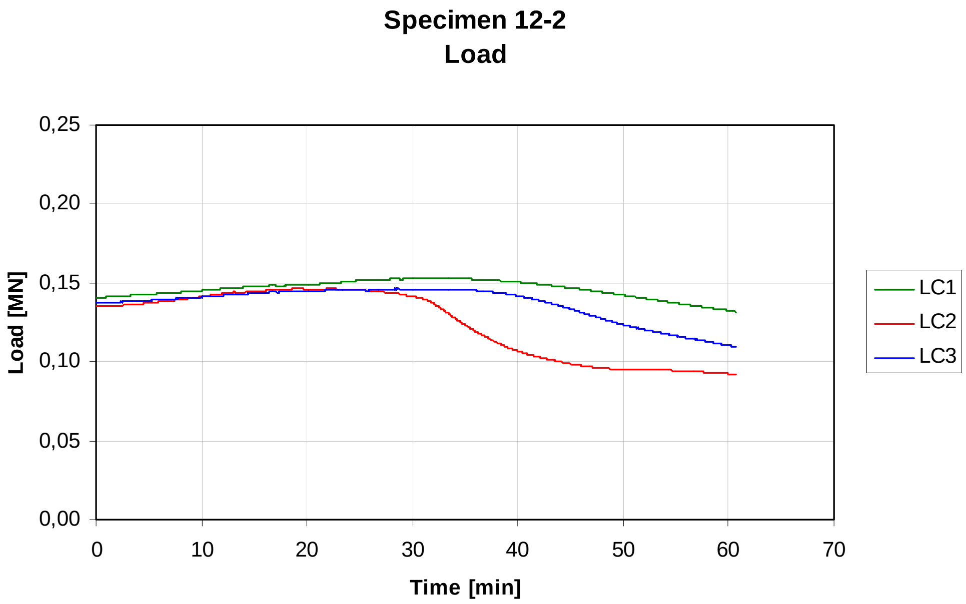


Figure A.179 Load measurements on specimen 12-2.

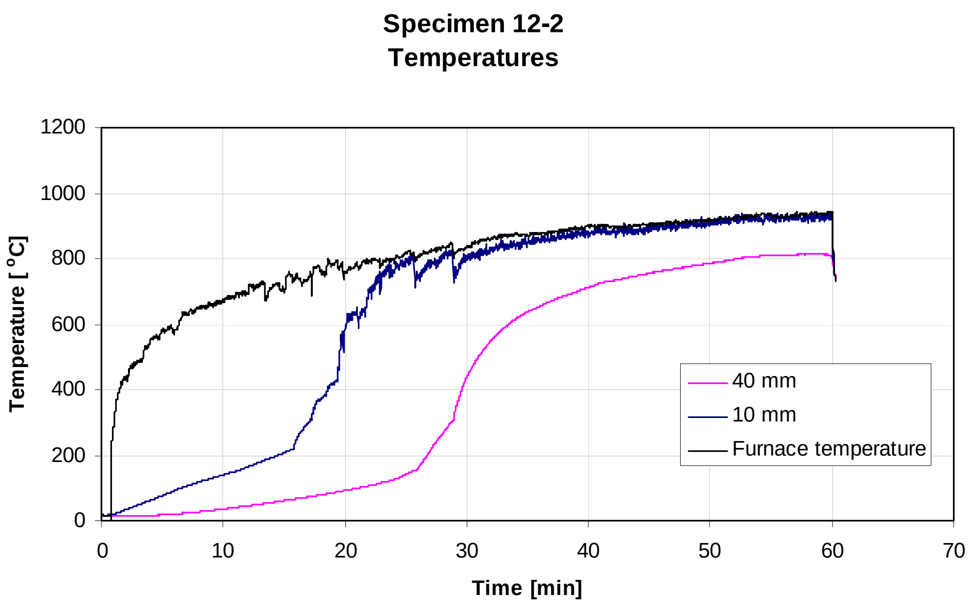


Figure A.180 Measured temperatures in furnace and in specimen 12-2.

Table A.93 Spalling measurements on specimen 12-2.

Position	0	100	200	300	400	500
0	0	5	2	0	0	0
100	0	11	29	37	30	1
200	0	10	39	37	29	1
300	0	15	44	41	27	0
400	0	23	39	45	25	0
500	0	20	21	36	20	2
600	0	2	0	3	0	2

Mean all	14
Mean inner	29
Max in diagram	45
Max measured	54

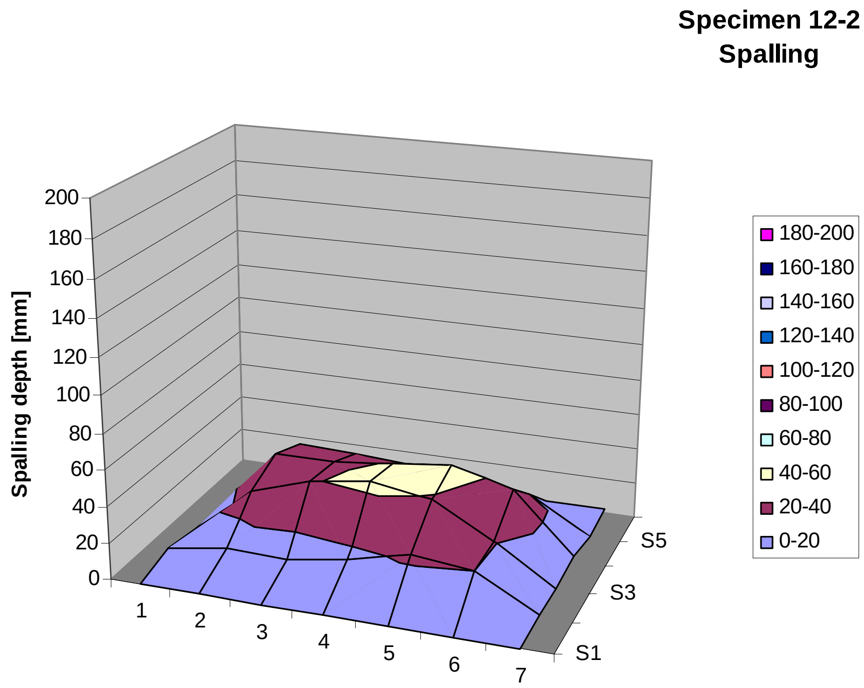


Figure A.181 Spalling measurements on specimen 12-2.

Table A.94 Observations made on specimen 12-2.

Time	Observation			
0,00	Start of test	Test date:	2006-03-08	
13,40	One loud explosion	Specimen:	12-2	
14,08	One small explosion	Load level:	138	kN/bar
14,13	One small explosion	Weight loss:	14,8	kg
14,42	One small explosion			
14,63	One small explosion			
14,90	One small explosion			
15,30	One small explosion			
15,40	One small explosion			
15,73	One explosion			
16,12	One small explosion			
16,82	One small explosion			
17,27	One loud explosion			
17,88	One small explosion			
18,03	One small explosion			
18,12	One small explosion			
18,47	One small explosion			
18,75	One small explosion			
18,87	One small explosion			
19,12	One small explosion			
19,42	One small explosion			
19,87	One loud explosion			
20,45	One small explosion			
21,03	Some small explosions			
21,62	Some small explosions			
22,15	One small explosion			
22,47	One small explosion			
22,73	One small explosion			
22,98	One explosion			
23,70	One small explosion			
24,25	One small explosion			
25,37	One small explosion			
25,73	One explosion			
27,50	One small explosion			
27,67	Water on top face and back side			
28,53	One small explosion			
28,97	One explosion			
60,00	Test terminates			

Figure A.182 Specimen 12-2 after test.

Specimen 12-3

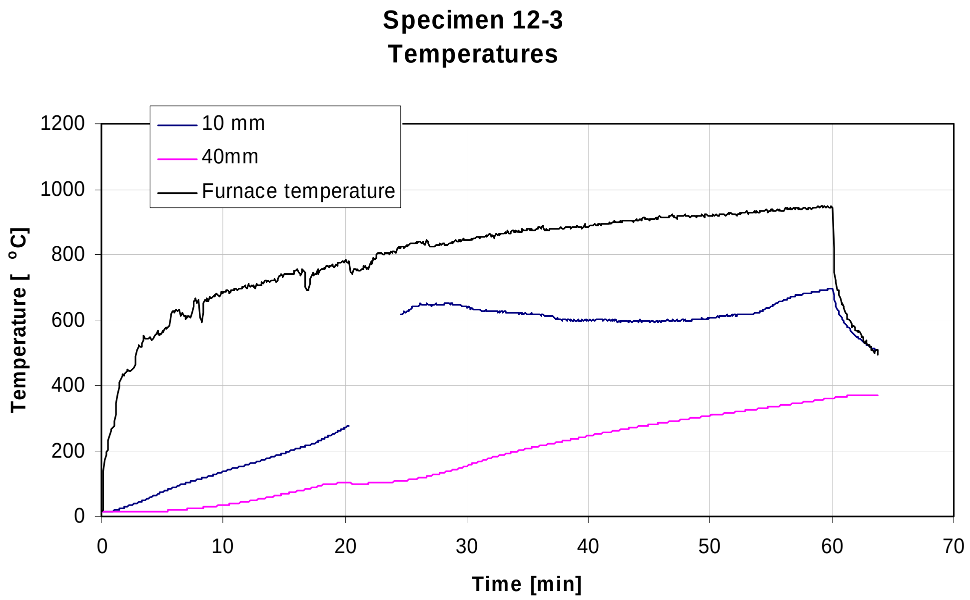


Figure A.183 Measured temperatures in furnace and in specimen 12-3.

Table A.95 Spalling measurements on specimen 12-3.

Position	0	100	200	300	400	500
0	0	7	2	5	5	0
100	0	18	15	15	17	1
200	0	3	21	13	6	0
300	0	9	14	2	7	0
400	2	15	13	19	23	1
500	3	11	13	21	26	2
600	1	0	0	1	2	2

Mean all	8
Mean inner	14
Max in diagram	26
Max measured	37

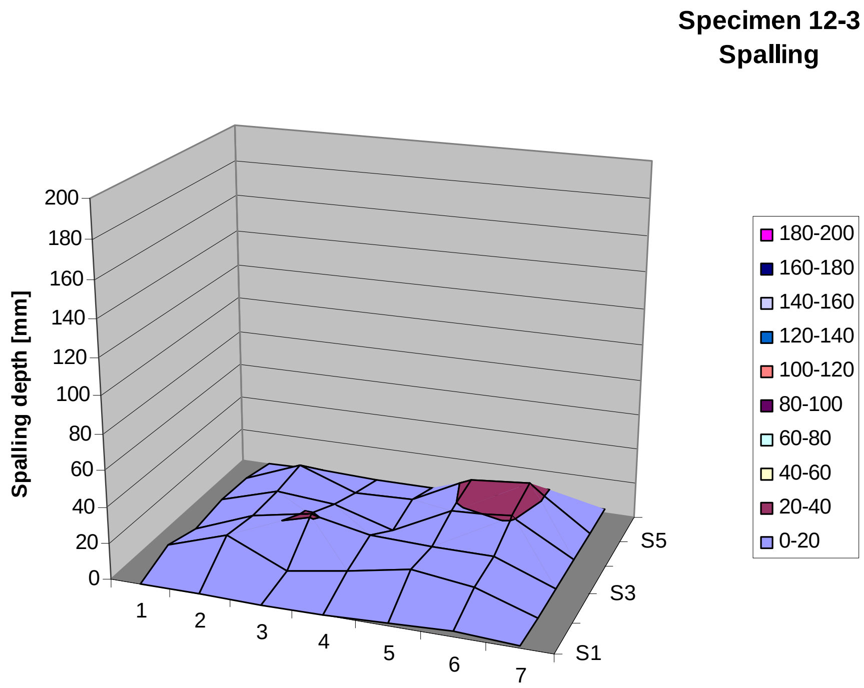


Figure A.184 Spalling measurements on specimen 12-3.

Table A.96 Observations made on specimen 12-3.

Time	Observation			
0,00	Start of test	Test date:	2006-03-03	
16,78	One very loud explosion	Specimen:	12-3	
17,17	Some small explosions	Load level:	0	kN/bar
17,42	One small explosion	Weight loss:	8,3	kg
17,83	One small explosion			
17,88	One small explosion			
18,73	One small explosion			
19,50	One explosion			
20,18	One small explosion			
20,45	One loud explosion			
21,28	One small explosion			
21,80	One small explosion			
23,07	One small explosion			
24,47	One small explosion			
29,17	Water on all sides and the top face			
60,00	Test terminates			

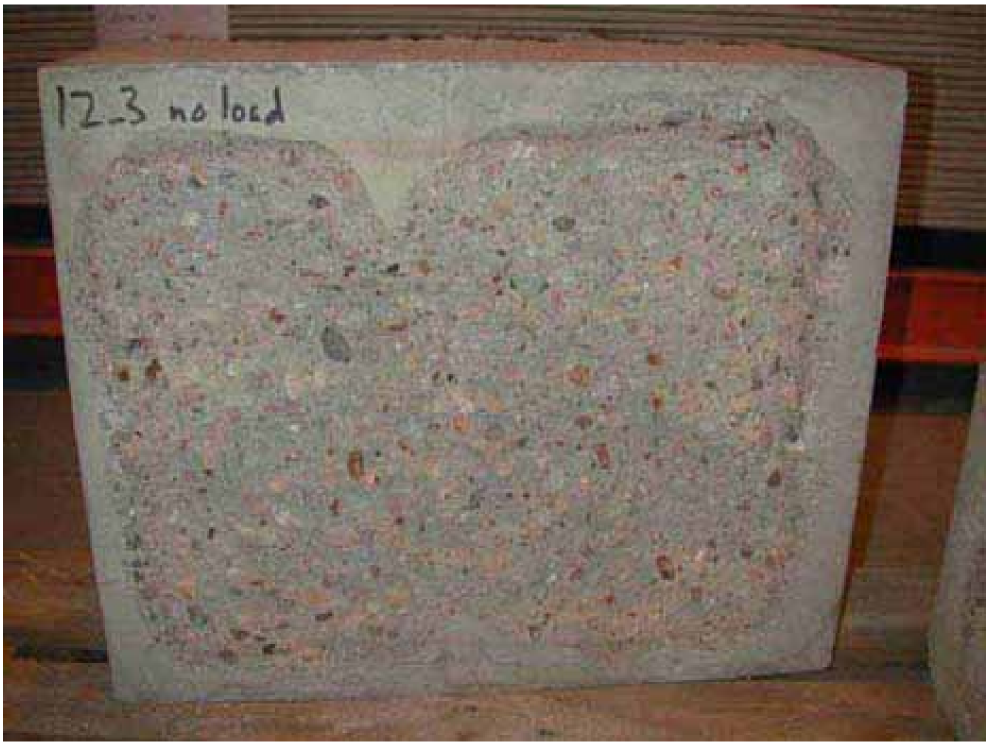


Figure A.185 Specimen 12-3 after test .

Specimen 12-8

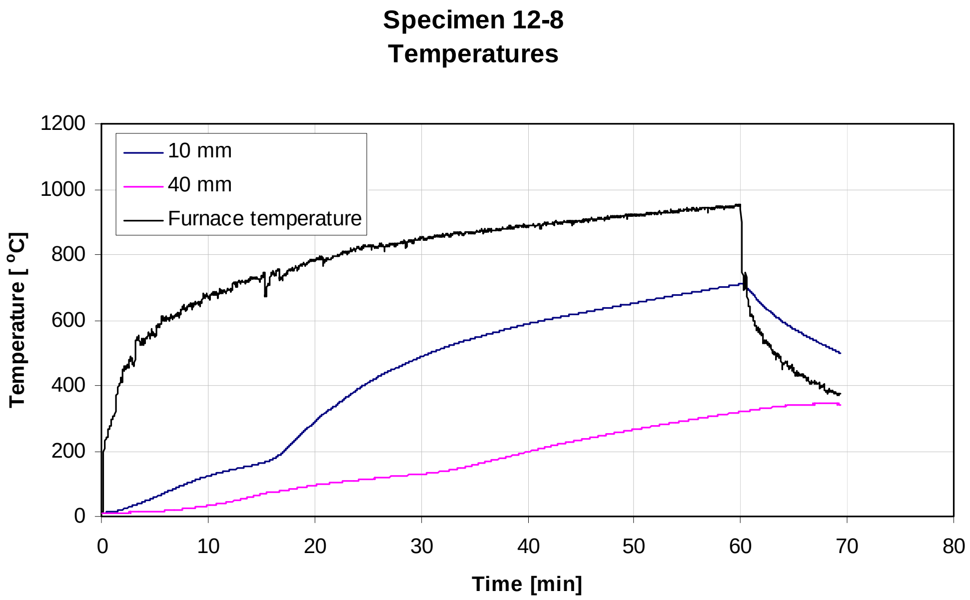


Figure A.186 Measured temperatures in furnace and in specimen 12-8.

Table A.97 Spalling measurements on specimen 12-8.

Position	0	100	200	300	400	500
0	0	1	6	1	2	1
100	0	20	19	17	19	2
200	0	15	20	18	8	1
300	0	9	7	16	12	2
400	0	0	2	19	18	1
500	0	0	1	18	18	2
600	0	1	1	2	4	2

Mean all	7
Mean inner	13
Max in diagram	20
Max measured	28

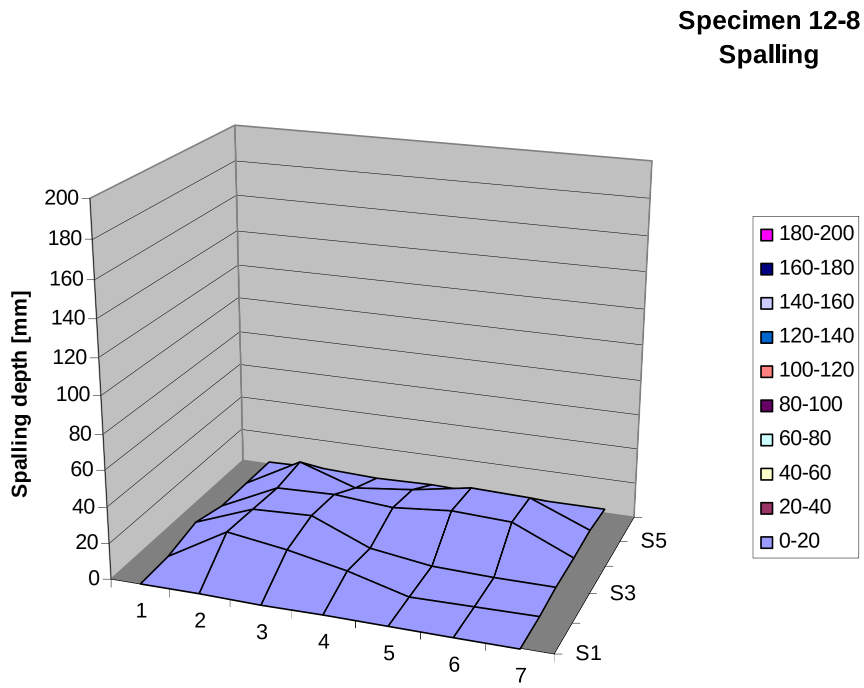


Figure A.187 Spalling measurements on specimen 12-8.

Table A.98 Observations made on specimen 12-8.

Time	Observation			
		Test date:	2006-03-02	
0,00	Start of test	Specimen:	12-8	
15,47	One loud explosion	Load level:	0	kN/bar
16,17	Some small explosions	Weight loss:	7,3	kg
16,72	One loud explosion			
16,85	One small explosion			
17,13	One small explosion			
17,47	One small explosion			
17,77	One small explosion			
18,20	One small explosion			
18,25	One explosion			
18,33	One small explosion			
18,78	One small explosion			
19,02	One small explosion			
19,77	One loud explosion			
22,00	Some water at pipes			
48,67	Water at pipes and sides			
54,50	Cracks visible on all sides			
60,00	Test terminates			

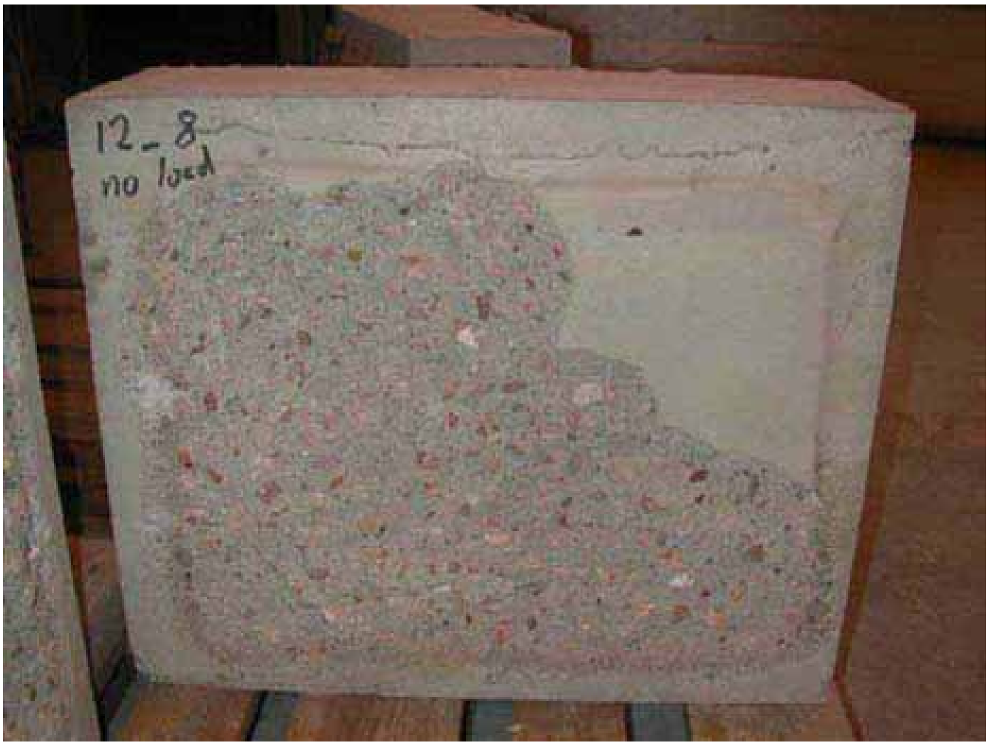


Figure A.188 Specimen 12-8 after test.

Concrete 13

Table A.99 Concrete admixture recipe 13.

Recipe	**13**
Water (kg/m^3)	230
CEM II 42,5R A-LL (kg/m^3)	355
Limestone filler, Limus 25 (kg/m^3)	105
Water-powder ratio, w/p	0,50
Water-cement ratio, w/c	0,65
Sikament 20HE 50 (20% torrhalt)	3,80
Sikament 20HE 50 (% of cement weight)	1,07
Sika IgniFill (kg/m^3)	0,50
Gravel 0 – 8 mm (%)	65
Partly crushed 8 – 16 mm (%)	35
Slump flow (mm)	670
T50 (s)	1-2
Air (%)	1.9
Compressive strength, 28 days (MPa)	37.3

Specimen 13-6

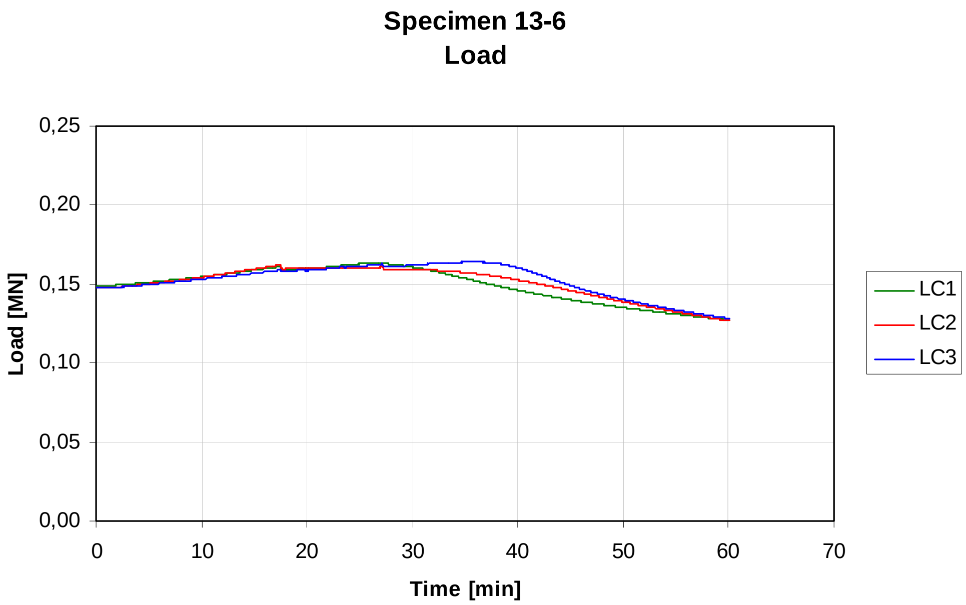


Figure A.189 Load measurements on specimen 13-6.

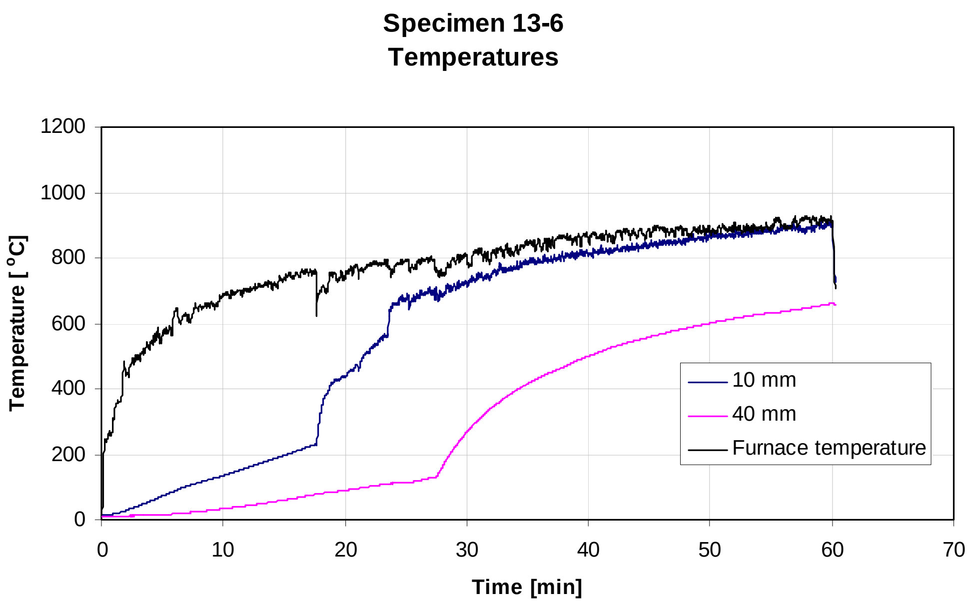


Figure A.190 Measured temperatures in furnace and in specimen 13-6.

Table A.100 Spalling measurements on specimen 13-6.

Position	0	100	200	300	400	500
0	0	1	0	6	3	0
100	4	12	14	25	13	5
200	0	19	32	31	25	7
300	4	20	36	36	22	14
400	0	16	25	34	13	3
500	0	8	27	20	18	2
600	0	4	12	7	0	0

Mean all	12
Mean inner	22
Max in diagram	36
Max measured	41

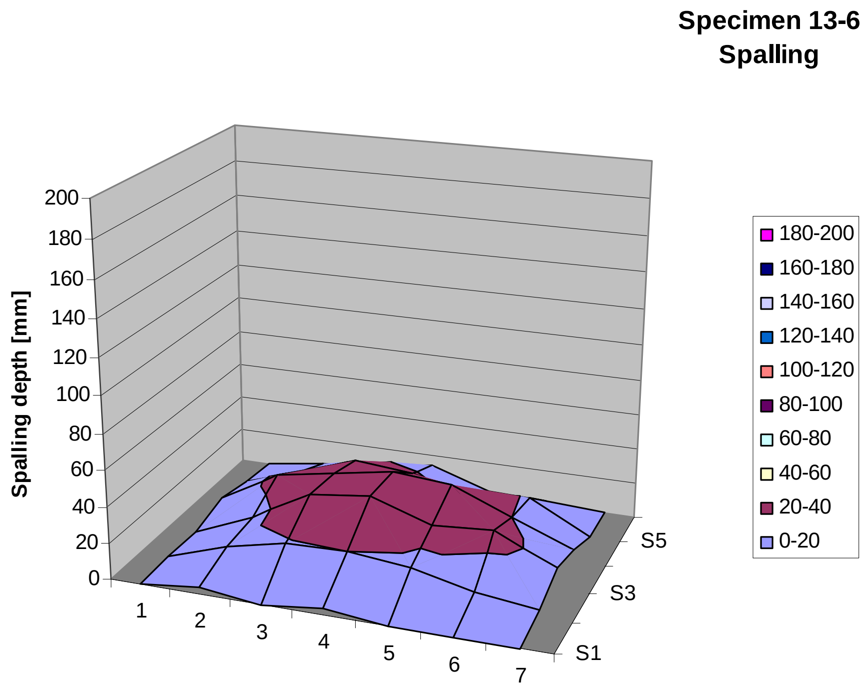


Figure A.191 Spalling measurements on specimen 13-6.

Table A.101 Observations made on specimen 13-6.

Time	Observation
0,00	Start of test
17,77	One loud explosion
18,97	Two small explosions
19,30	One small explosion
19,48	One small explosion
19,78	One small explosion
19,88	One small explosion
20,00	One explosion
20,20	One small explosion
21,07	One explosion
21,48	One small explosion
21,87	One small explosion
22,62	One small explosion
23,53	One small explosion
23,78	One explosion
27,27	One small explosion
27,40	One explosion
40,17	No water on the cold faces
47,00	One spot with water on the top face
51,00	Small spots with water on back and front sides
60,00	Test terminates

Test date:	2006-03-23	
Specimen:	13-6	
Load level:	148	kN/bar
Weight loss:	9,8	kg

Figure A.192 Specimen 13-6 after test.

Specimen 13-7

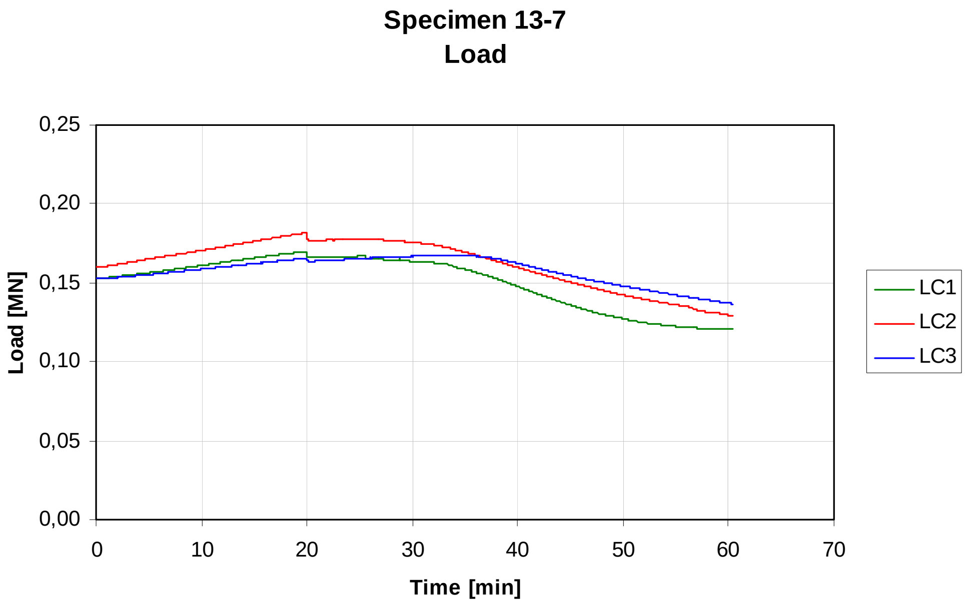


Figure A.193 Load measurements on specimen 13-7.

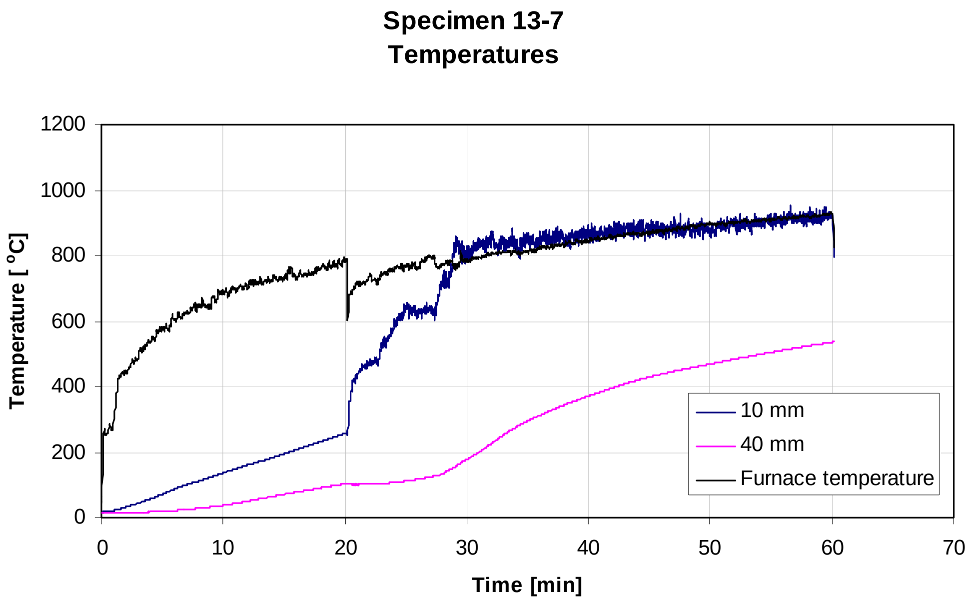


Figure A.194 Measured temperatures in furnace and in specimen 13-7.

Table A.102 Spalling measurements on specimen 13-7.

Position	0	100	200	300	400	500
0	0	3	4	8	7	1
100	2	15	16	17	29	17
200	3	10	20	26	24	30
300	3	13	18	30	31	37
400	1	16	23	22	27	39
500	3	17	24	24	25	24
600	0	7	13	16	5	2

Mean all	16
Mean inner	21
Max in diagram	39
Max measured	44

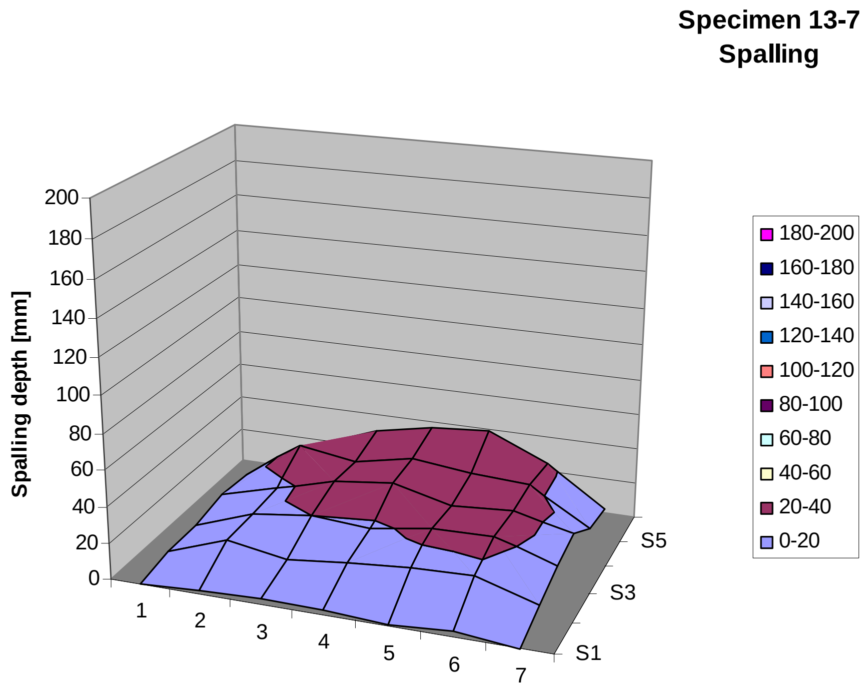


Figure A.195 Spalling measurements on specimen 13-7.

Table A.103 Observations made on specimen 13-7.

Time	Observation			
0,00	Start of test	Test date:	2006-03-23	
20,40	One very loud explosion, horizontal crack on side	Specimen:	13-7	
21,27	One small explosion	Load level:	155	kN/bar
21,62	One small explosion	Weight loss:	14,2	kg
21,70	One small explosion			
22,18	One small explosion			
22,53	One small explosion			
22,63	One small explosion			
23,22	One small explosion			
23,42	One small explosion			
24,00	One small explosion			
25,17	One small explosion			
25,75	One explosion			
27,07	One small explosion			
27,42	One explosion			
29,67	One small explosion			
32,23	One small explosion			
34,08	One small explosion			
34,88	Water on sides and top			
60,00	Test terminates			

Figure A.196 Specimen 13-7 after test.

Concrete 14

Table A.104 Concrete admixture recipe 14.

Recipe	14

Water (kg/m^3)	236
CEM II 42,5R A-LL (kg/m^3)	365
Limestone filler, Limus 25 (kg/m^3)	109
Water-powder ratio, w/p	0,50
Water-cement ratio, w/c	0,65
Sikament 20HE 50 (20% torrhalt)	5,20
Sikament 20HE 50 (% of cement weight)	1,42
Fiber, Sika Crackstop, ϕ=18 μm, l=12 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	65
Partly crushed 8 – 16 mm (%)	35
Slump flow (mm)	670
T50 (s)	1-2
Air (%)	1.7
Compressive strength, 28 days (MPa)	35.1

Specimen 14-3

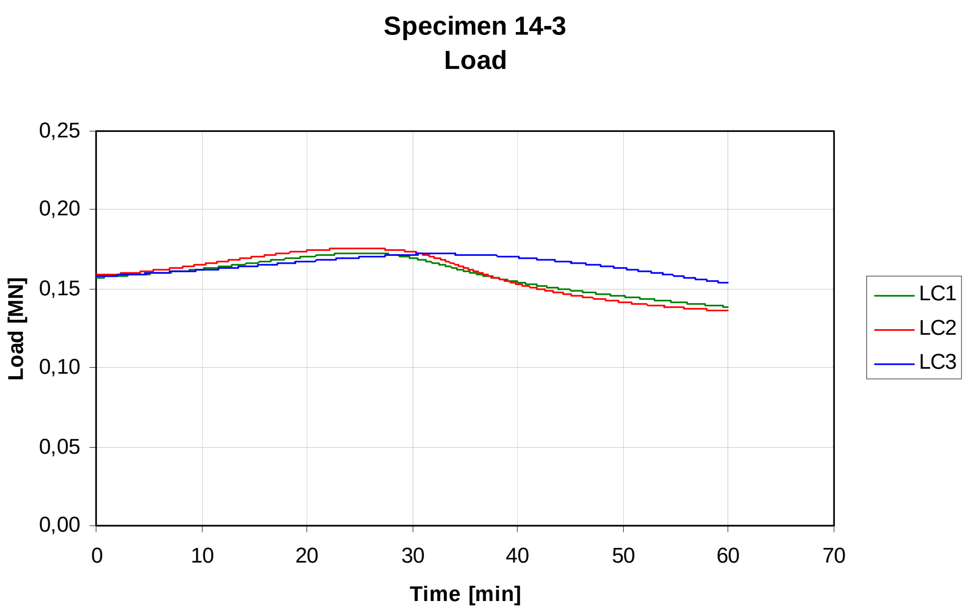


Figure A.197 Load measurements on specimen 14-3.

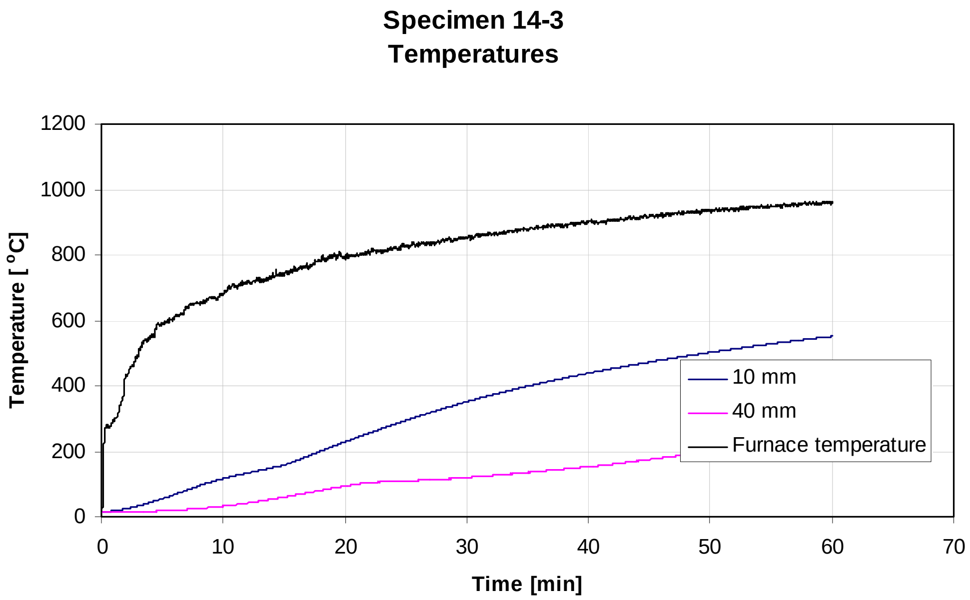


Figure A.198 Measured temperatures in furnace and in specimen 14-3.

Table A.105 Spalling measurements on specimen 14-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

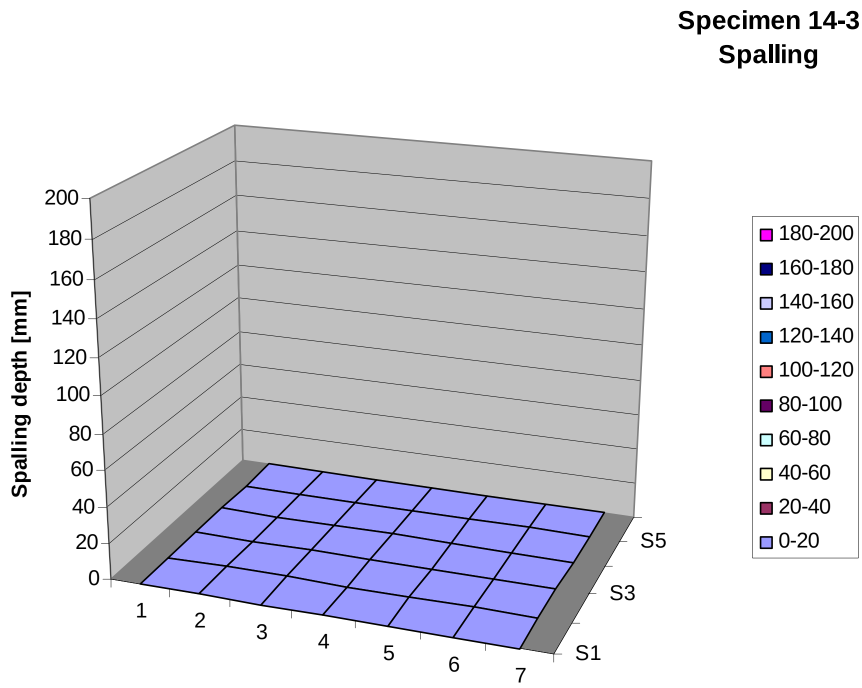


Figure A.199 Spalling measurements on specimen 14-3.

Table A.106 Observations made on specimen 14-3.

Time	Observation			
0,00	Start of test	Test date:	2006-04-13	
30,67	Water at pipes	Specimen:	14-3	
43,33	Horizontal crack on front side	Load level:	158	kN/bar
60,00	Test terminates	Weight loss:	2,4	kg

Figure A.200 Specimen 14-3 after test.

Specimen 14-8

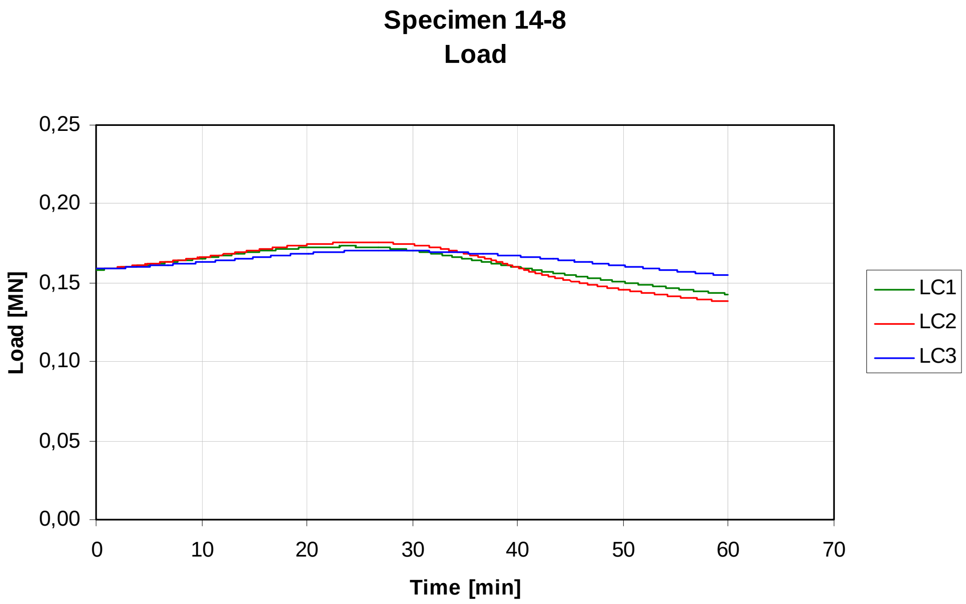


Figure A.201 Load measurements on specimen 14-8.

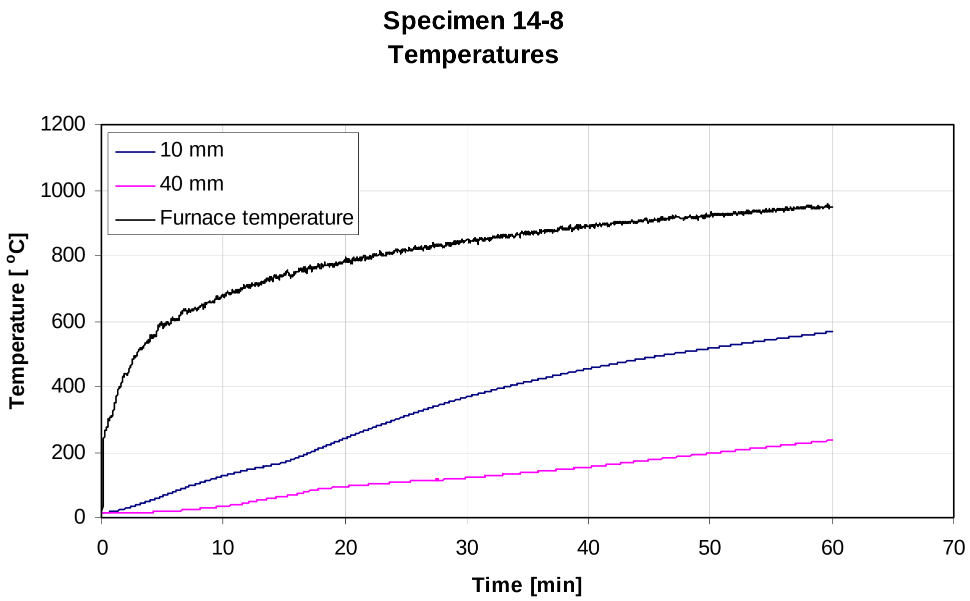


Figure A.202 Measured temperatures in furnace and in specimen 14-8.

Table A.107 Spalling measurements on specimen 14-8.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

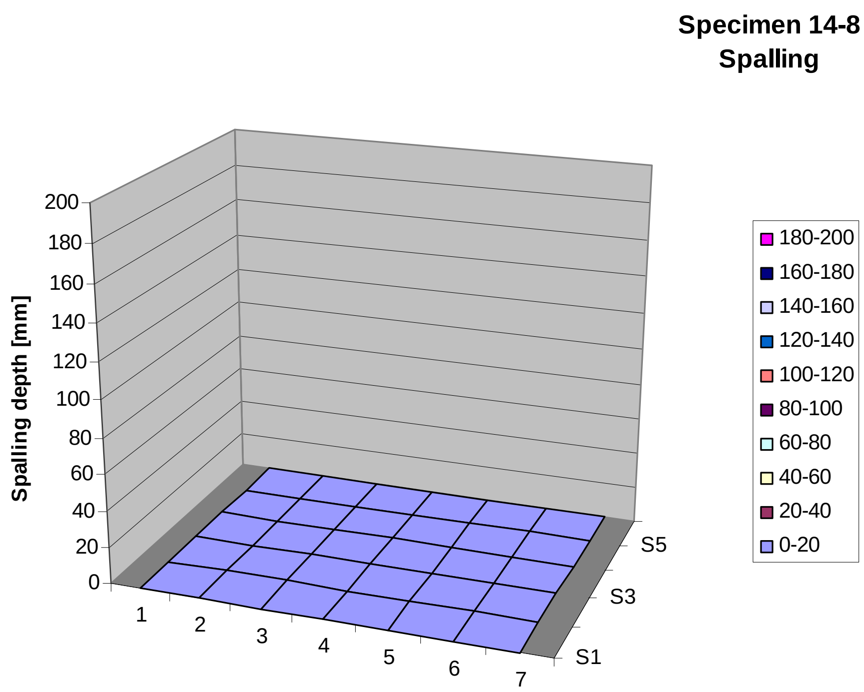


Figure A.203 Spalling measurements on specimen 14-8.

Table A.108 Observations made on specimen 14-8.

Time	Observation			
0,00	Start of test	Test date:	2006-04-18	
60,00	Test terminates	Specimen:	14-8	
		Load level:	159	kN/bar
		Weight loss:	2,0	kg

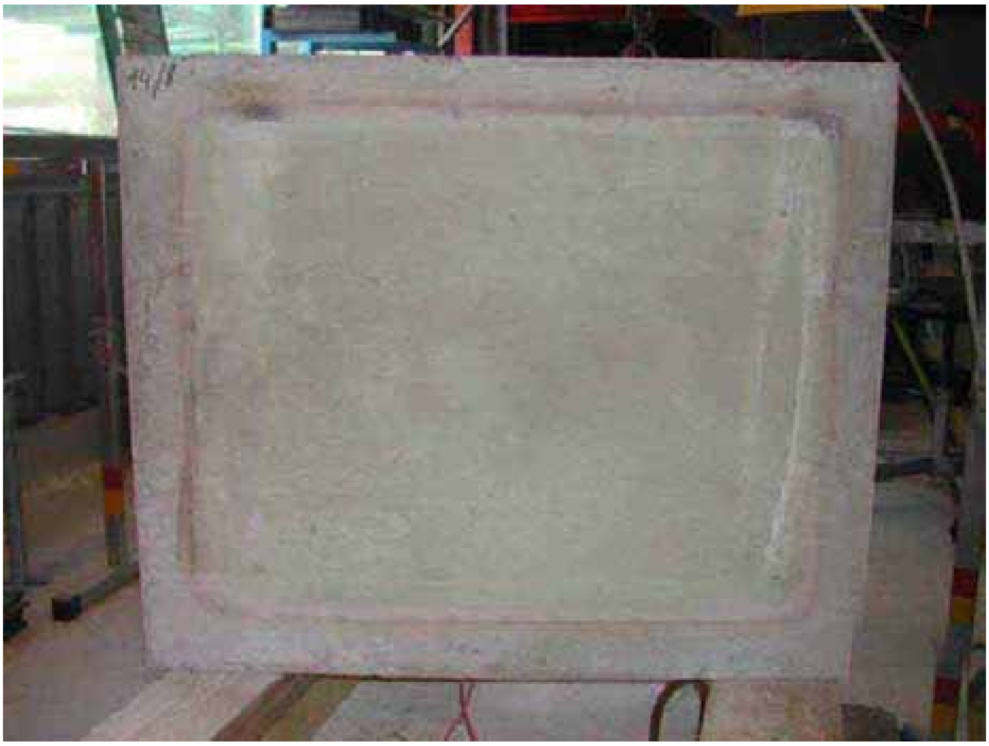


Figure A.204 Specimen 14-8 after test.

Concrete 15

Table A.109 Concrete admixture recipe 15.

Recipe	**15**
Water (kg/m^3)	180
CEM II 42,5R A-LL (kg/m^3)	450
Limestone filler, Limus 25 (kg/m^3)	50
Water-powder ratio, w/p	0,36
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	6,7
Sikament 20HE 50 (% of cement weight)	1,49
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	650
T50 (s)	3-4
Air (%)	2.7
Compressive strength, 28 days (MPa)	54.2

Specimen 15-5

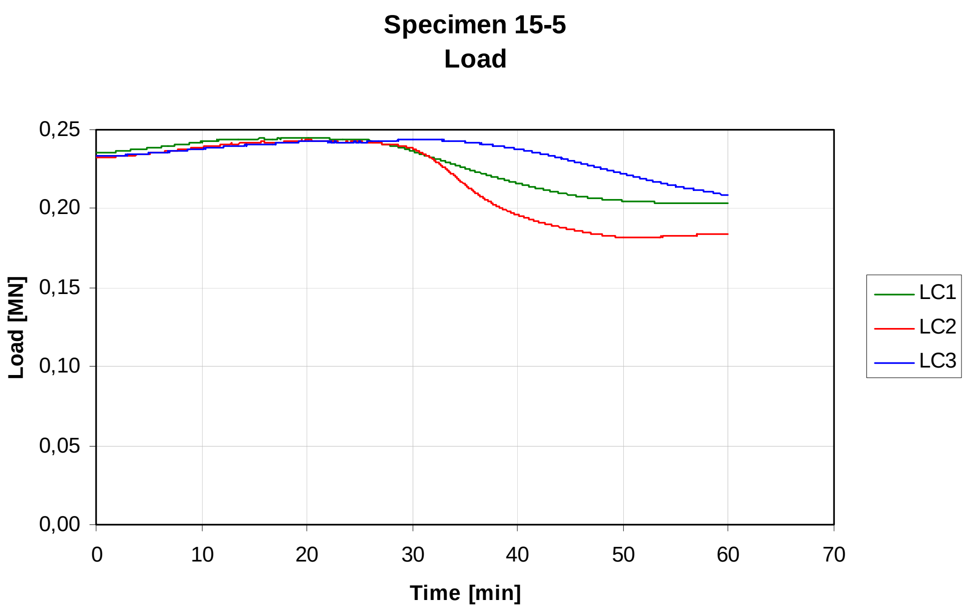


Figure A.205 Load measurements on specimen 15-5.

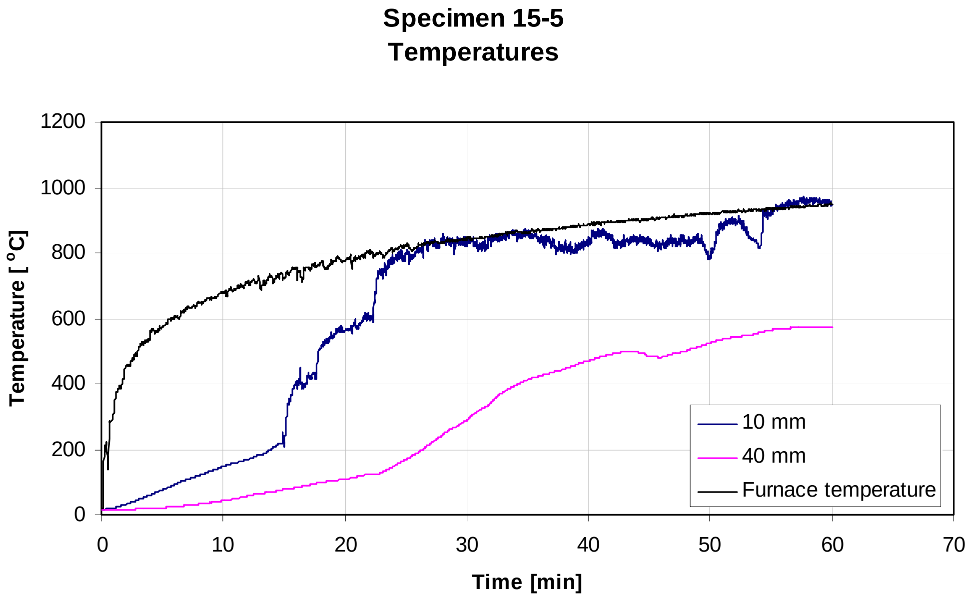


Figure A.206 Measured temperatures in furnace and in specimen 15-5.

Table A.110 Spalling measurements on specimen 15-5.

Position	0	100	200	300	400	500
0	0	4	0	4	4	0
100	0	12	26	43	29	1
200	0	8	37	38	28	2
300	0	19	35	27	25	3
400	4	18	32	36	32	1
500	4	13	13	27	20	2
600	0	0	0	4	3	0

Mean all	13
Mean inner	26
Max in diagram	43
Max measured	50

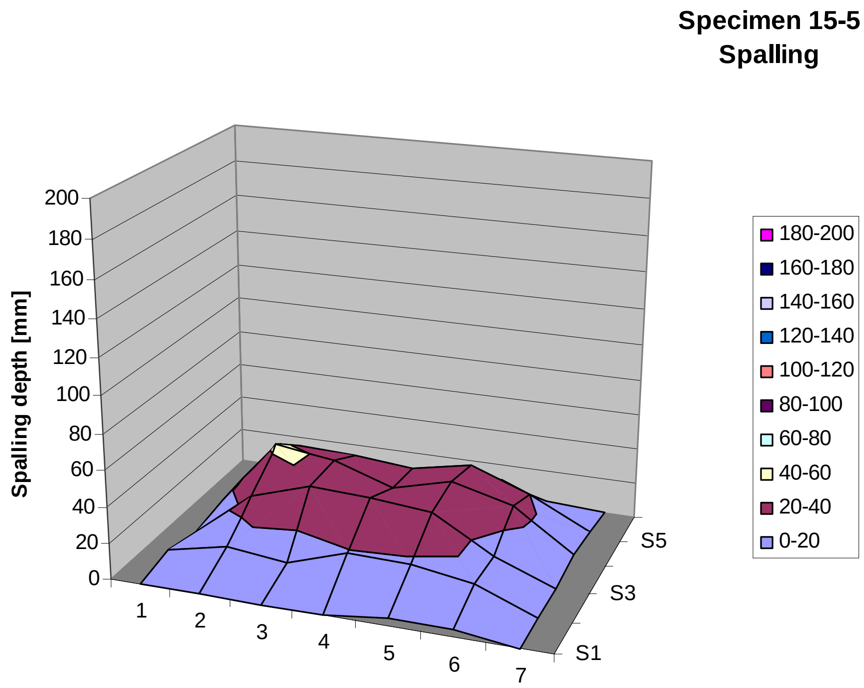


Figure A.207 Spalling measurements on specimen 15-5.

Table A.111 Observations made on specimen 15-5.

Time	Observation			
0,00	Start of test	Test date:	2006-09-29	
10,22	One small explosion	Specimen:	15-5	
10,67	One small explosion	Load level:	234	kN/bar
11,48	One small explosion	Weight loss:	10,2	kg
11,62	One small explosion			
12,07	One small explosion			
12,62	One small explosion			
12,97	Three small explosions			
13,40	One small explosion			
14,03	One explosion			
14,33	One small explosion			
14,47	One small explosion			
14,52	One small explosion			
14,53	One small explosion			
14,82	One small explosion			
15,02	One small explosion			
15,33	One small explosion			
16,15	One explosion			
16,37	Two small explosions			
16,67	One small explosion			
17,17	Two small explosions			
17,60	One small explosion			
18,23	One small explosion			
18,27	One small explosion			
18,38	Two small explosions			
18,88	Many small explosions			
19,67	One small explosion			
19,73	Many small explosions			
20,53	One explosion			
21,25	One small explosion			
21,67	One small explosion			
21,85	Two small explosions			
22,07	Many small explosions			
22,32	One small explosion			
22,50	One small explosion			
23,00	One small explosion			
23,13	One small explosion			
23,67	One small explosion			
23,95	One small explosion, water on top and back side			
24,77	One small explosion			
25,25	Two small explosions			
26,43	One small explosion			
27,00	Horizontal crack on back side			
60,00	Test terminates			

Figure A.208 Specimen 15-5 after test.

Specimen 15-6

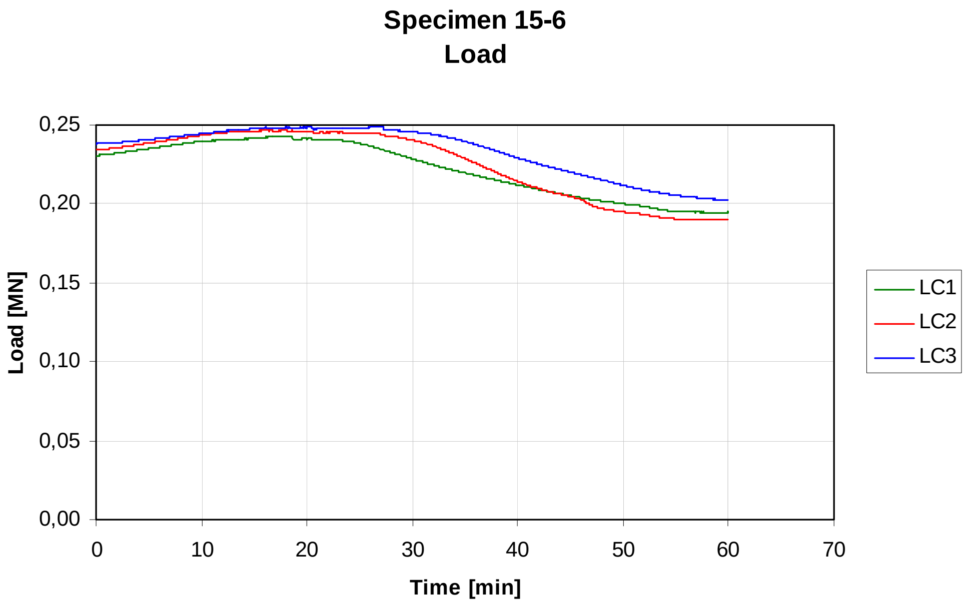


Figure A.209 Load measurements on specimen 15-6.

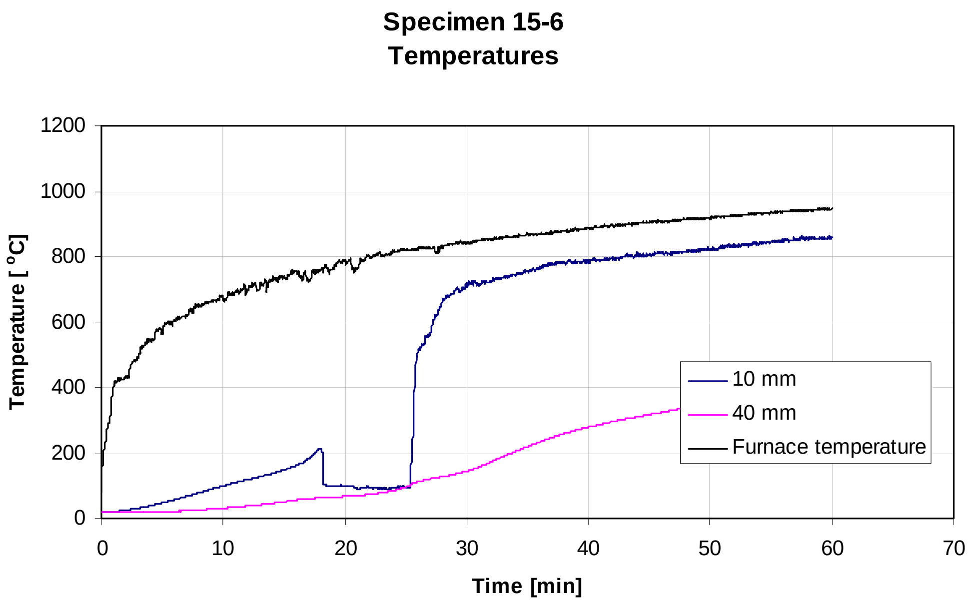


Figure A.210 Measured temperatures in furnace and in specimen 15-6.

Table A.112 Spalling measurements on concrete 15-6.

Position	0	100	200	300	400	500
0	2	0	0	0	9	0
100	3	13	22	16	30	5
200	3	22	21	25	34	8
300	9	27	32	32	23	3
400	0	24	27	39	32	3
500	2	12	30	36	27	5
600	0	3	5	4	14	0

Mean all	14
Mean inner	26
Max in diagram	39
Max measured	49

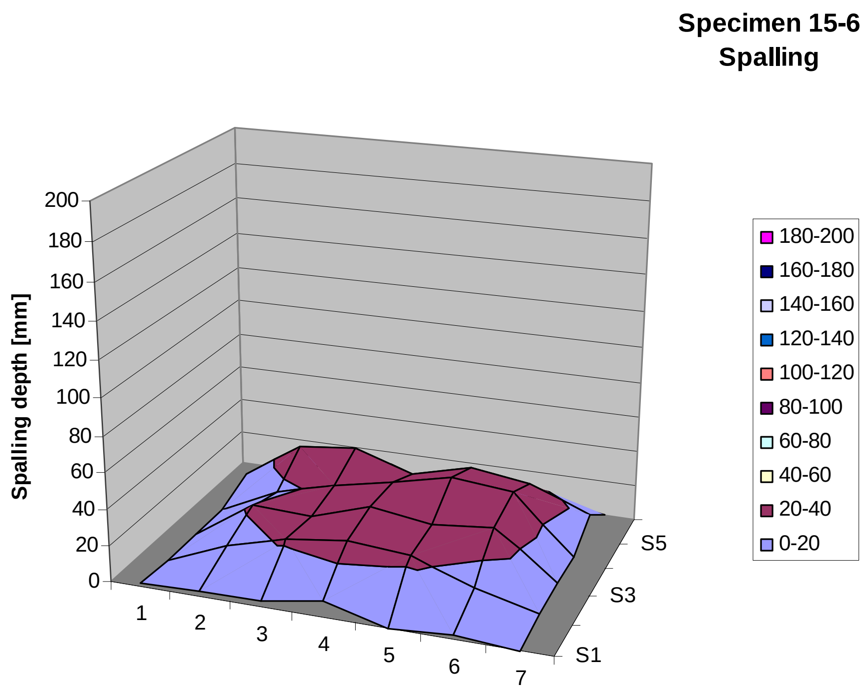


Figure A.211 Spalling measurements on concrete 15-6.

Table A.113 Observations made on specimen 15-6.

Time	Observation			
0,00	Start of test	Test date:	2006-09-21	
9,98	One explosion	Specimen:	15-6	
10,73	One small explosion	Load level:	234	kN/bar
11,22	One small explosion	Weight loss:	13,8	kg
11,82	One small explosion			
12,42	One small explosion			
12,72	One explosion			
13,02	One small explosion			
13,50	One explosion			
13,83	Two small explosions			
14,12	One small explosion			
14,27	One small explosion			
14,30	One small explosion			
14,42	One small explosion			
14,87	One small explosion			
14,98	One small explosion			
15,03	One small explosion			
15,12	One small explosion			
15,67	One small explosion			
16,25	Three small explosions			
16,35	One small explosion			
16,43	Two small explosions			
16,83	One small explosion			
16,87	Two small explosions			
17,02	One small explosion			
17,33	One small explosion			
17,50	One small explosion			
17,78	One small explosion			
18,13	One small explosion			
18,15	Two small explosions			
18,48	One small explosion			
18,67	One small explosion			
18,70	One small explosion			
18,80	One small explosion			
18,87	One small explosion			
19,52	One small explosion			
20,03	One explosion			
20,50	One small explosion			
20,52	One small explosion			
20,55	One small explosion			
20,72	Two small explosions			
21,48	One small explosion			
21,57	Two small explosions			
22,95	One small explosion			
23,45	One explosion			
27,37	One small explosion			
32,00	Water on back side			
60,00	Test terminates			

Figure A.212 Specimen 15-6 after test.

Concrete 16

Table A.114 Concrete admixture recipe 16.

Recipe	**16**
Water (kg/m^3)	198
CEM II 42,5R A-LL (kg/m^3)	380
Limestone filler, Limus 25 (kg/m^3)	60
Water-powder ratio, w/p	0,45
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,6
Sikament 20HE 50 (% of cement weight)	1,47
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	710
T50 (s)	2-3
Air (%)	1.8
Compressive strength, 28 days (MPa)	42.9

Specimen 16-4

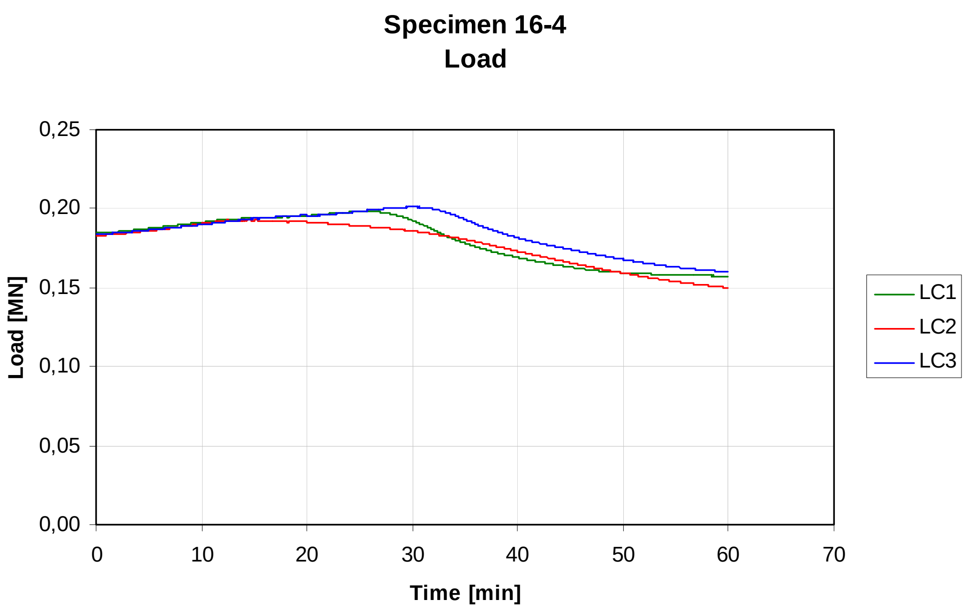


Figure A.213 Load measurements on specimen 16-4.

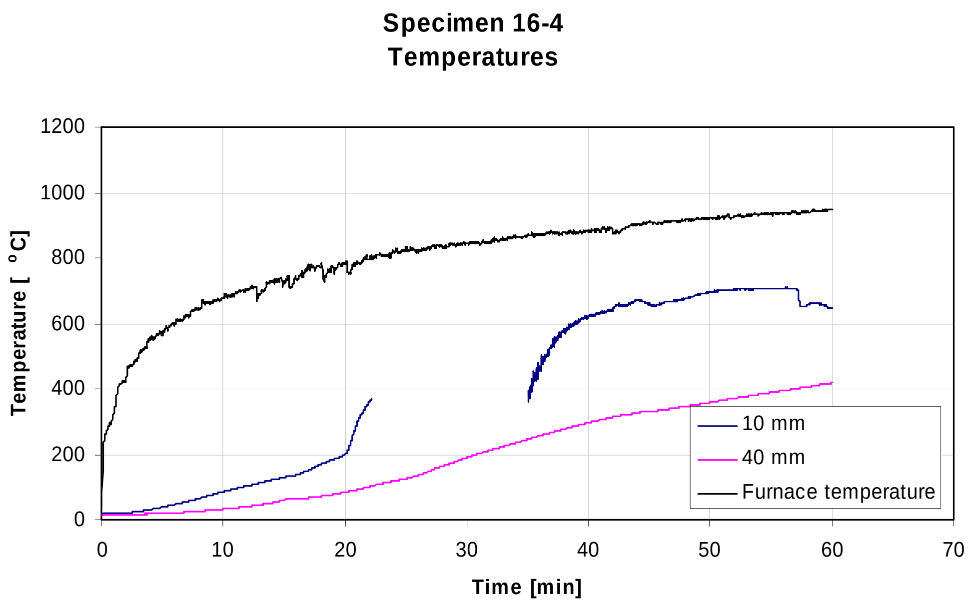


Figure A.214 Measured temperatures in furnace and in specimen 16-4.

Table A.115 Spalling measurements on specimen 16-4.

Position	0	100	200	300	400	500
0	0	4	1	6	10	0
100	0	14	30	26	29	10
200	0	19	31	26	30	8
300	6	21	26	37	26	4
400	1	12	19	20	24	3
500	3	13	10	12	16	3
600	0	2	0	0	0	0

Mean all	12
Mean inner	22
Max in diagram	37
Max measured	40

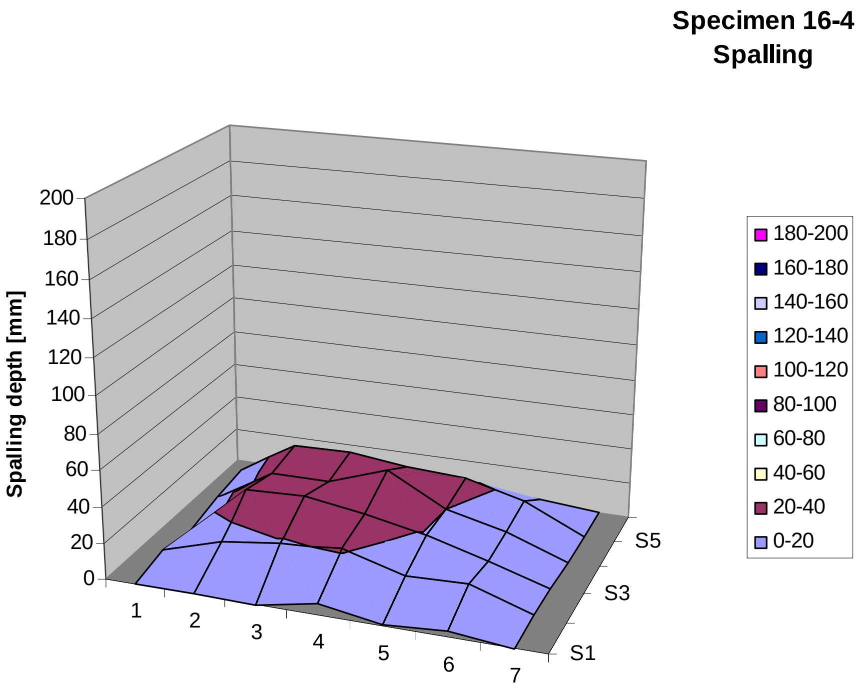


Figure A.215 Spalling measurements on specimen 16-4.

Table A.116 Observations made on specimen 16-4.

Time	Observation			
0,00	Start of test	Test date:	2006-09-20	
12,72	One explosion	Specimen:	16-4	
14,08	One small explosion	Load level:	184	kN/bar
14,20	One small explosion	Weight loss:	12,2	kg
14,33	Two small explosions			
14,87	One explosion, fine horizontal crack on back side			
15,50	Two explosions			
15,98	One small explosion			
16,38	One small explosion			
16,57	Two small explosions			
16,65	One small explosion			
17,53	One small explosion			
18,25	Lots of explosions			
19,17	Two small explosions			
19,62	One small explosion			
20,28	Two small explosions			
21,32	One small explosion			
22,27	One small explosion			
23,72	One small explosion			
33,00	Water on top face			
60,00	Test terminates			

Figure A.216 Specimen 16-4 after test.

Specimen 16-6

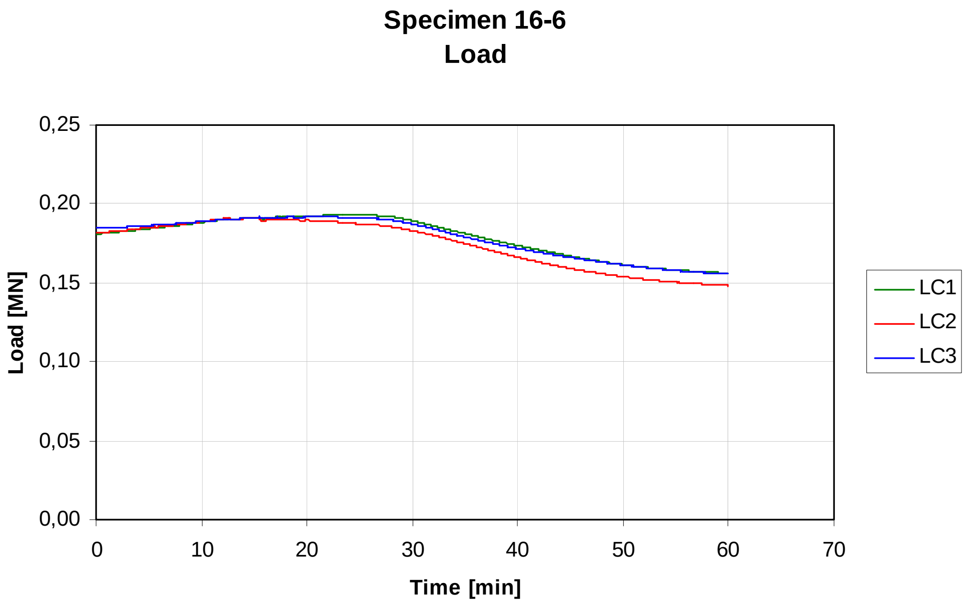


Figure A.217 Load measurements on specimen 16-6.

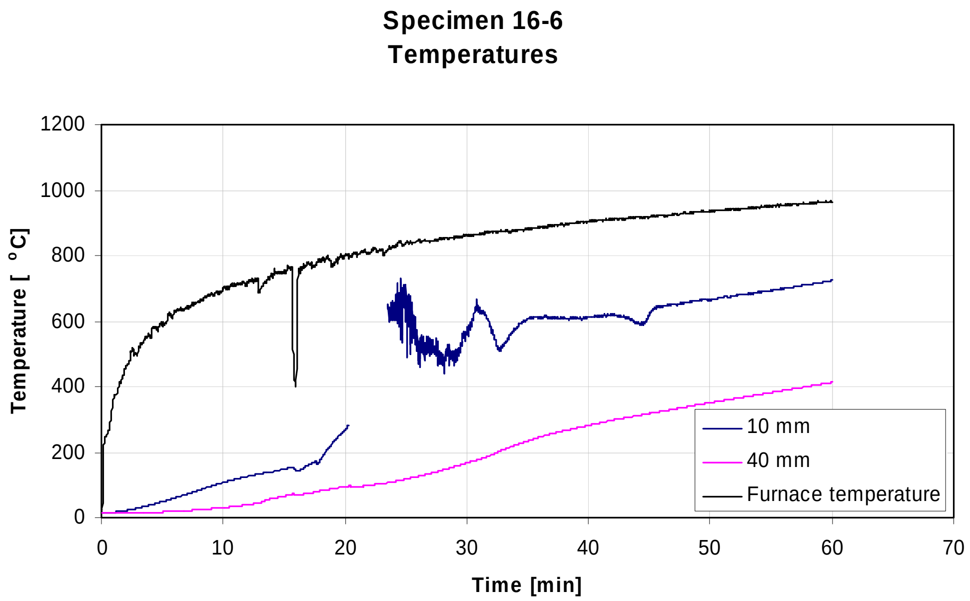


Figure A.218 Measured temperatures in furnace and in specimen 16-6.

Table A.117 Spalling measurements on specimen 16-6.

Position	0	100	200	300	400	500
0	0	4	5	6	2	0
100	0	31	32	24	20	4
200	2	31	36	28	19	0
300	2	29	35	27	28	4
400	0	26	28	23	24	2
500	0	7	11	22	13	3
600	0	0	0	2	4	0

Mean all	13
Mean inner	25
Max in diagram	36
Max measured	44

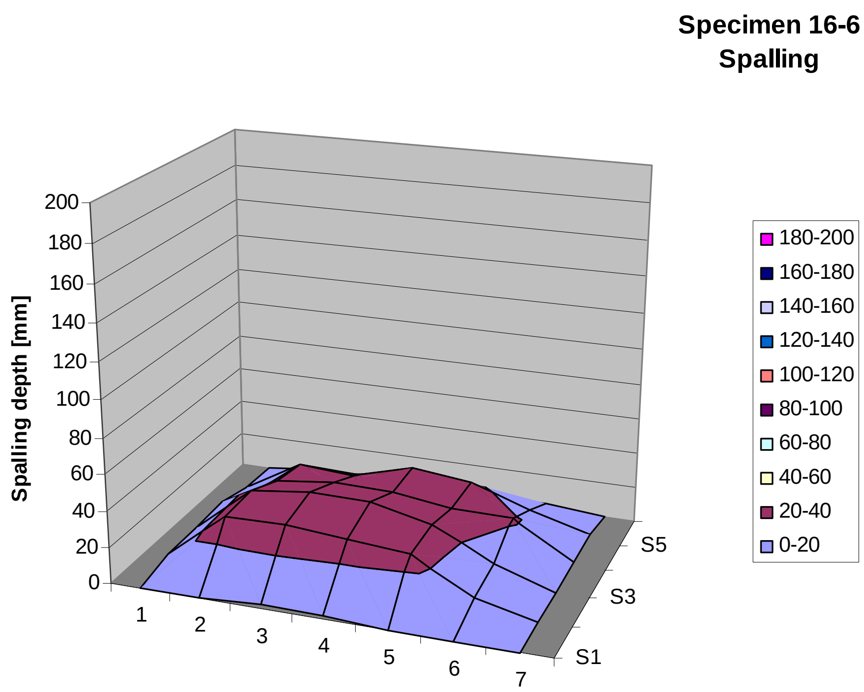


Figure A.219 Spalling measurements on specimen 16-6.

Table A.118 Observations made on specimen 16-6.

Time	Observation			
0,00	Start of test	Test date:	2006-09-21	
12,97	One explosion	Specimen:	16-6	
13,80	One small explosion	Load level:	183	kN/bar
15,00	One small explosion	Weight loss:	11,6	kg
15,33	One small explosion			
15,73	One large explosion, burner blown off			
16,77	One small explosion			
17,30	One explosion			
17,67	One small explosion			
18,42	One small explosion			
18,88	Two small explosions			
19,30	One small explosion, water on top face			
19,47	Three small explosions			
20,35	One explosion			
20,88	One small explosion			
21,02	One small explosion			
22,63	Two small explosions			
23,10	One small explosion			
24,70	One small explosion			
39,00	Water on front and back side			
60,00	Test terminates			

Figure A.220 Specimen 16-6 after test.

Specimen 16-9

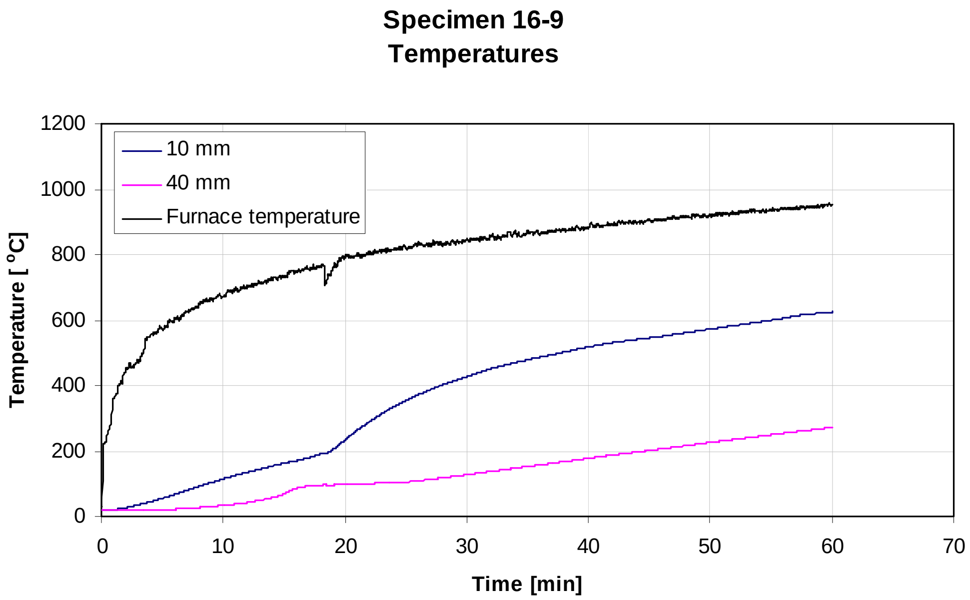


Figure A.221 Measured temperatures infurnace and in specimen 16-9.

Table A.119 Spalling measurements on specimen 16-9

Position	0	100	200	300	400	500
0	0	6	5	0	0	0
100	0	12	18	0	0	0
200	0	4	15	0	0	0
300	0	11	12	11	0	0
400	3	14	21	15	0	0
500	0	17	13	3	0	0
600	0	0	0	0	0	0

Mean all	4
Mean inner	8
Max in diagram	21
Max measured	25

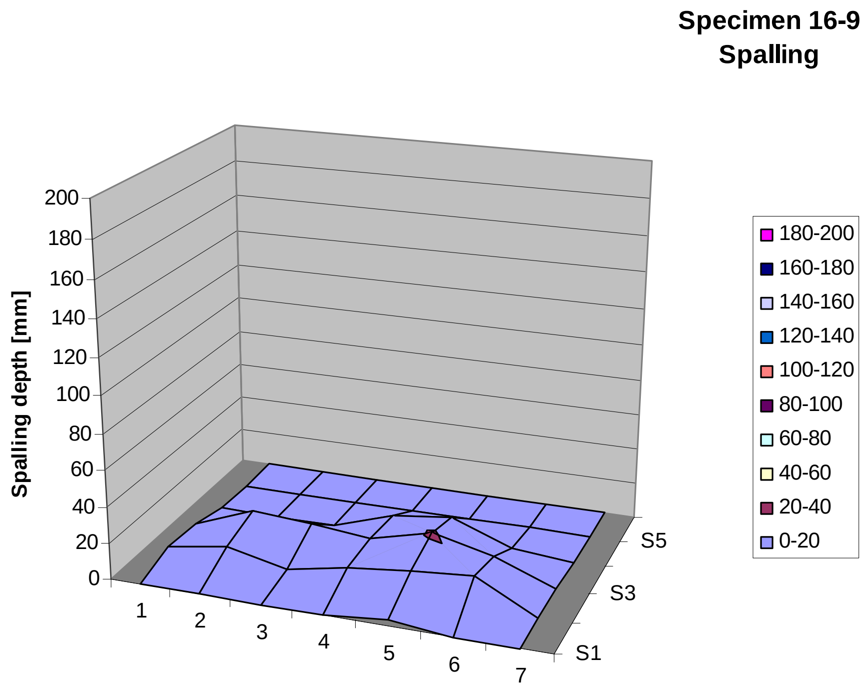


Figure A.222 Spalling measurements on specimen 16-9.

Table A.120 Observations made on specimen 16-9.

Time	Observation				
0,00	Start of test				
18,33	One loud explosion				
19,50	One small explosion				
19,65	One small explosion, water flow out				
19,72	One small explosion				
20,62	One small explosion				
21,23	One small explosion				
22,02	One small explosion				
60,00	Test terminates				

Test date:	2006-09-19	
Specimen:	16-9	
Load level:	0	kN/bar
Weight loss:	5,6	kg

Figure A.223 Specimen 16-9 after test.

Specimen 16-10

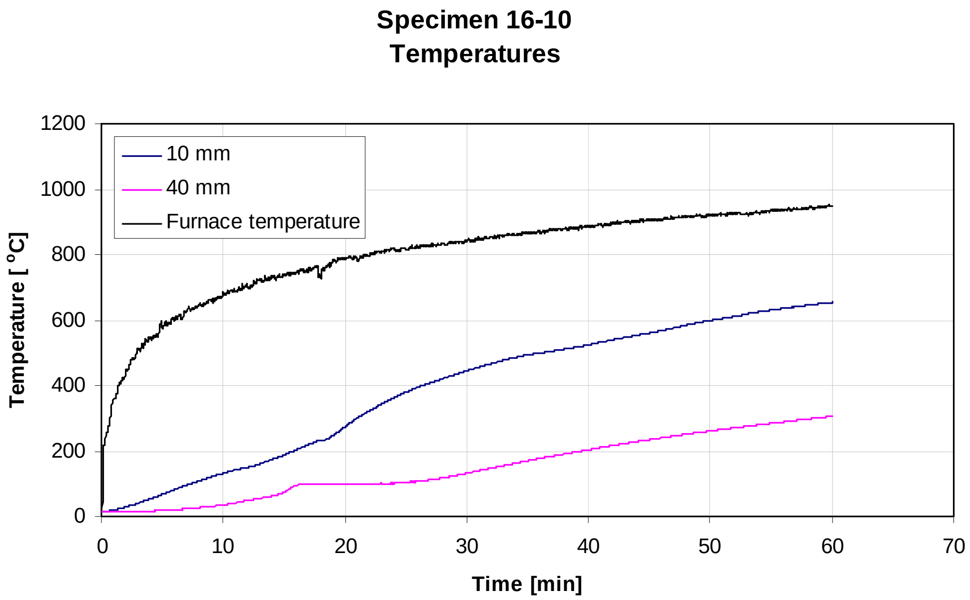


Figure A.224 Measured temperatures in furnace and in specimen 16-10.

Table A.121 Spalling measurements on specimen 16-10.

Position	0	100	200	300	400	500
0	0	0	0	1	3	0
100	3	10	14	14	17	0
200	0	6	16	19	13	3
300	0	3	8	20	4	0
400	0	0	2	11	3	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	4
Mean inner	8
Max in diagram	20
Max measured	24

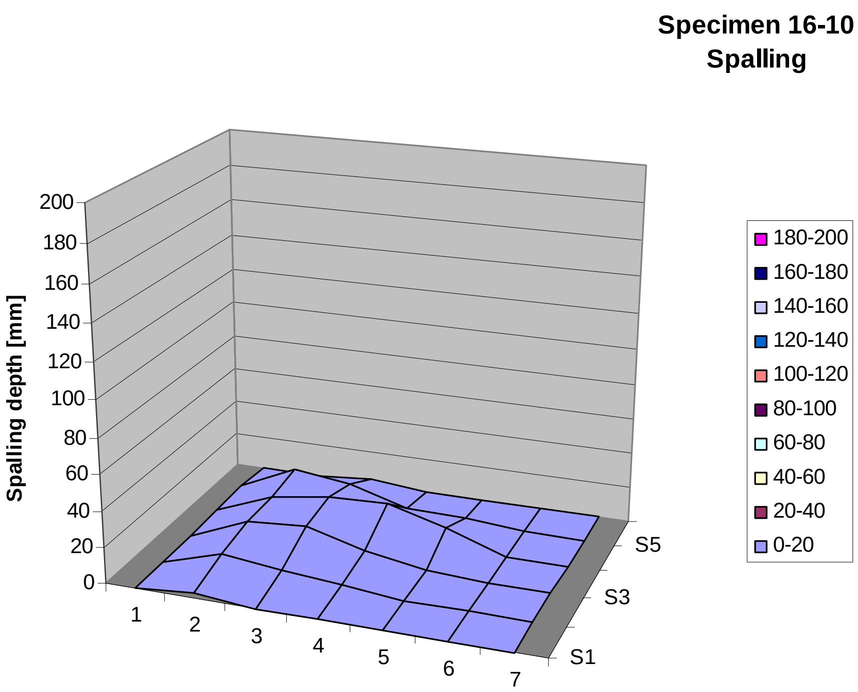


Figure A.225 Spalling measurements on specimen 16-10.

Table A.122 Observations made on specimen 16-10.

Time	Observation			
0,00	Start of test	Test date:	2006-09-20	
17,83	One explosion	Specimen:	16-10	
18,97	One small explosion	Load level:	0	kN/bar
19,58	One small explosion, water on sides	Weight loss:	5,6	kg
20,95	One small explosion			
60,00	Test terminates			

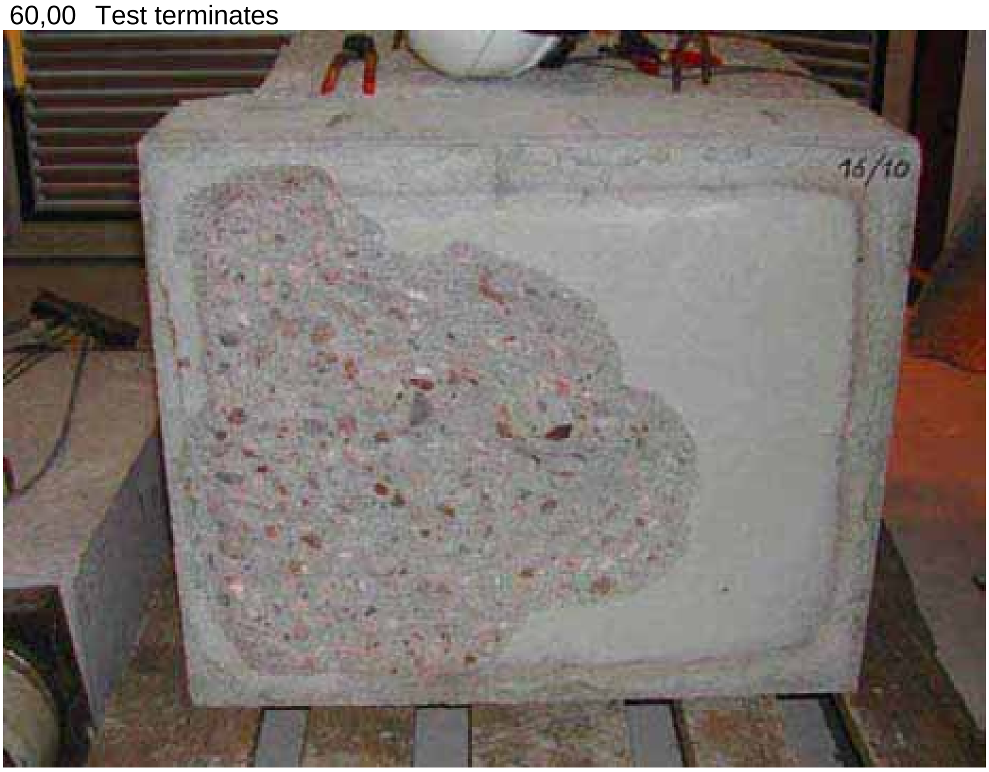


Figure A.226 Specimen 16-10 after test.

Concrete 17

Table A.123 Concrete admixture recipe 17.

Recipe	**17**
Water (kg/m^3)	198
CEM II 42,5R A-LL (kg/m^3)	380
Limestone filler, Limus 25 (kg/m^3)	60
Water-powder ratio, w/p	0,45
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,7
Sikament 20HE 50 (% of cement weight)	1,50
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	0,50
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	690
T50 (s)	2-3
Air (%)	2.8
Compressive strength, 28 days (MPa)	39.1

Specimen 17-3

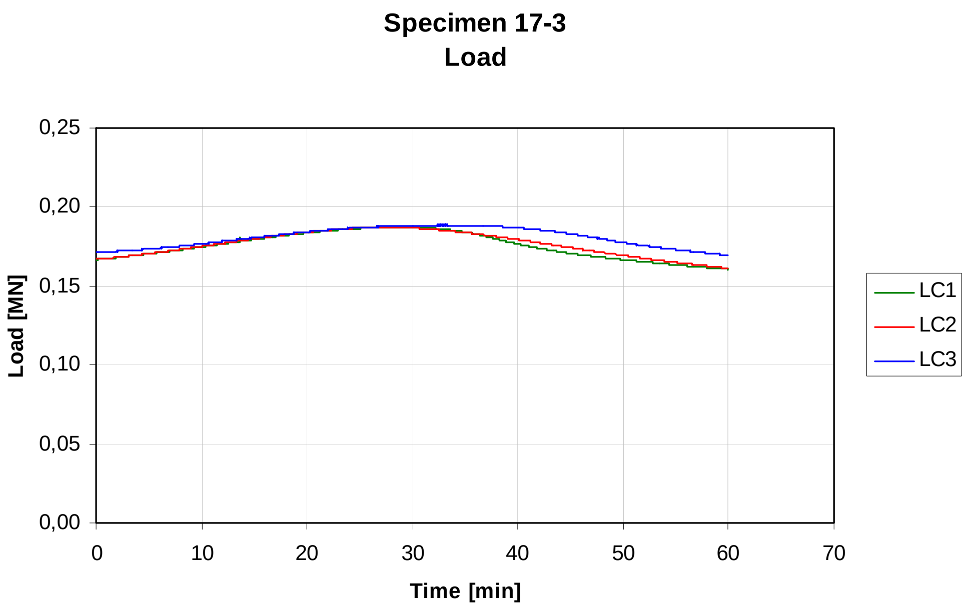


Figure A.227 Load measurements on specimen 17-3.

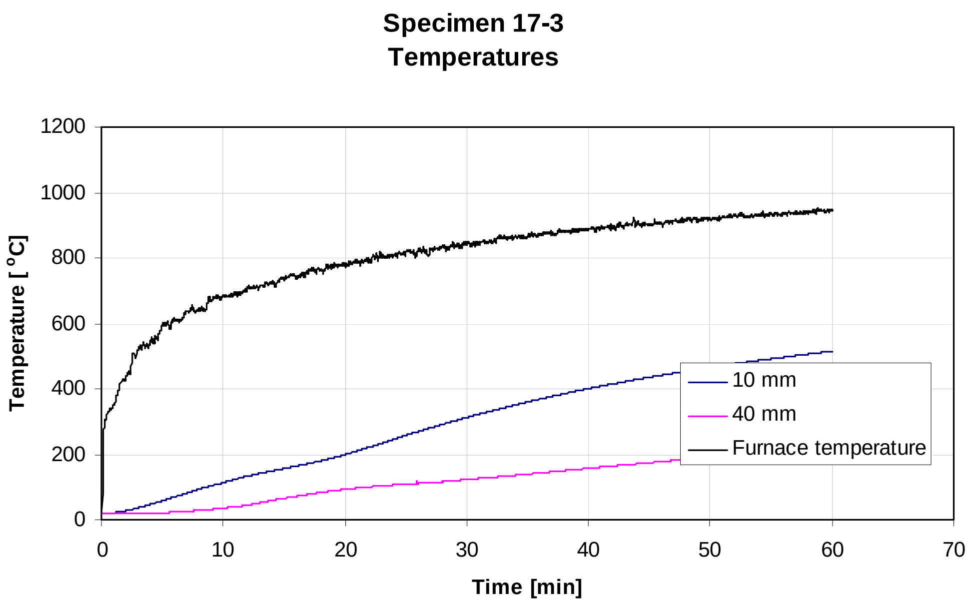


Figure A.228 Measured temperatures in furnace and in specimen 17-3.

Table A.124 Spalling measurements on specimen 17-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

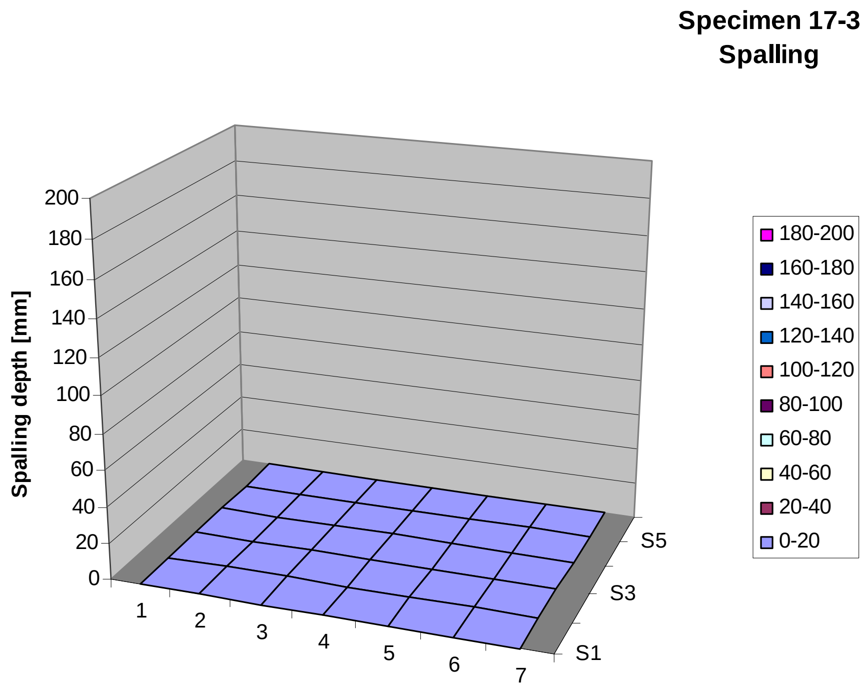


Figure A.229 Spalling measurements on specimen 17-3.

Table A.125 Observations made on specimen 17-3.

Time	Observation			
		Test date:	2006-09-27	
0,00	Start of test	Specimen:	17-3	
25,00	Water on top surface	Load level:	168	kN/bar
60,00	Test terminates	Weight loss:	2,1	kg

Figure A.230 Specimen 17-3 after test.

Specimen 17-9

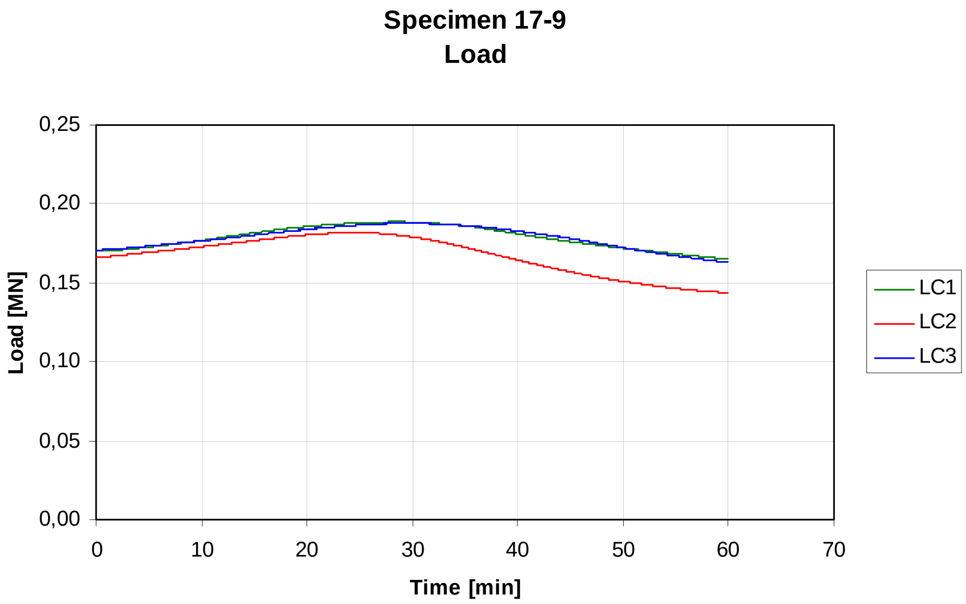


Figure A.231 Load measurements on specimen 17-9.

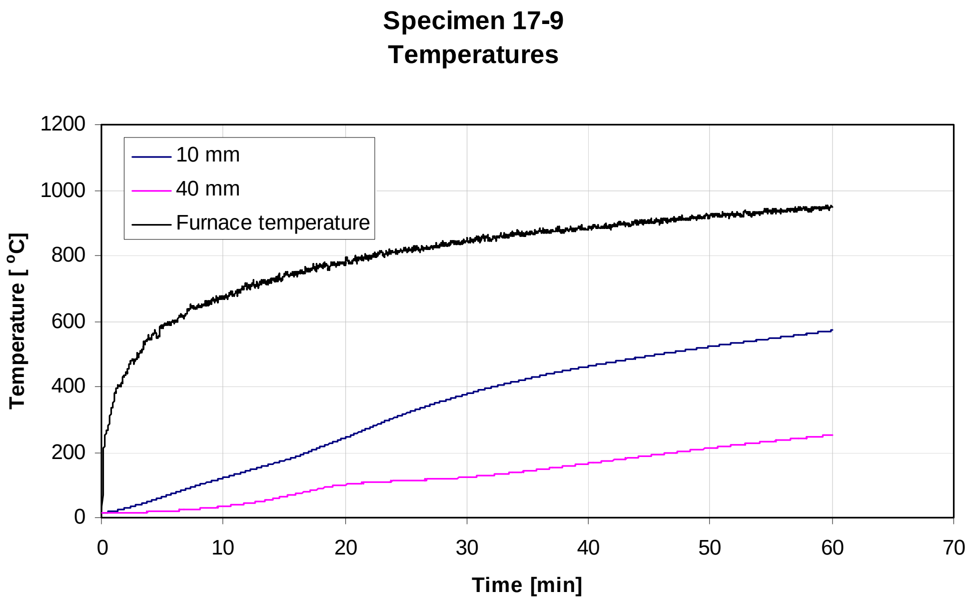


Figure A.232 Measured temperatures in furnace and in specimen 17-9.

Table A.126 Spalling measurements on specimen 17-9

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

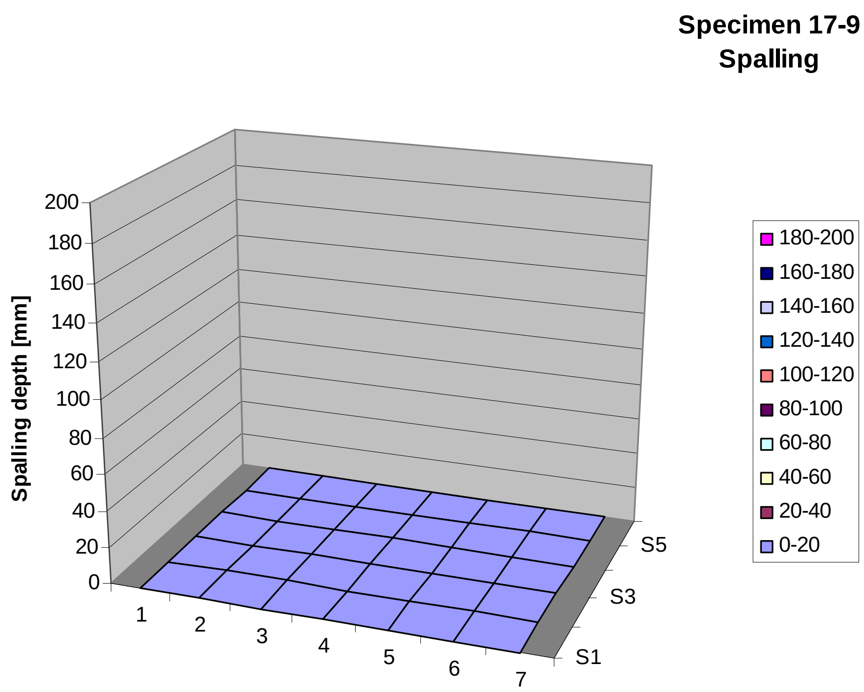


Figure A.233 Spalling measurements on specimen 17-9.

Table A.127 Observations made on specimen 17-9.

Time	Observation			
0,00	Start of test	Test date:	2006-09-25	
27,00	Water on top surface	Specimen:	17-9	
60,00	Test terminates	Load level:	169	kN/bar
		Weight loss:	2,0	kg

Figure A.234 Specimen 17-9 after test.

Concrete 18

Table A.128 Concrete admixture recipe 18.

Recipe	**18**
Water (kg/m^3)	230
CEM II 42,5R A-LL (kg/m^3)	355
Limestone filler, Limus 25 (kg/m^3)	105
Water-powder ratio, w/p	0,50
Water-cement ratio, w/c	0,65
Sikament 20HE 50 (20% torrhalt)	5,10
Sikament 20HE 50 (% of cement weight)	1,44
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	65
Partly crushed 8 – 16 mm (%)	35
Slump flow (mm)	700
T50 (s)	2
Air (%)	1.6
Compressive strength, 28 days (MPa)	32.3

Specimen 18-5

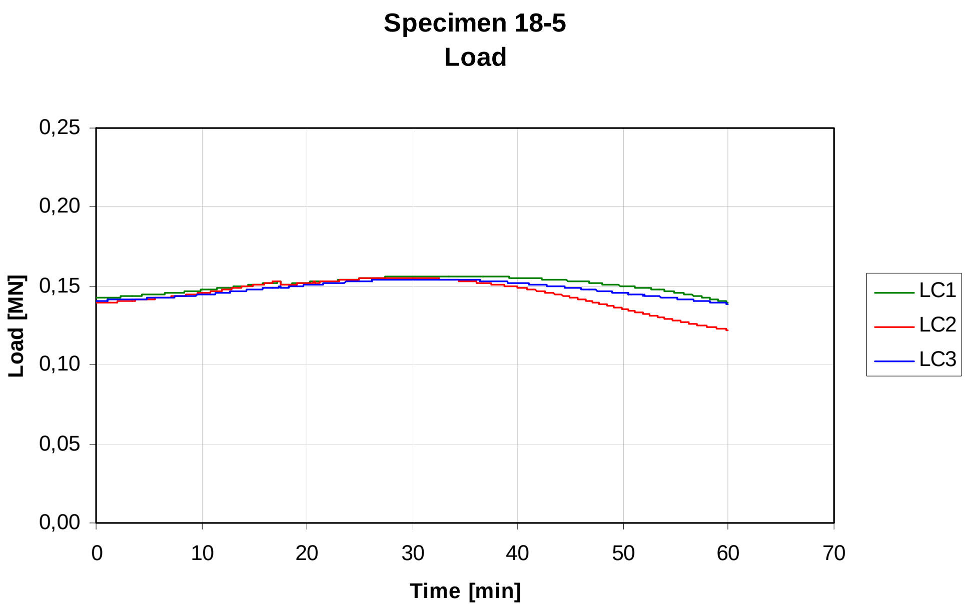


Figure A.235 Load measurements on specimen 18-5.

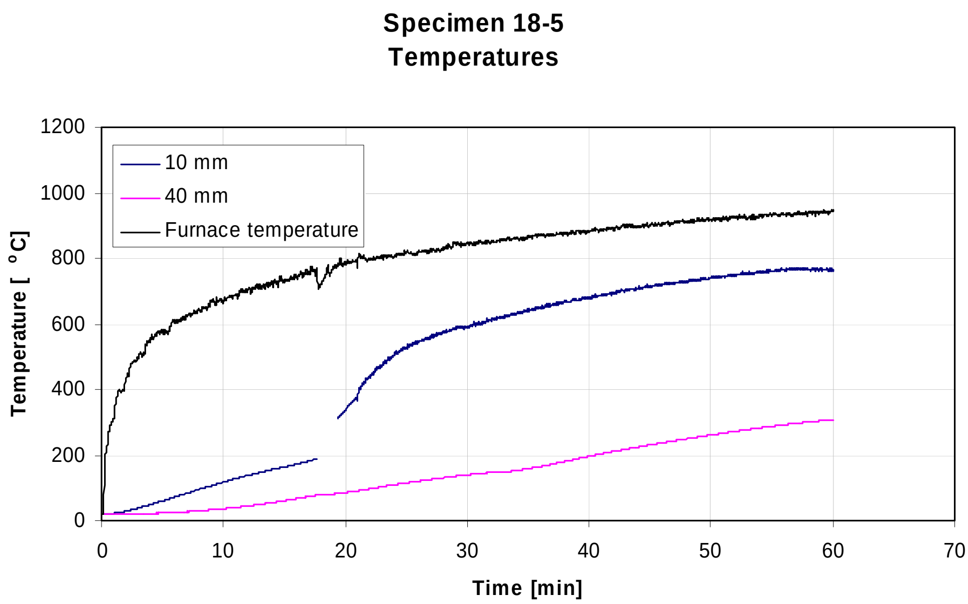


Figure A.236 Measured temperatures in furnace and in specimen 18-5.

Table A.129 Spalling measurements on specimen 18-5.

Position	0	100	200	300	400	500
0	0	0	11	18	7	0
100	0	0	10	31	36	7
200	0	0	4	25	26	7
300	0	0	3	13	16	4
400	0	0	1	5	18	0
500	0	0	0	2	5	0
600	0	0	0	0	0	0

Mean all	6
Mean inner	10
Max in diagram	36
Max measured	36

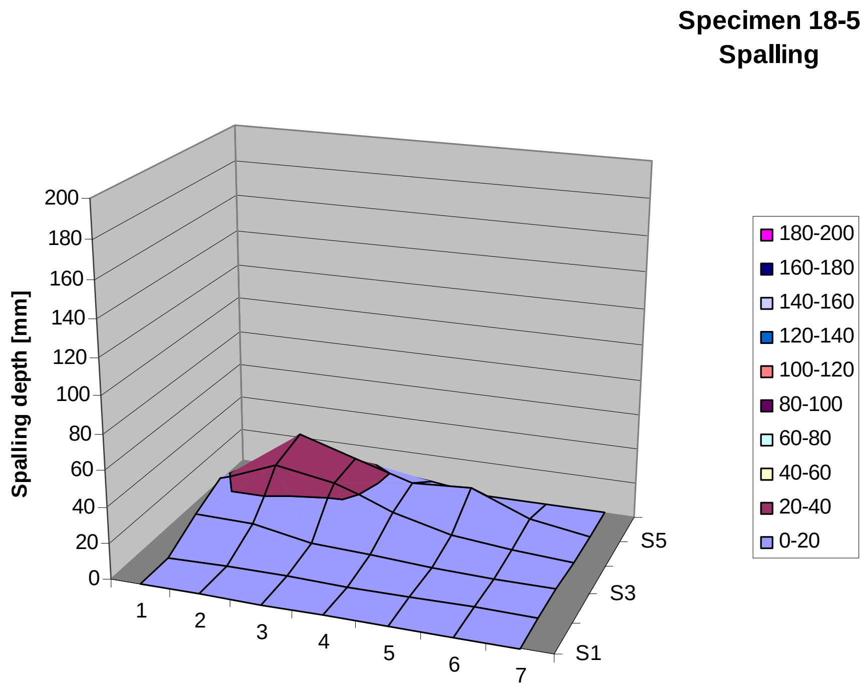


Figure A.237 Spalling measurements on specimen 18-5.

Table A.130 Observations made on specimen 18-5

Time	Observation			
0,00	Start of test	Test date:	2006-05-09	
17,73	One explosion	Specimen:	18-5	
20,95	One small explosion	Load level:	141	kN/bar
33,00	Water on top surface	Weight loss:	6,3	kg
60,00	Test terminates			

Figure A.238 Specimen 18-5 after test.

Specimen 18-6

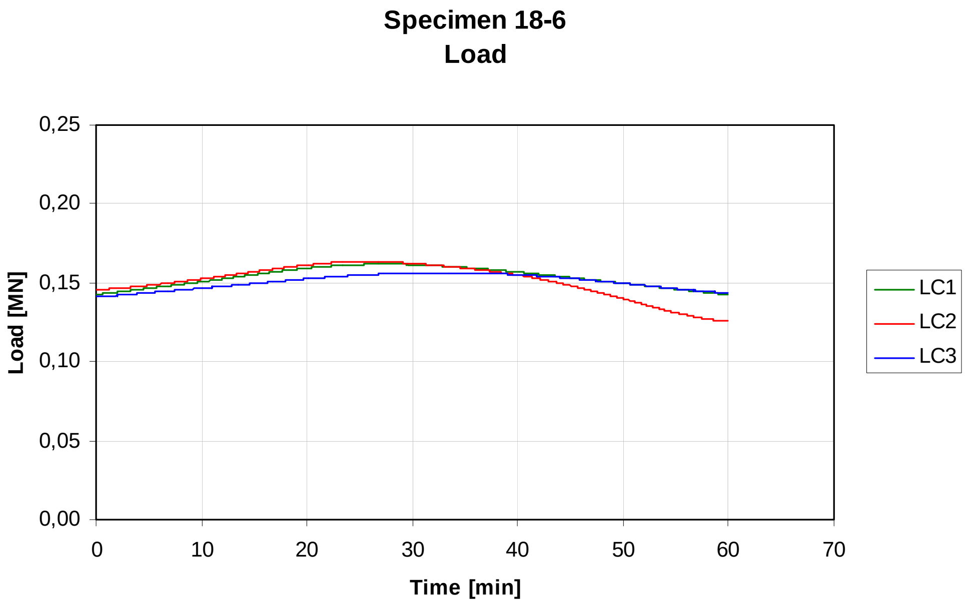


Figure A.239 Load measurements on specimen 18-6.

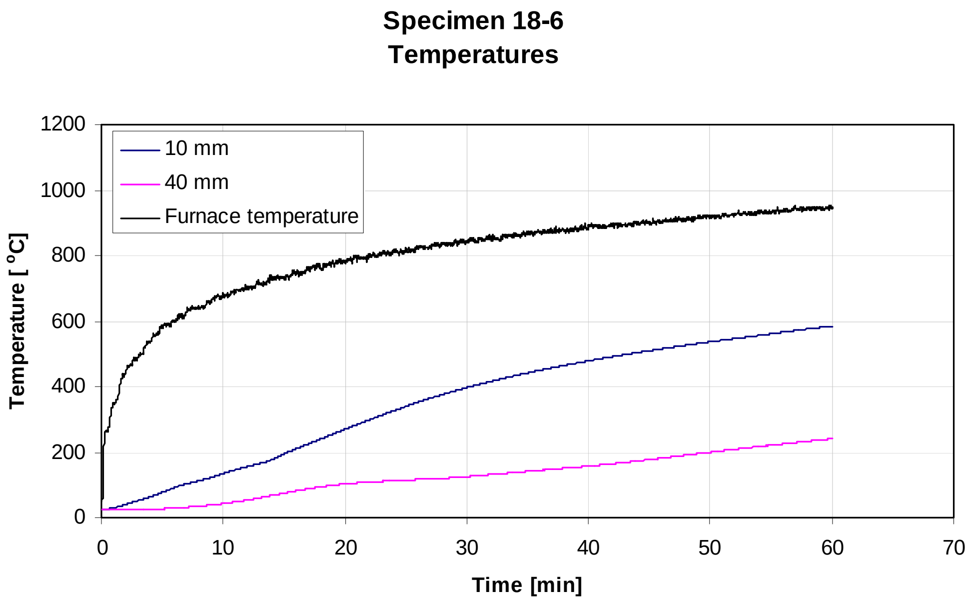


Figure A.240 Measured temperatures in furnace and in specimen 18-6.

Table A.131 Spalling measurements on specimen 18-6

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

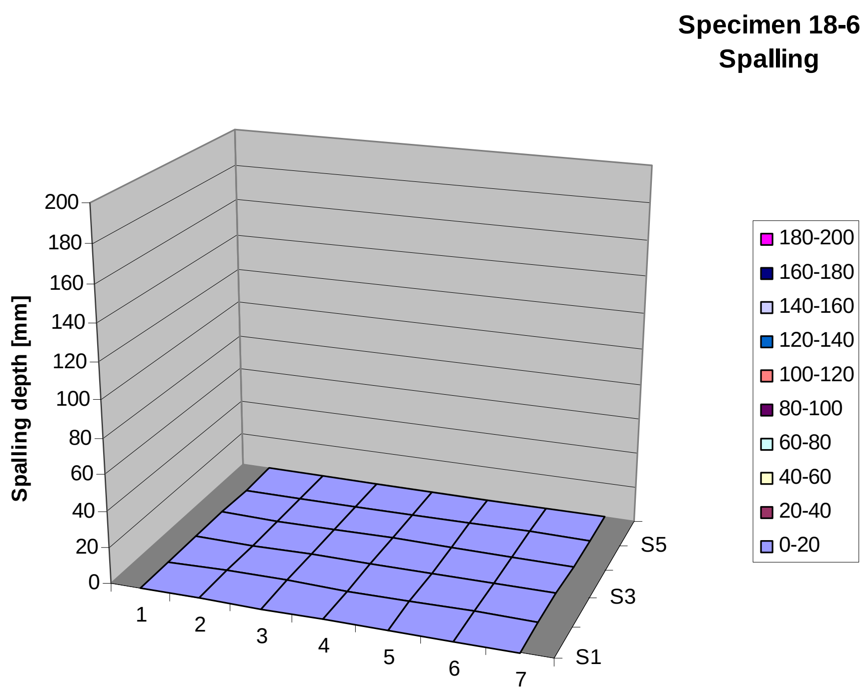


Figure A.241 Spalling measurements on specimen 18-6.

Table A.132 Observations made on specimen 18-6.

Time	Observation			
0,00	Start of test	Test date:	2006-05-09	
29,00	Water on top surface	Specimen:	18-6	
60,00	Test terminates	Load level:	143	kN/bar
		Weight loss:	5,1	kg

Figure A.242 Specimen 18-6 after test.

Concrete 19

Table A.133 Concrete admixture recipe 19.

Recipe	**19**
Water (kg/m^3)	236
CEM II 42,5R A-LL (kg/m^3)	365
Limestone filler, Limus 25 (kg/m^3)	109
Water-powder ratio, w/p	0,50
Water-cement ratio, w/c	0,65
Glenium	2,45
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	65
Partly crushed 8 – 16 mm (%)	35
Slump flow (mm)	610
T50 (s)	1-2
Air (%)	1.6
Compressive strength, 28 days (MPa)	33.7

Specimen 19-5

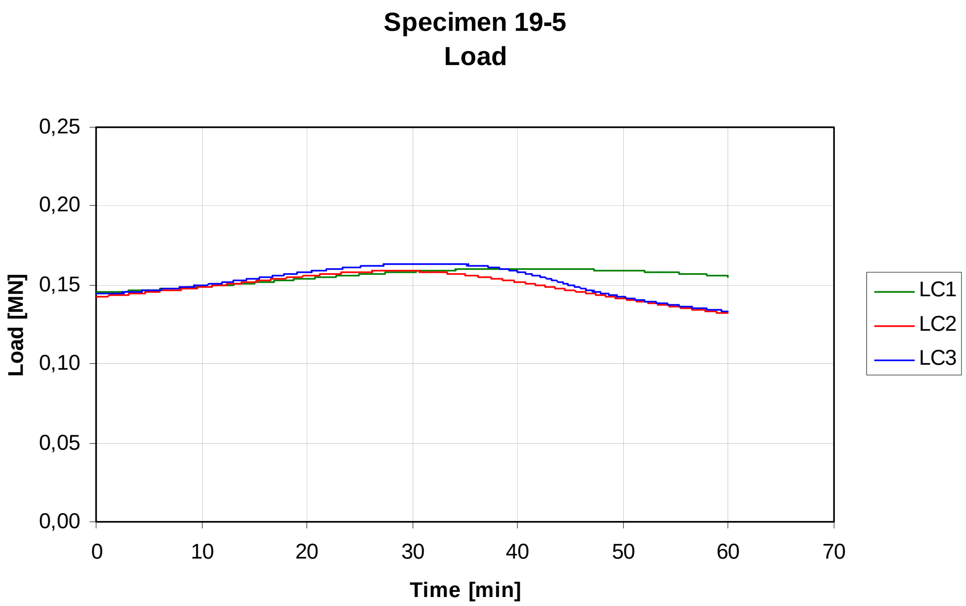


Figure A.243 Load measurements on specimen 19-5.

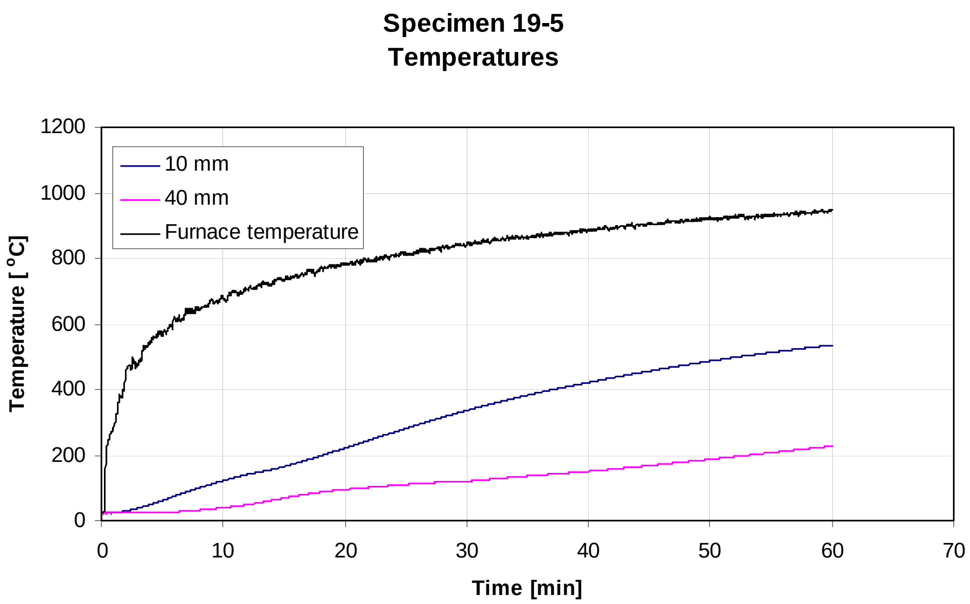


Figure A.244 Measured temperatures in furnace and in specimen 19-5.

Table A.134 Spalling measurements on concrete 19-5.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

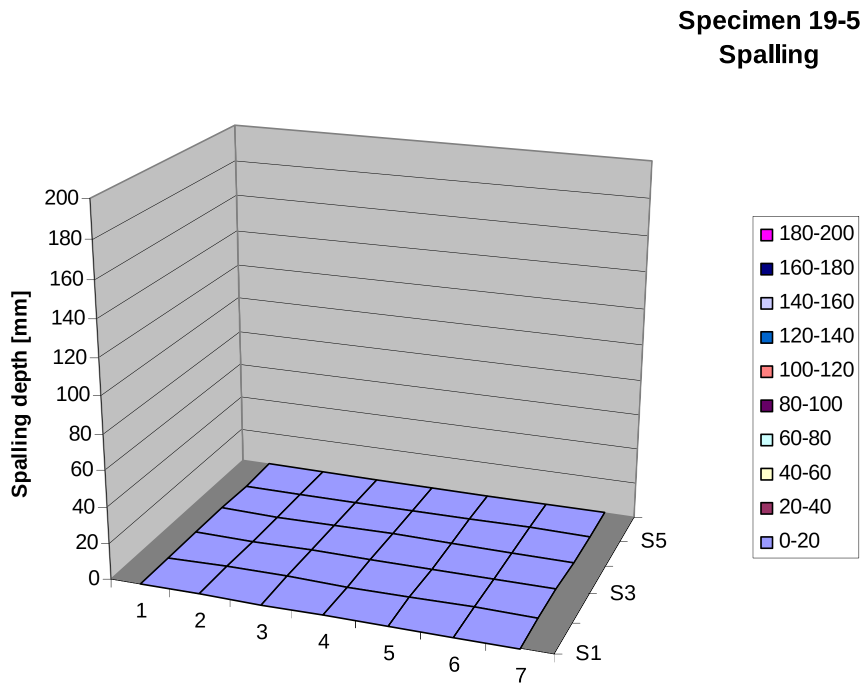


Figure A.245 Spalling measurements on concrete 19-5.

Table A.135 Observations made on specimen 19-5.

Time	Observation			
0,00	Start of test	Test date:	2006-06-12	
60,00	Test terminates	Specimen:	19-5	
		Load level:	144	kN/bar
		Weight loss:	1,7	kg

Figure A.246 Specimen 19-5 after test.

Specimen 19-6

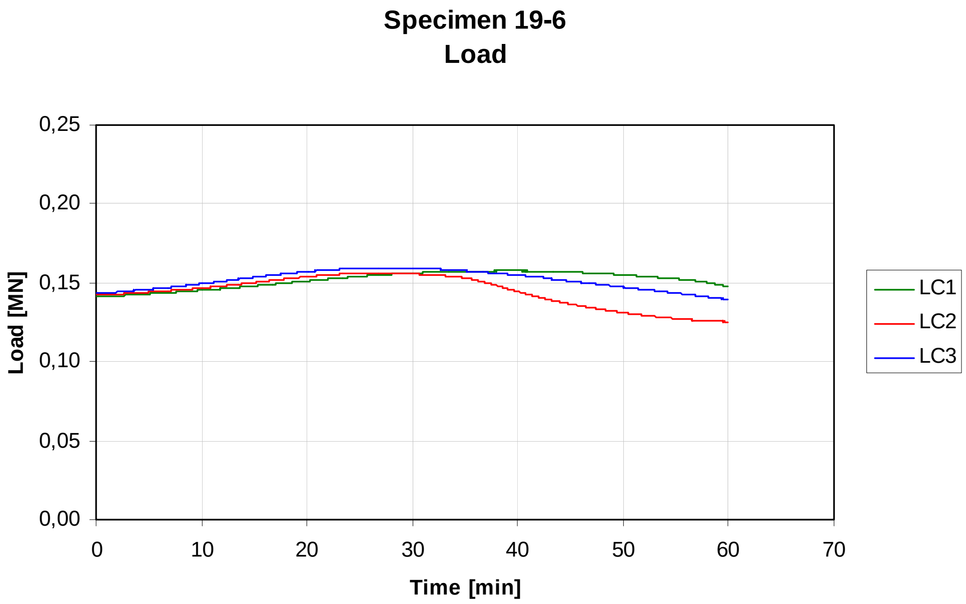


Figure A.247 Load measurements on specimen 19-6.

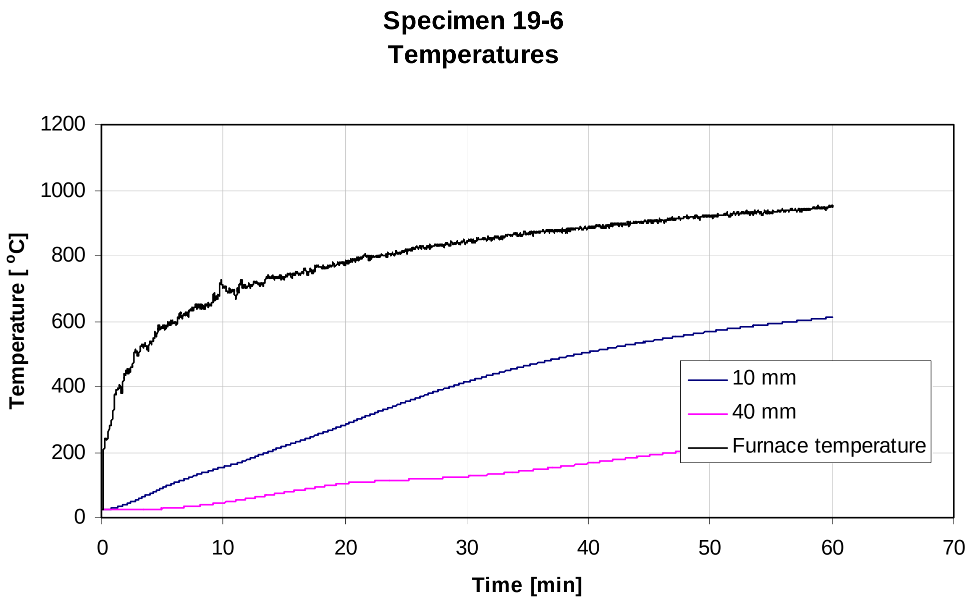


Figure A.248 Measured temperatures in furnace and in specimen 19-6.

Table A.136 Spalling measurements on specimen 19-6

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

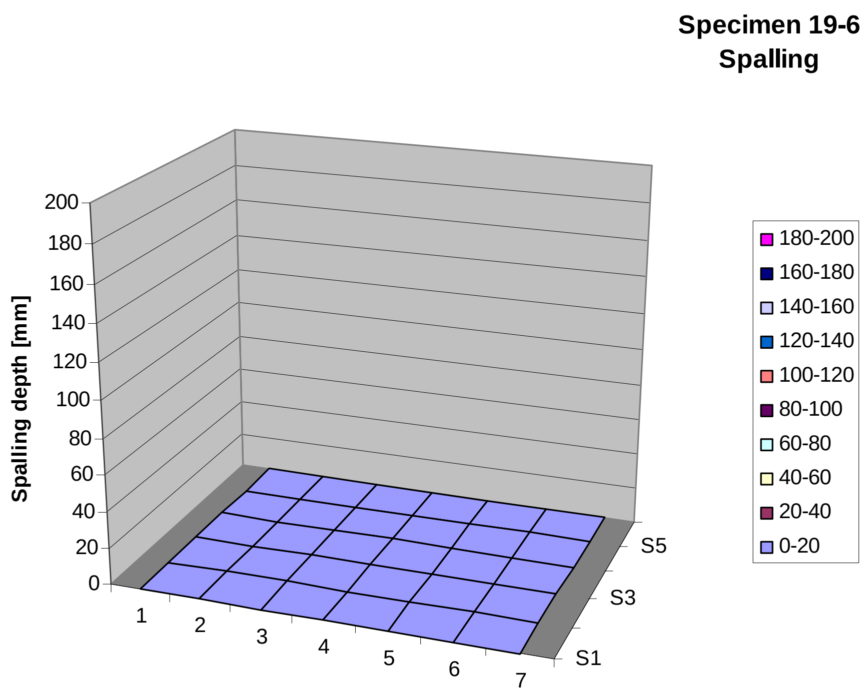


Figure A.249 Spalling measurements on specimen 19-6.

Table A.137 Observations made on specimen 19-6.

Time	Observation			
0,00	Start of test	Test date:	2006-06-13	
35,00	Water on top	Specimen:	19-6	
60,00	Test terminates	Load level:	142	kN/bar
		Weight loss:	1,5	kg

Figure A.250 Specimen 19-6 after test.

Concrete 25

Table A.138 Concrete admixture recipe 25.

Recipe	**25**
Water (kg/m^3)	198
CEM II 42,5R A-LL (kg/m^3)	380
Limestone filler, Limus 25 (kg/m^3)	60
Water-powder ratio, w/p	0,45
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,7
Sikament 20HE 50 (% of cement weight)	1,50
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	650
T50 (s)	2-3
Air (%)	2.0
Compressive strength, 28 days (MPa)	43.9

Specimen 25-5

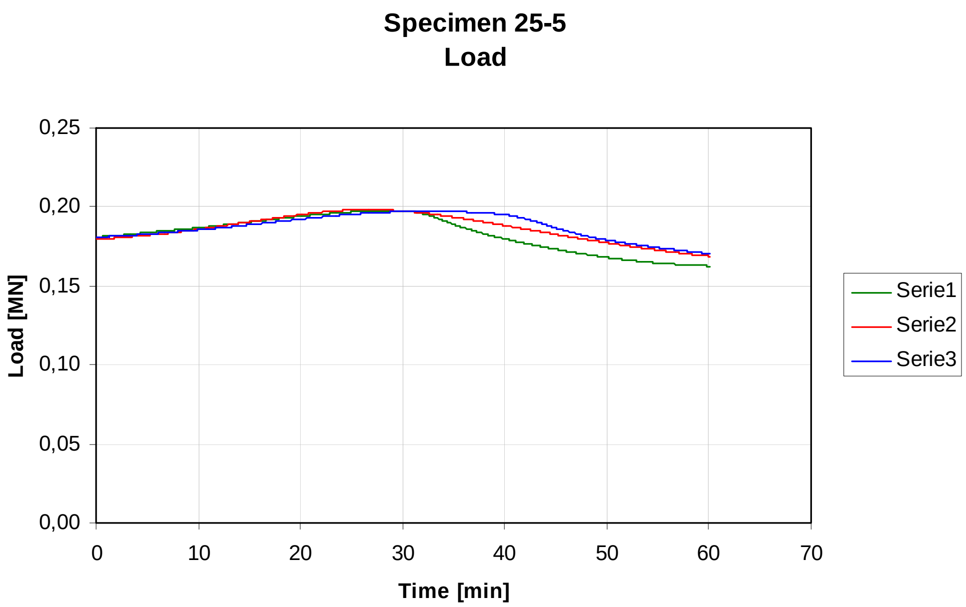


Figure A.251 Load measurements on specimen 25-5.

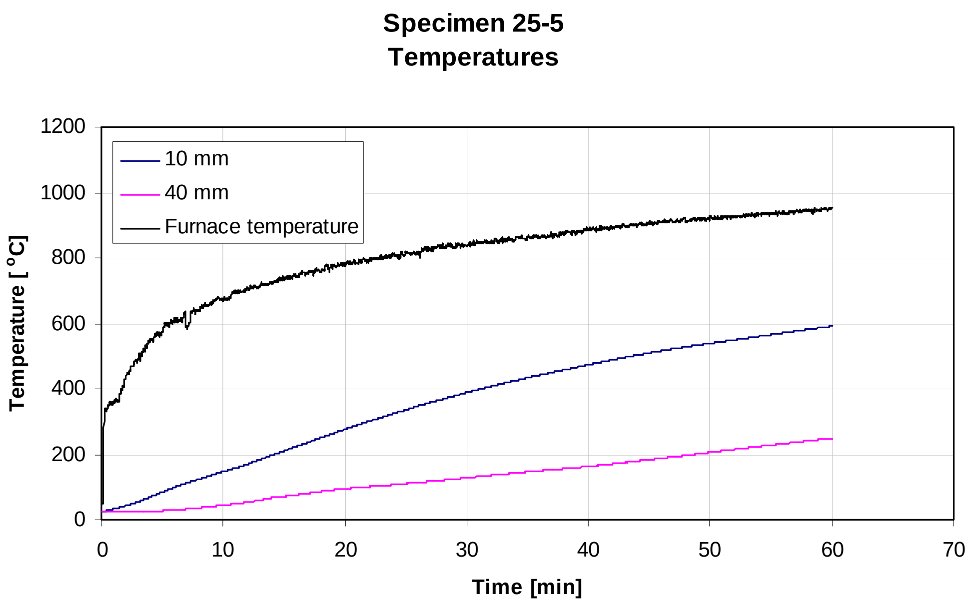


Figure A.252 Measured temperatures in furnace and in specimen 25-5.

Table A.139 Spalling measurements on specimen 25-5.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

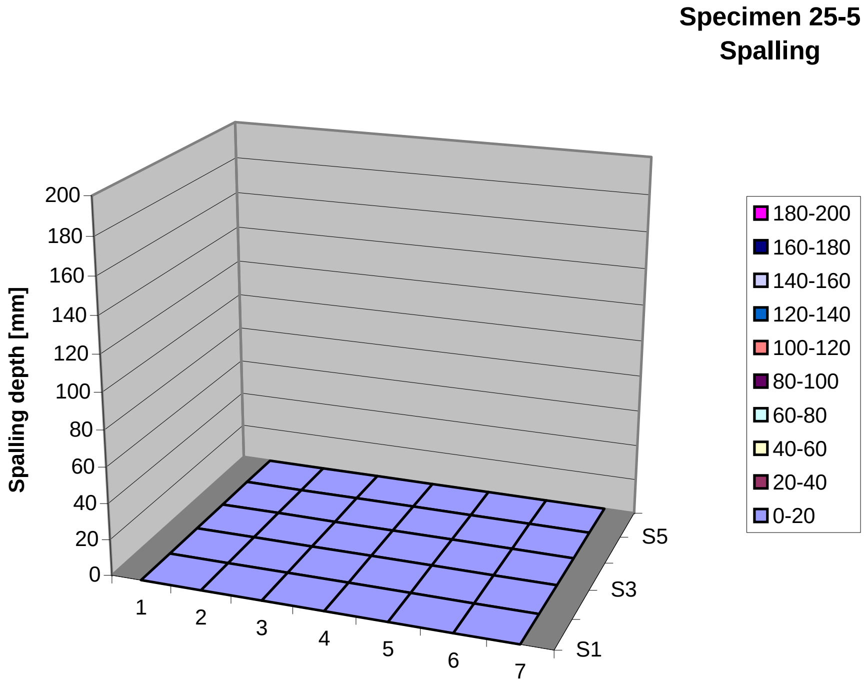


Figure A.253 Spalling measurements on specimen 25-5.

Table A.140 Observations made on specimen 25-5.

Time	Observation			
0,00	Start of test	Test date:	2006-09-12	
30,00	Water on top face	Specimen:	25-5	
60,00	Test terminates	Load level:	181	kN/bar
		Weight loss:	1,7	kg

Specimen 25-6

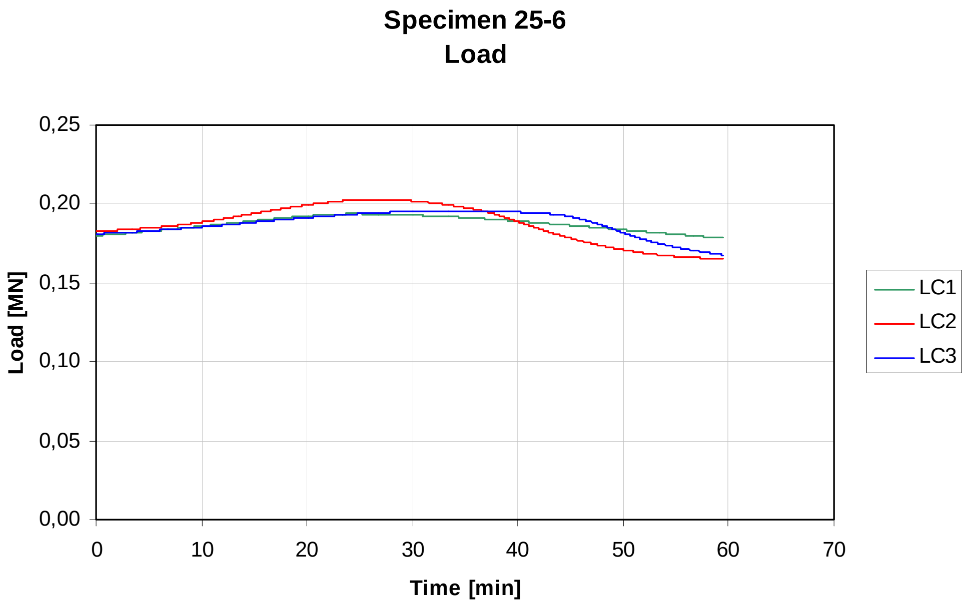


Figure A.254 Load measurements on specimen 25-6.

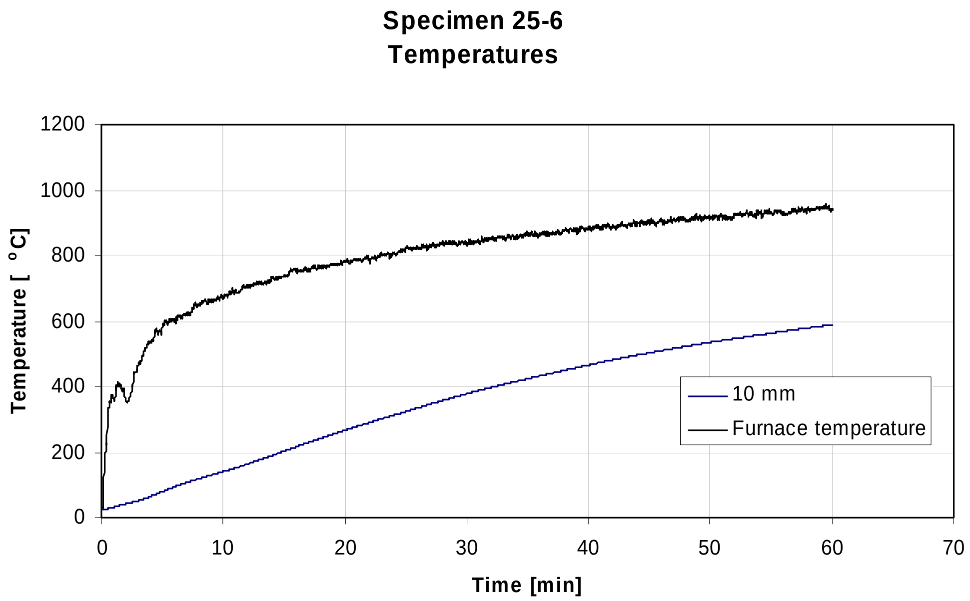


Figure A.255 Measured temperatures in furnace and in specimen 25-6.

Table A.141 Spalling measurements on specimen 25-6.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

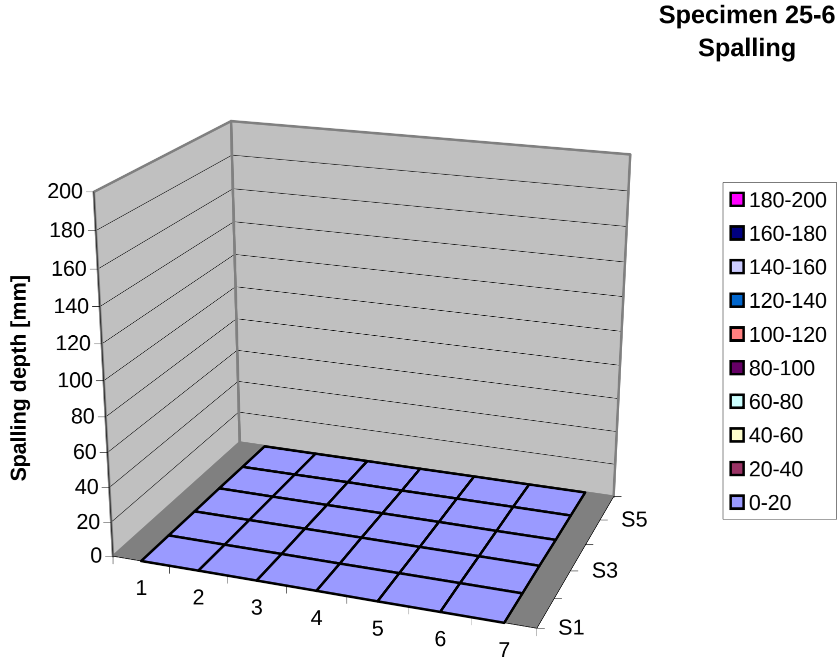


Figure A.256 Spalling measurements on specimen 25-6.

Table A.142 Observations made on specimen 25-6.

Time	Observation			
0,00	Start of test	Test date:	2006-09-12	
30,00	Water on top face	Specimen:	25-6	
60,00	Test terminates	Load level:	181	kN/bar
		Weight loss:	1,8	kg

Concrete 26

Table A.143 Concrete admixture recipe 26.

Recipe	**26**
Water (kg/m^3)	222
CEM II 42,5R A-LL (kg/m^3)	430
Limestone filler, Limus 25 (kg/m^3)	124
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,2
Sikament 20HE 50 (% of cement weight)	1,21
Fiber, Sika Crackstop, ϕ=18 µm, l=6 mm (kg/m^3)	1,5
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	600
T50 (s)	4-5
Air (%)	2.0
Compressive strength, 28 days (MPa)	41.1

Specimen 26-3

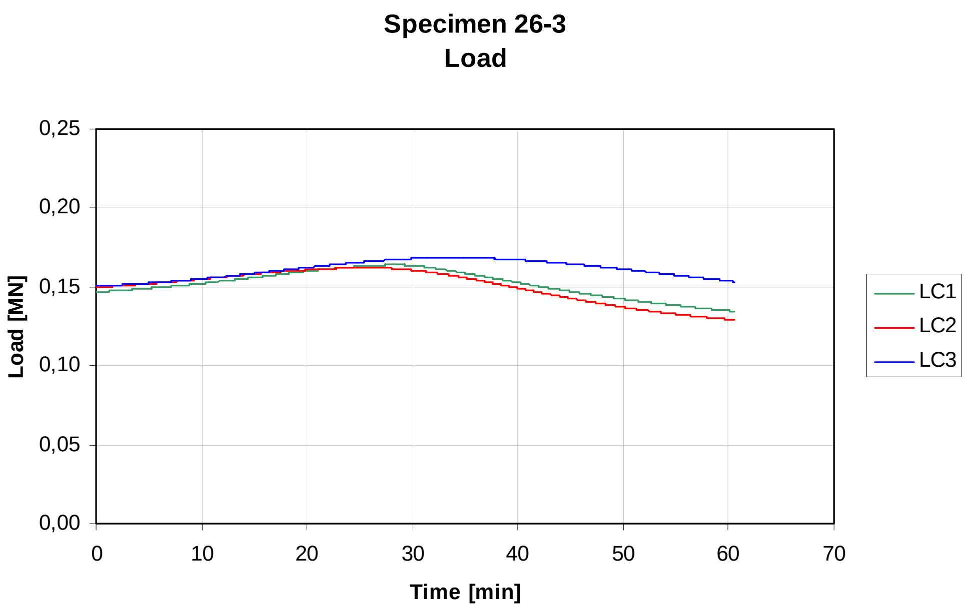


Figure A.257 Load measurements on specimen 26-3.

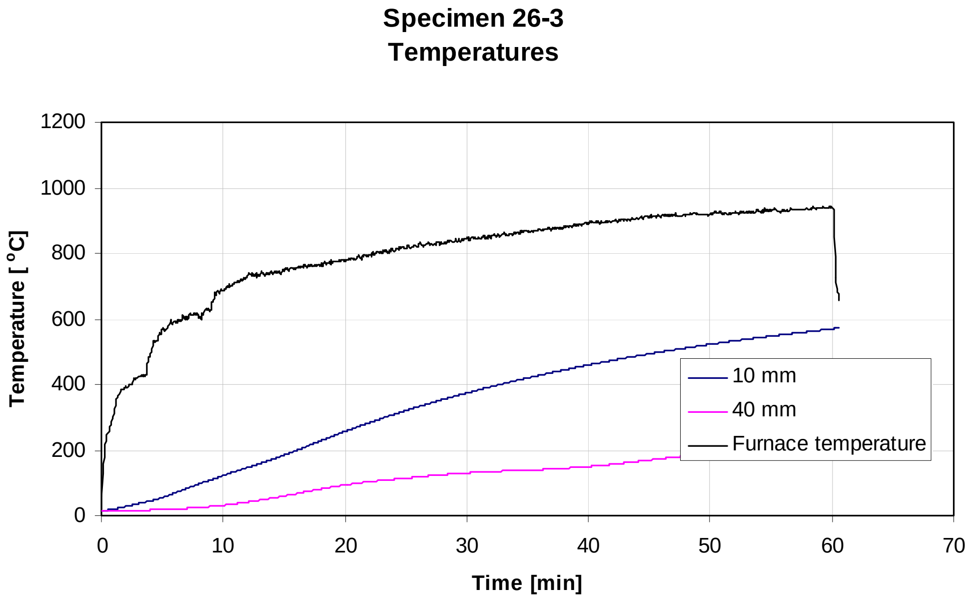


Figure A.258 Measured temperatures in furnace and in specimen 26-3.

Table A.144 Spalling measurements on specimen 26-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

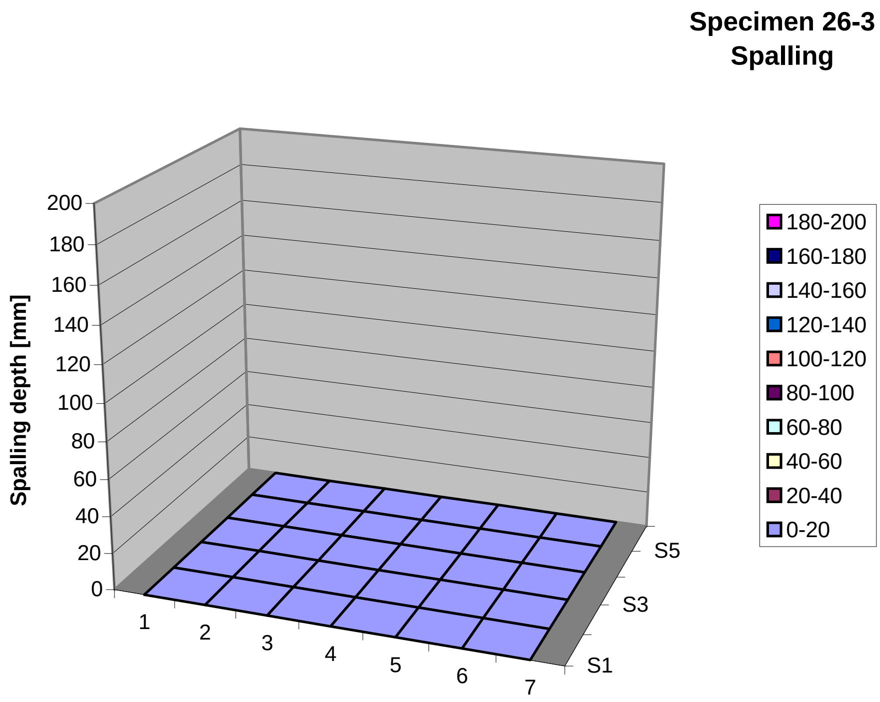


Figure A.259 Spalling measurements on specimen 26-3.

Table A.145 Observations made on specimen 26-3.

Time	Observation			
0,00	Start of test	Test date:	2006-10-12	
25,00	Water on one side and a crack	Specimen:	26-3	
60,00	Test terminates	Load level:	149	kN/bar
		Weight loss:	1,7	kg

Figure A.260 Specimen 26-3 after test.

Specimen 26-8

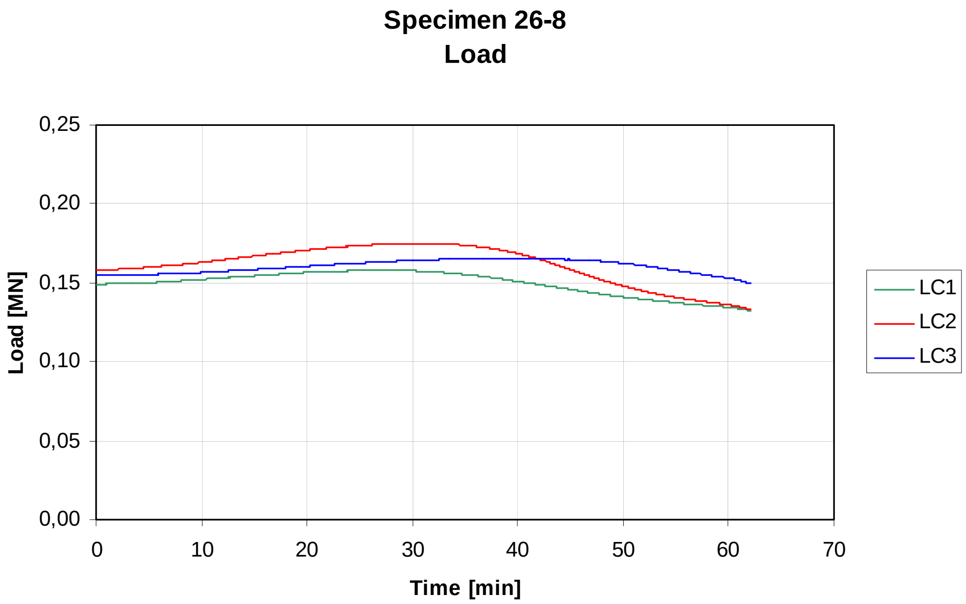


Figure A.261 Load measurements on specimen 26-8.

Table A.146 Spalling measurements on specimen 26-8.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

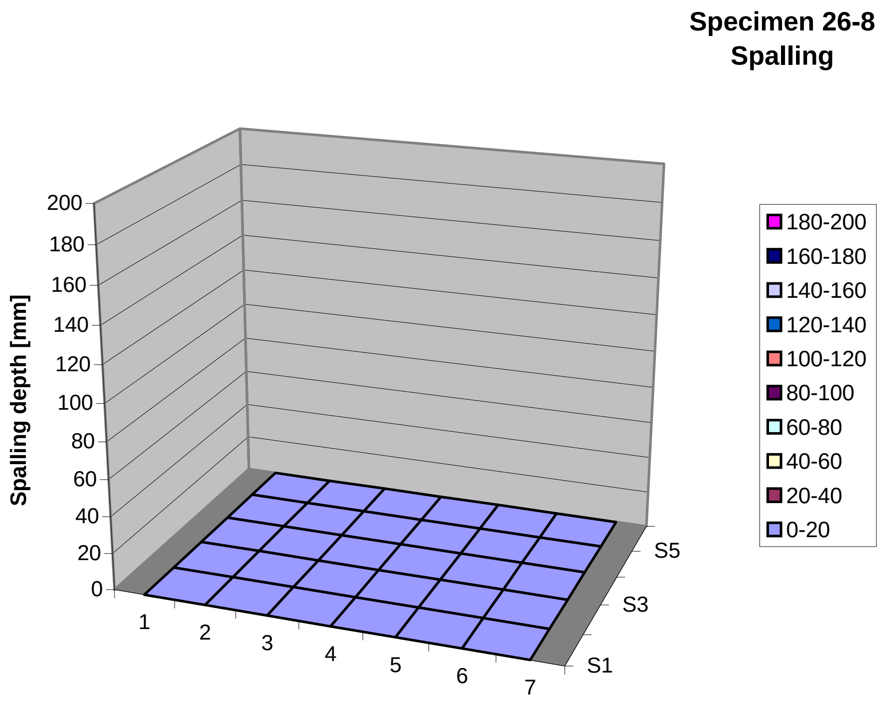


Figure A.262 Spalling measurements on specimen 26-8.

Table A.147 Observations made on specimen 26-8.

Time	Observation			
0,00	Start of test	Test date:	2006-10-16	
38,00	Water on top face	Specimen:	26-8	
60,00	Test terminates	Load level:	154	kN/bar
		Weight loss:	1,4	kg

Figure A.263 Specimen 26-8 after test.

Concrete 27

Table A.148 Concrete admixture recipe 27.

Recipe	**27**
Water (kg/m^3)	198
CEM II 42,5R A-LL (kg/m^3)	380
Limestone filler, Limus 25 (kg/m^3)	60
Water-powder ratio, w/p	0,45
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	6,0
Sikament 20HE 50 (% of cement weight)	1,58
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	1,5
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	620
T50 (s)	3-4
Air (%)	2.6
Compressive strength, 28 days (MPa)	44.2

Specimen 27-1

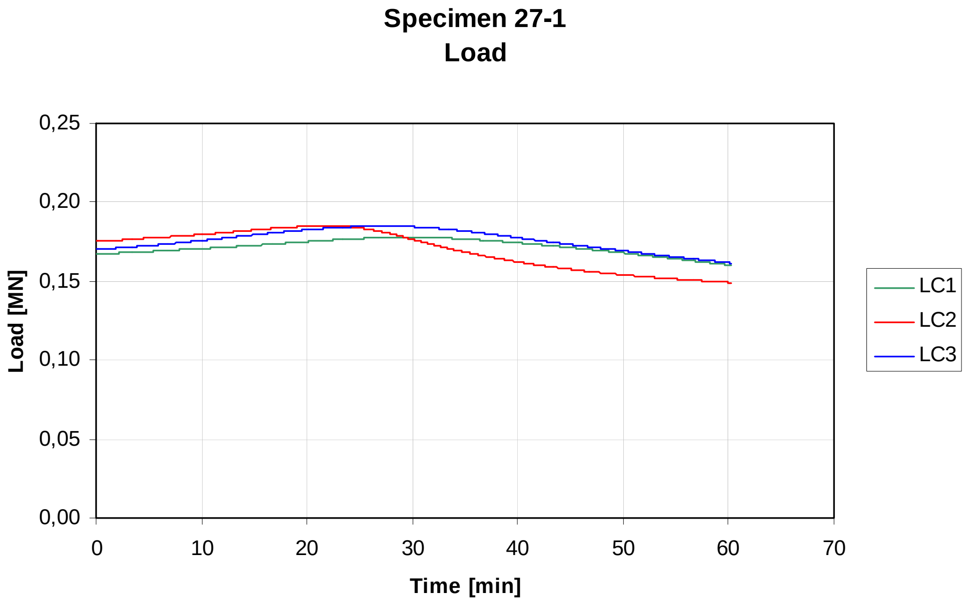


Figure A.264 Load measurements on specimen 27-1.

Table A.149 Spalling measurements on 27-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

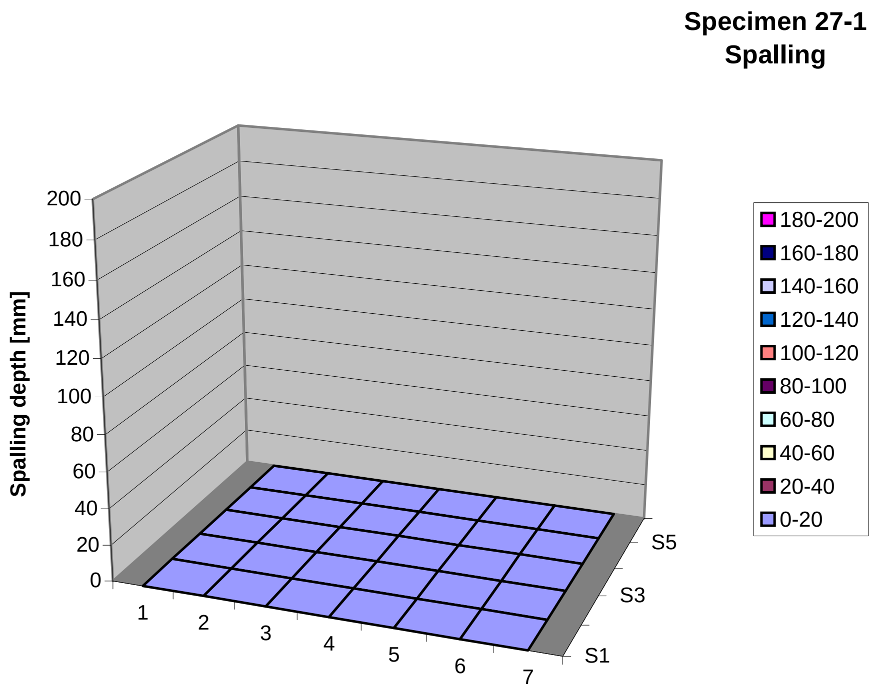


Figure A.265 Spalling measurements on 27-1.

Table A.150 Observations made on specimen 27-1.

Time	Observation			
0,00	Start of test	Test date:	2006-10-17	
22,00	Water on top face	Specimen:	27-1	
33,00	Water on front side and horizontal crack	Load level:	171	kN/bar
43,00	Water on back side and horizontal crack	Weight loss:	1,7	kg
60,00	Test terminates			

Figure A.266 Specimen 27-1 after test.

Specimen 27-2

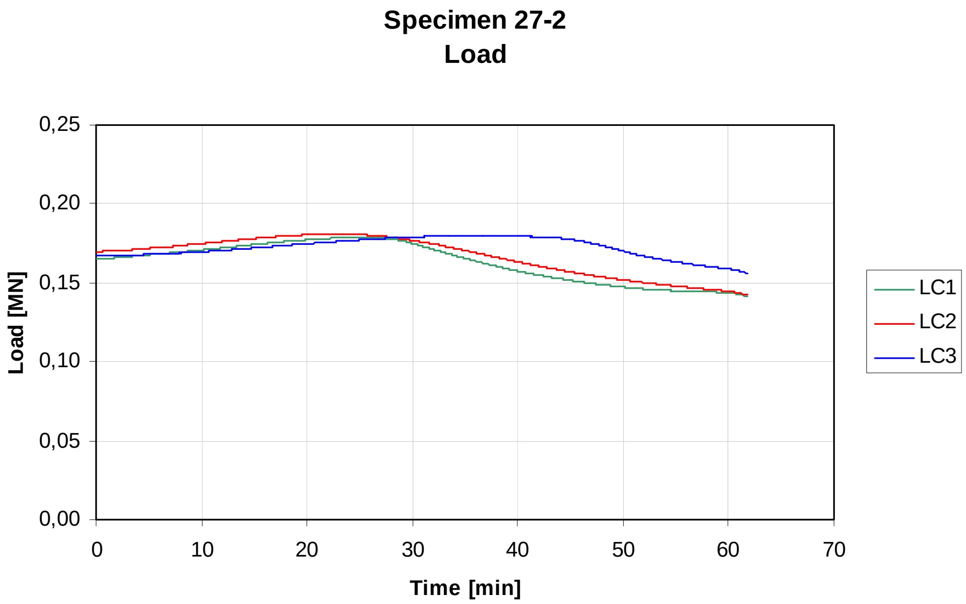


Figure A.267 Load measurements on specimen 27-2.

Table A.151 Spalling measurements on 27-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

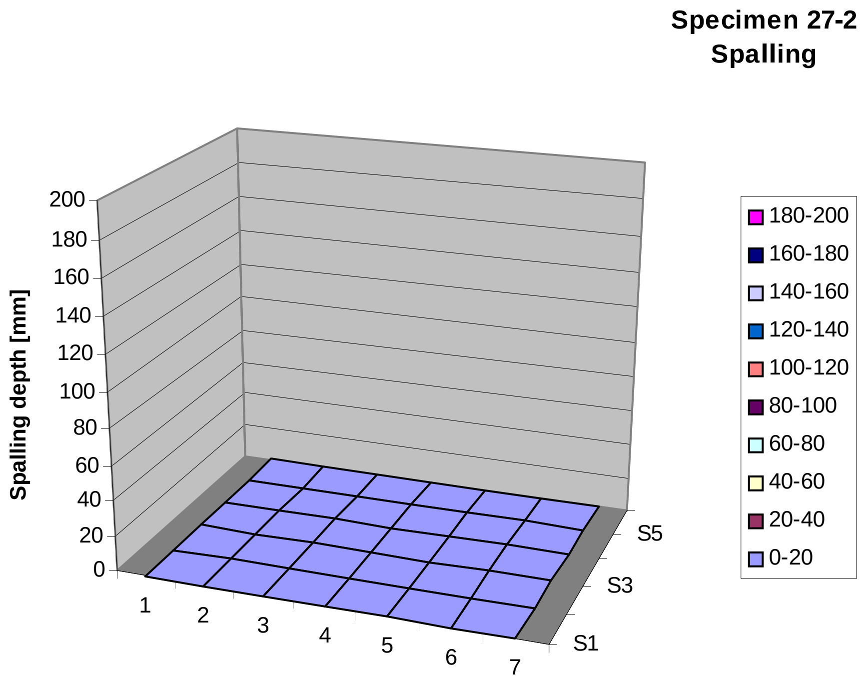


Figure A.268 Spalling measurements on 27-2.

Table A.152 Observations made on specimen 27-2.

Time	Observation			
0,00	Start of test	Test date:	2006-10-18	
40,00	Water on front side and horizontal crack	Specimen:	27-2	
50,00	Water on back side and horizontal crack	Load level:	167	kN/bar
60,00	Test terminates	Weight loss:	2,0	kg

Figure A.269 Specimen 27-2 after test.

Concrete 28

Table A.153 Concrete admixture recipe 28.

Recipe	28
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	140
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	5,4
Sikament 20HE 50 (% of cement weight)	1,29
Sikament 20HE (40% torrhalt, anv. i lab)	3,20
Sikament 20HE (% of cement weight)	0,76
Fiber, Sika Crackstop, ϕ=18 µm, l=6 mm (kg/m^3)	0,5
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	665
T50 (s)	6
Air (%)	2.9
Compressive strength, 28 days (MPa)	64.9

Specimen 28-3

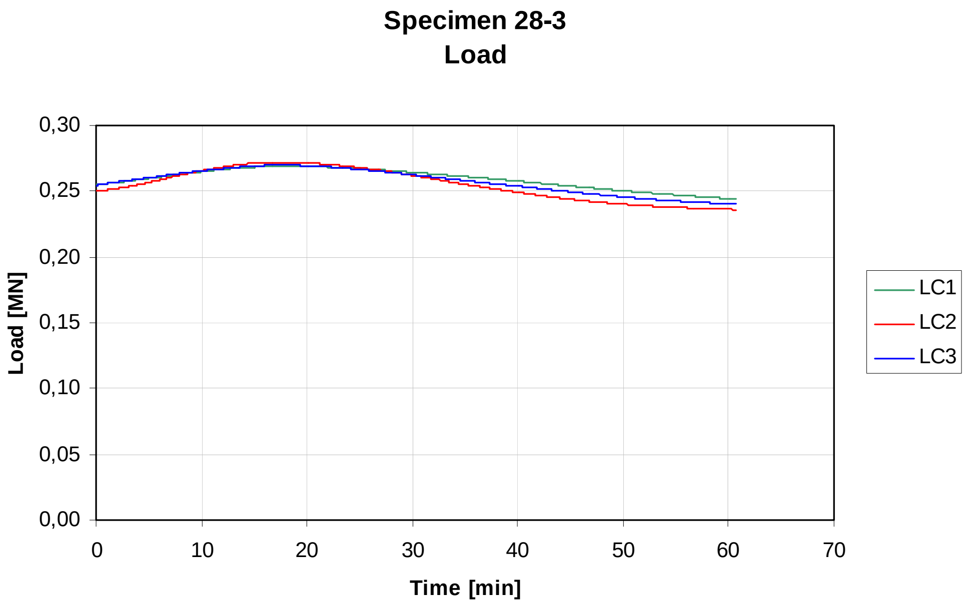


Figure A.270 Load measurements on specimen 28-3.

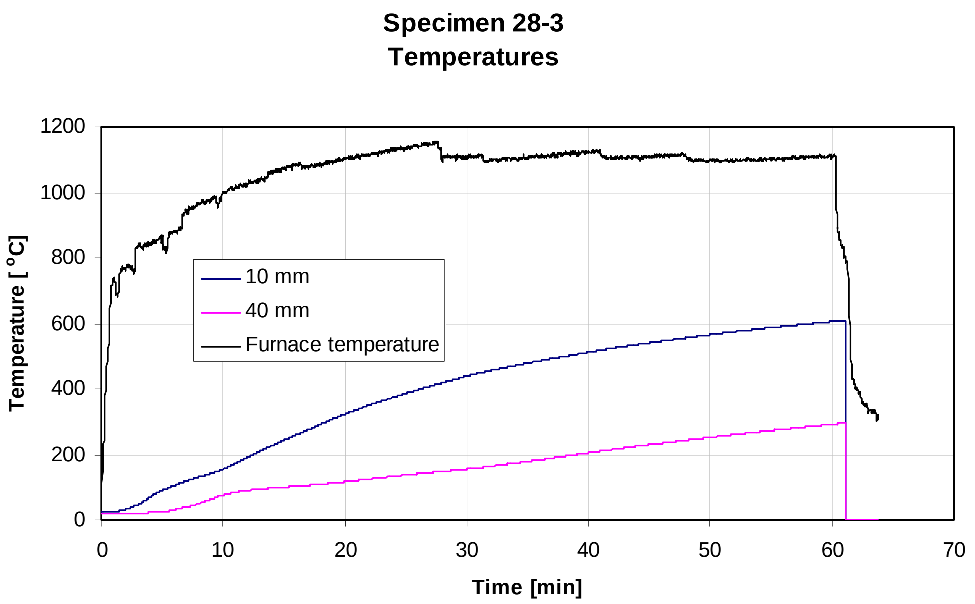


Figure A.271 Measured temperatures in furnace and in specimen 28-3.

Table A.154 Spalling measurements on specimen 28-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

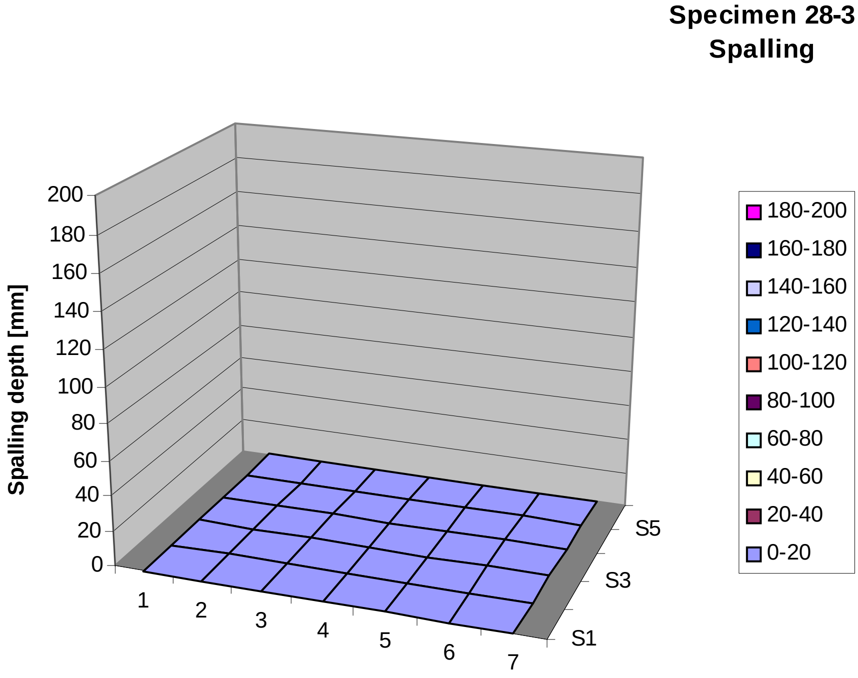


Figure A.272 Spalling measurements on specimen 28-3.

Table A.155 Observations made on specimen 28-3.

Time	Observation			
0,00	Start of test	Test date:	2006-12-21	
28,00	Water on back side and horizontal crack	Specimen:	28-3	
60,00	Test terminates	Load level:	253	kN/bar
		Weight loss:	2,2	kg

Figure A.273 Specimen 28-3 after test.

Specimen 28-8

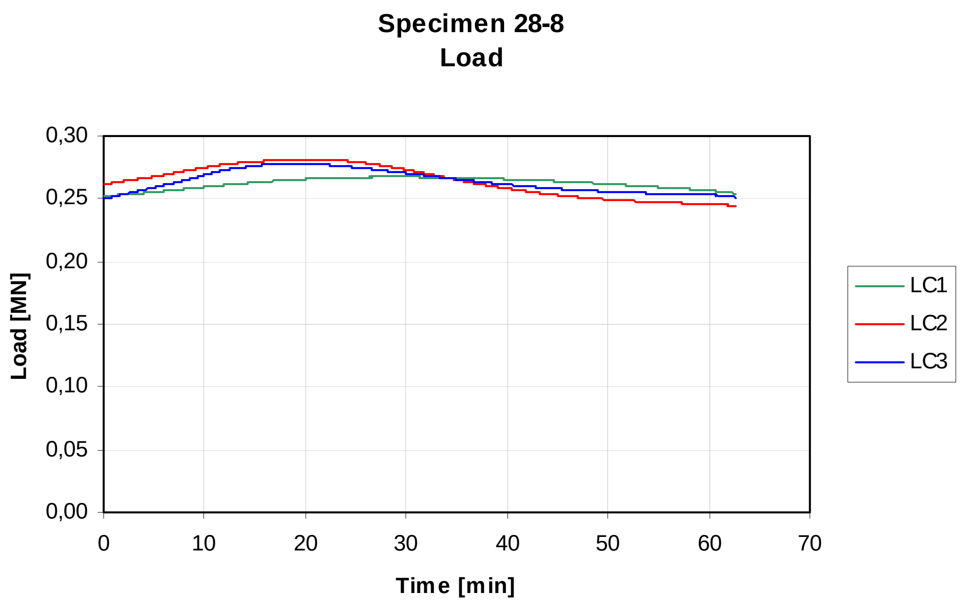


Figure A.274 Load measurements on specimen 28-8.

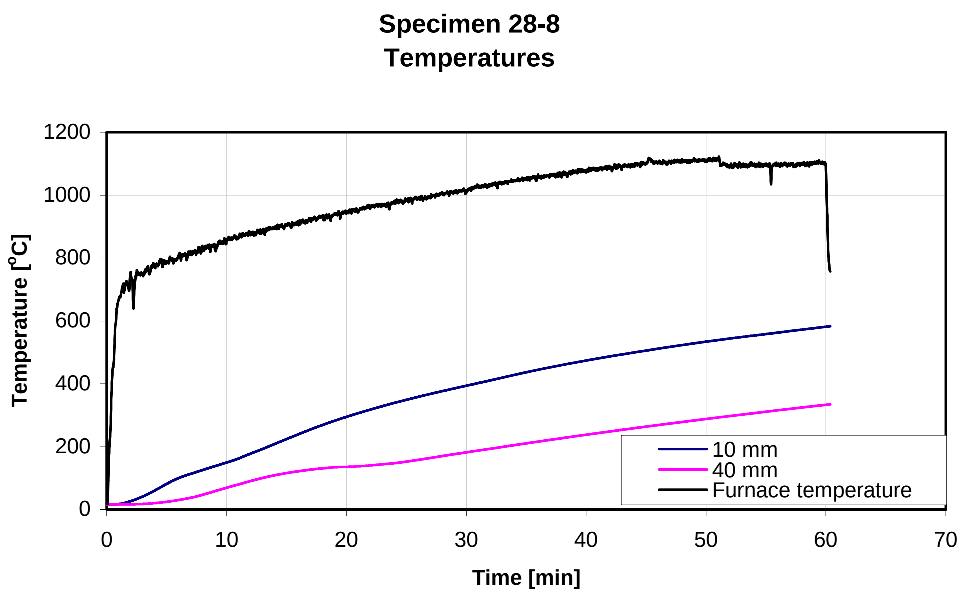


Figure A.275 Measured temperatures in furnace and in specimen 28-8.

Table A.156 Spalling measurements on specimen 28-8.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

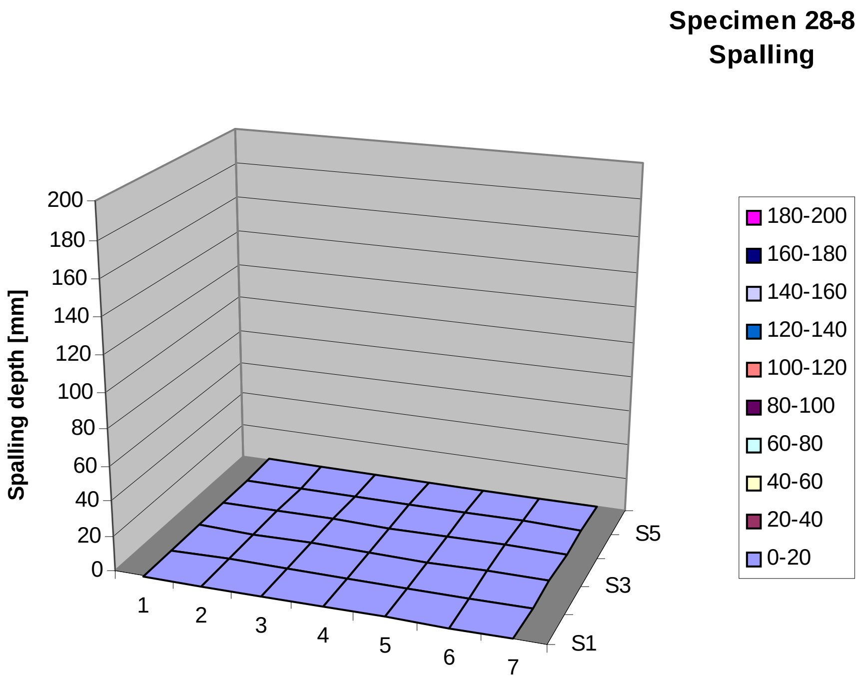


Figure A.276 Spalling measurements on specimen 28-8.

Table A.157 Observations made on specimen 28-8.

Time	Observation			
0,00	Start of test	Test date:	21/12/2006	
16,00	Water on top face	Specimen:	28-8	
46,00	Horizontal crack on back side	Load level:	255	kN/bar
60,00	Test terminates	Weight loss:	2,0	kg

Figure A.277 Specimen 28-8 after test.

Concrete 30

Table A.158 Concrete admixture recipe 30.

Recipe	30
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	560
Limestone filler, Limus 25 (kg/m^3)	0
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,30
Sikament 20HE 50 (20% torrhalt)	5,3
Sikament 20HE 50 (% of cement weight)	0,94
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	710
T50 (s)	6
Air (%)	2.8
Compressive strength, 28 days (MPa)	82.0

Specimen 30-2

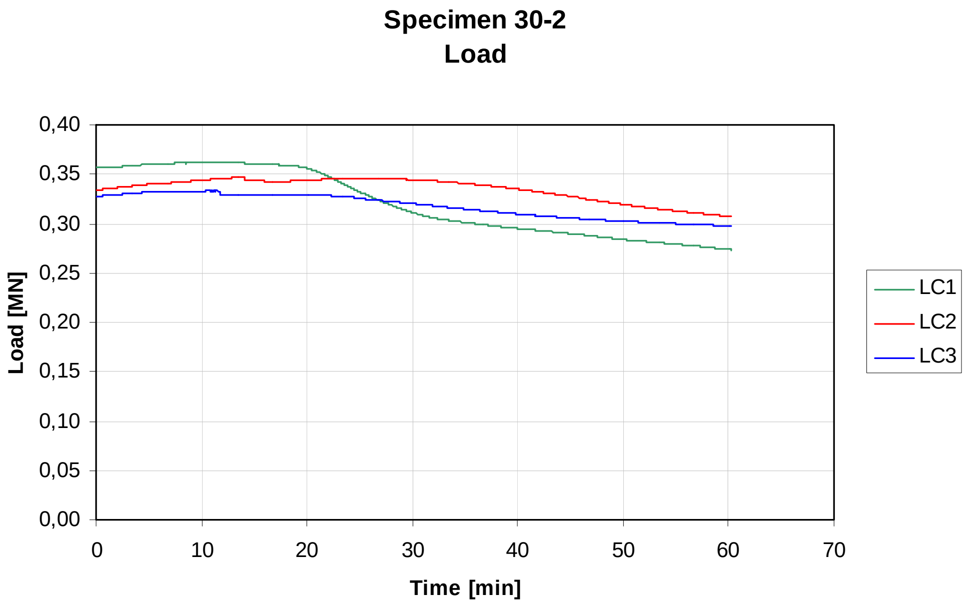


Figure A.278 Load measurements on specimen 30-2.

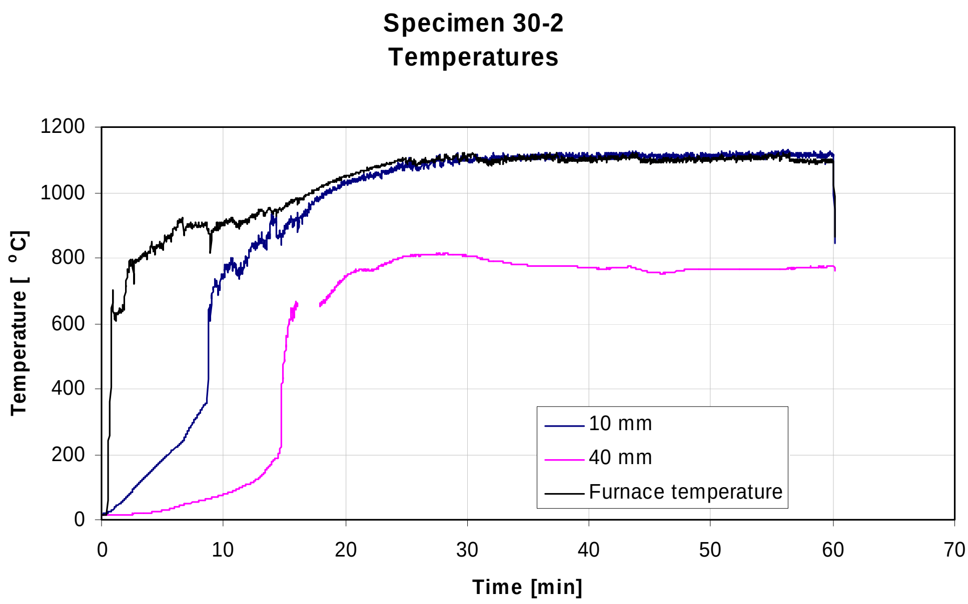


Figure A.279 Measured temperatures in furnace and in specimen 30-2.

Table A.159 Spalling measurements on specimen 30-2.

Position	0	100	200	300	400	500
0	0	0	19	0	0	0
100	0	10	38	19	12	4
200	0	21	40	40	17	0
300	0	28	36	42	21	6
400	0	31	82	35	5	0
500	0	3	93	30	10	0
600	0	1	100	8	0	0

Mean all	18
Mean inner	31
Max in diagram	100
Max measured	100

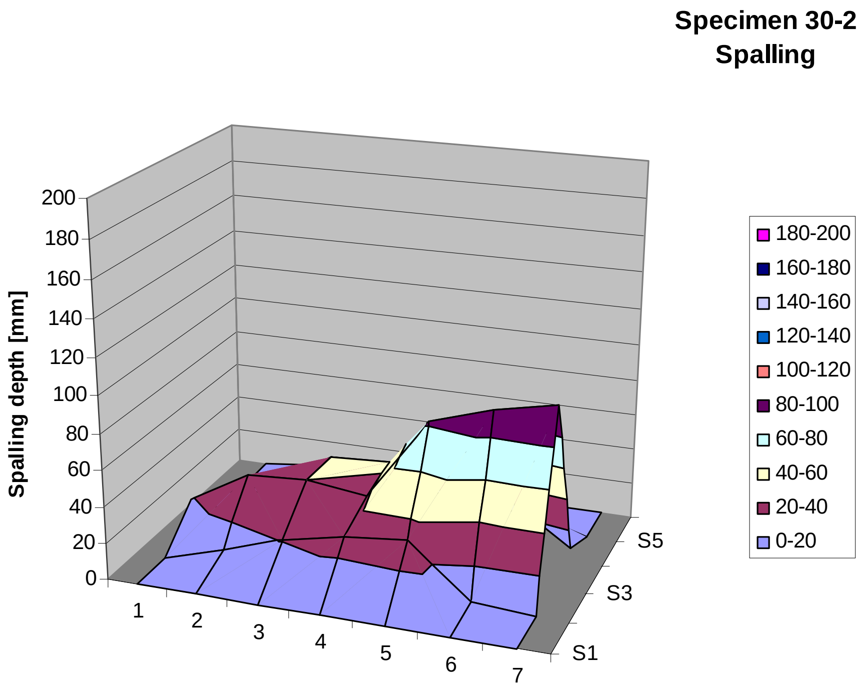


Figure A.280 Spalling measurements on specimen 30-2.

Table A.160 Observations made on specimen 30-2.

Time	Observation
0,00	Start of test
5,13	One explosion
5,53	One explosion
5,70	One loud explosion
6,08	One explosion
6,25	One explosion
6,37	One small explosion
6,50	One small explosion
6,72	One loud explosion
7,08	Two explosions, spalling continues
16,00	Spalling ends
39,00	Horizontal cracks on front and back sides
60,00	Test terminates

Test date:	2006-12-27	
Specimen:	30-2	
Load level:	339	kN/bar
Weight loss:	12,5	kg

Figure A.281 Specimen 30-2 after test.

Specimen 30-3

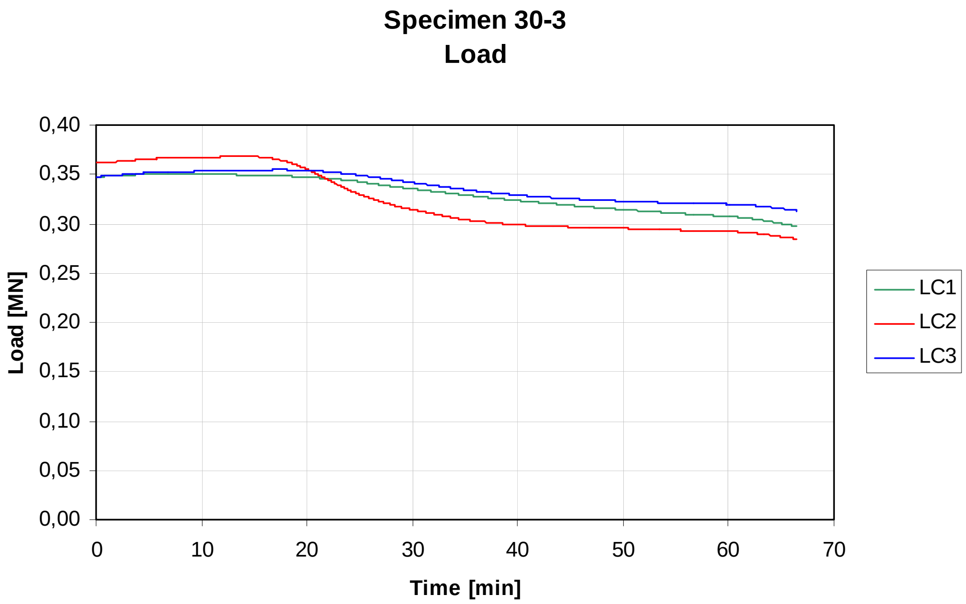


Figure A.282 Load measurements on specimen 30-3.

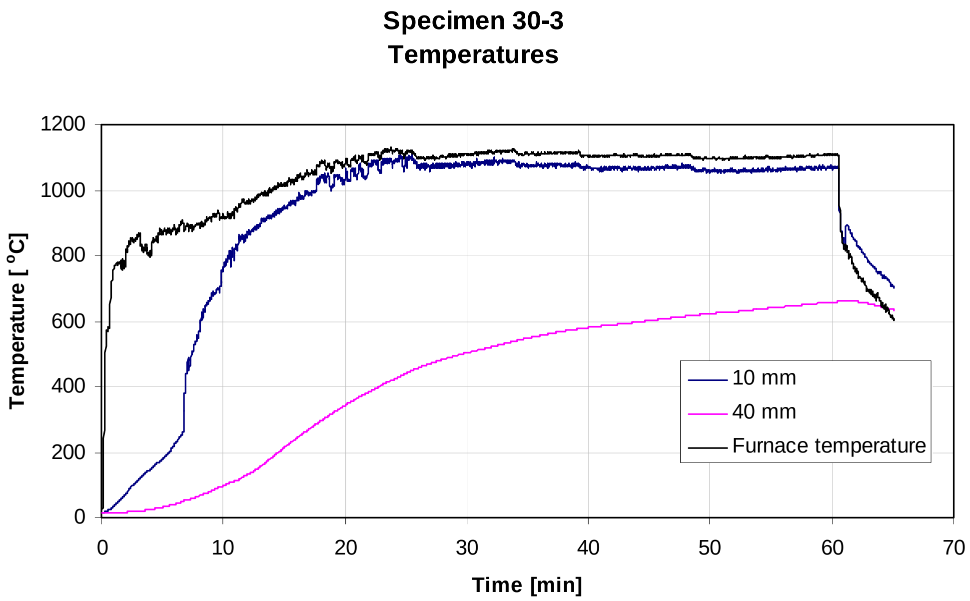


Figure A.283 Measured temperatures in furnace and in specimen 30-3.

Table A.161 Spalling measurements on specimen 30-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	1	7	18	2	0
200	1	11	28	33	12	0
300	1	16	37	31	8	0
400	0	20	23	28	4	0
500	0	14	19	15	2	0
600	0	0	0	0	0	0

Mean all	8
Mean inner	16
Max in diagram	37
Max measured	37

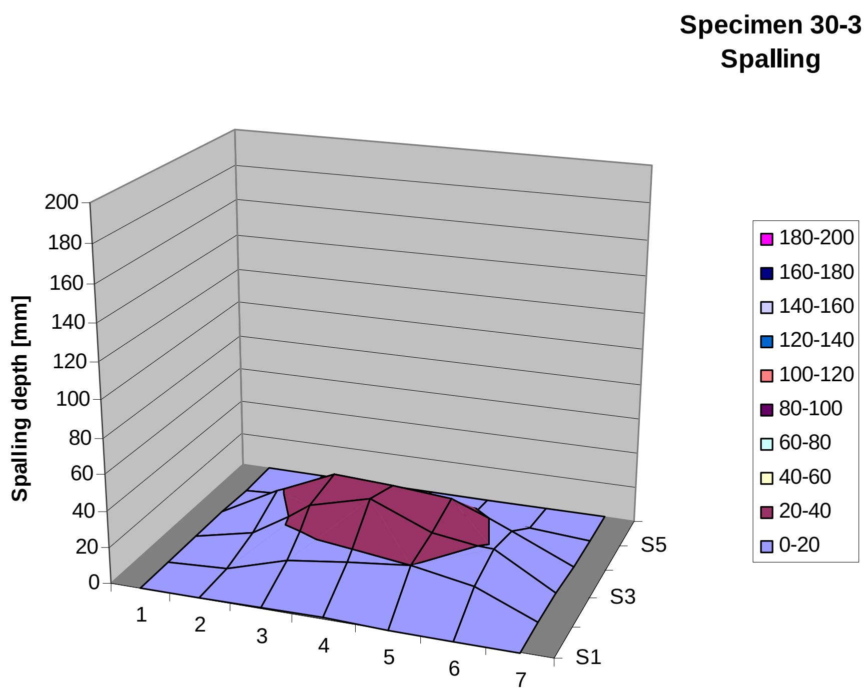


Figure A.284 Spalling measurements on specimen 30-3.

Figure A.285 Specimen 30-3 after test.

Concrete 31

Table A.162 Concrete admixture recipe 31.

Recipe	**31**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	60
Water-powder ratio, w/p	0,35
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	5,00
Sikament 20HE 50 (% of cement weight)	1,19
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	700
T50 (s)	7-8
Air (%)	2.7
Compressive strength, 28 days (MPa)	68.4

Specimen 31-4

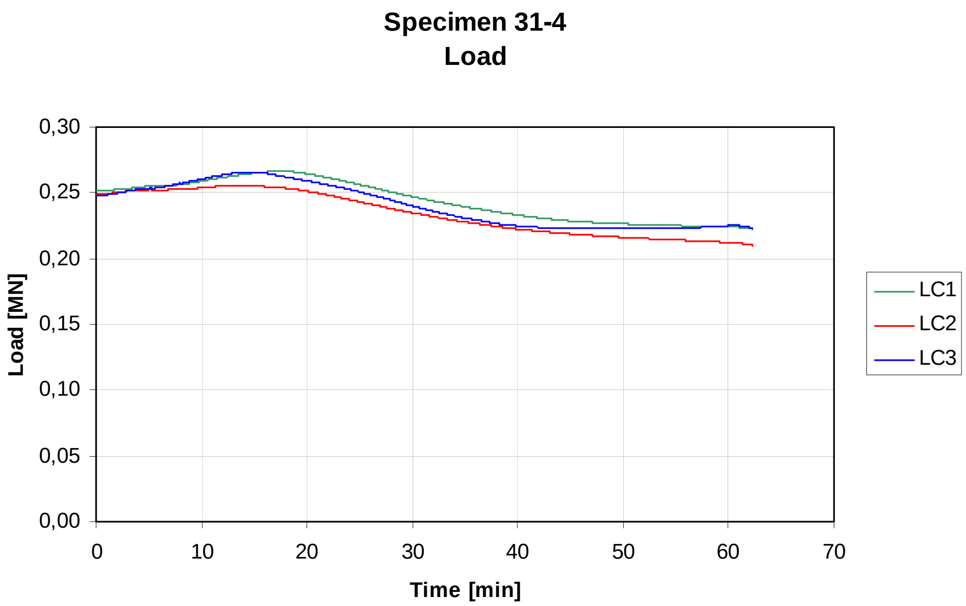


Figure A.286 Load measurements on specimen 31-4.

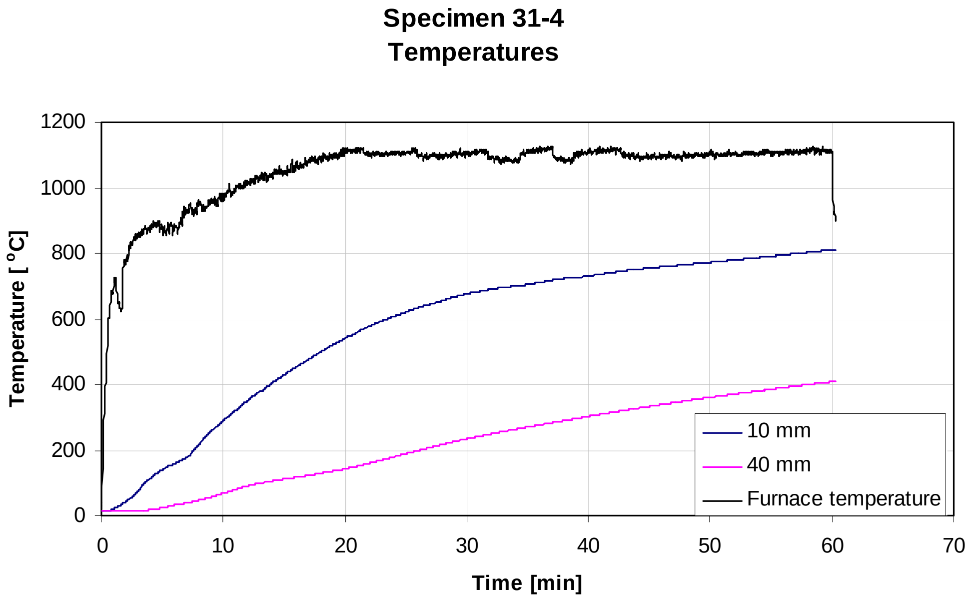


Figure A.287 Measured temperatures in furnace and in specimen 31-4.

Table A.163 Spalling measurements on specimen 31-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	7	12	0	15	1
200	0	10	17	9	15	5
300	0	14	16	4	11	0
400	0	12	13	8	9	0
500	0	10	8	18	13	0
600	0	0	0	0	0	0

Mean all	5
Mean inner	11
Max in diagram	18
Max measured	21

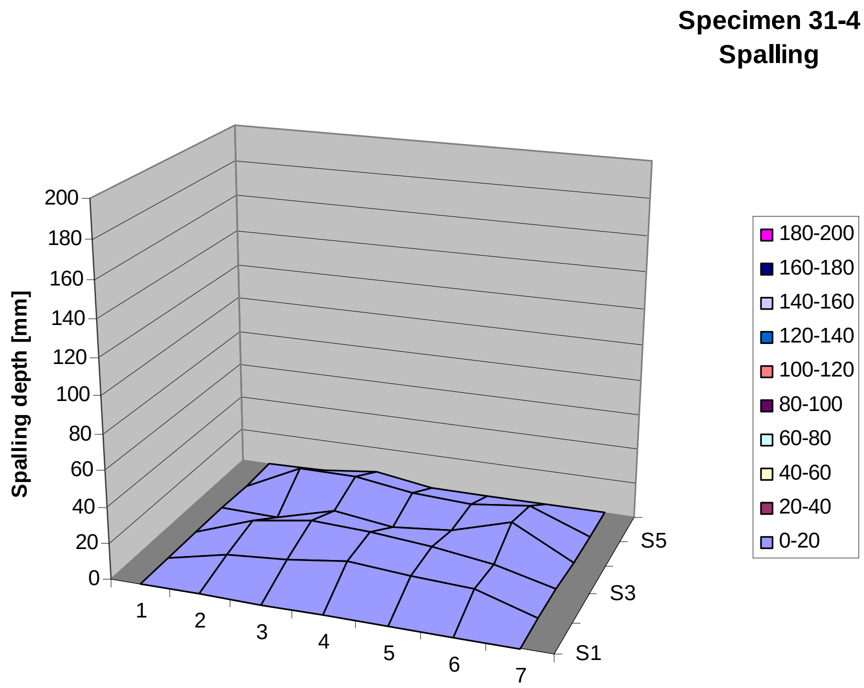


Figure A.288 Spalling measurements on specimen 31-4.

Table A.164 Observations made on specimen 31-4.

Time	Observation
0,00	Start of test
4,20	One small explosion
4,67	One explosion
4,75	One explosion
4,97	One explosion
5,30	One explosion
5,52	One loud explosion
5,83	One loud explosion
6,22	One explosion
6,23	One explosion
6,37	One small explosion
7,58	One explosion
7,70	One explosion
8,15	One small explosion
8,77	One small explosion
17,57	Large horizontal crack on back and front face
60,00	Test terminates

Test date:	2006-12-29	
Specimen:	31-4	
Load level:	249	kN/bar
Weight loss:	9,2	kg

Figure A.289 Specimen 31-4 after test.

Specimen 31-5

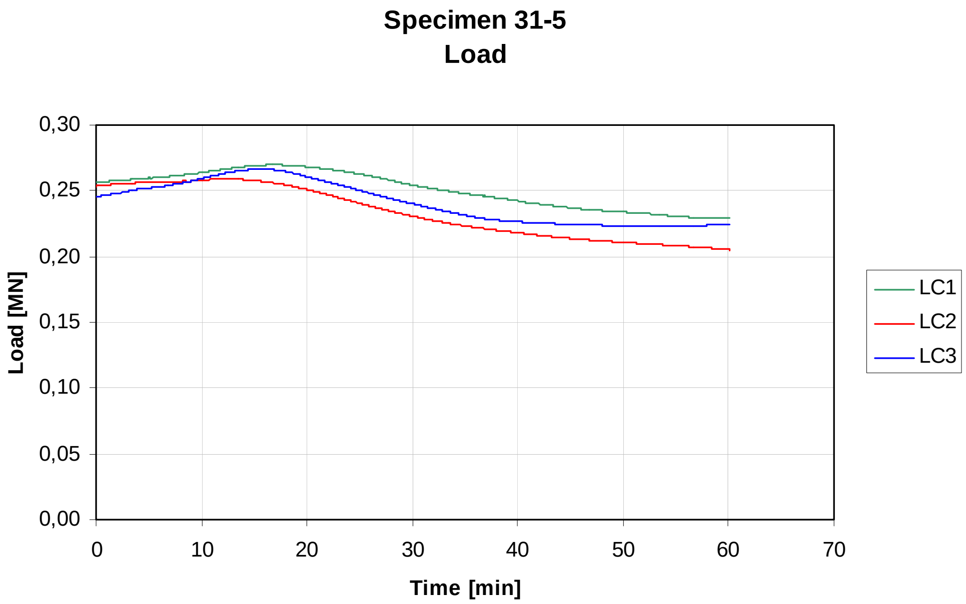


Figure A.290 Load measurements on specimen 31-5.

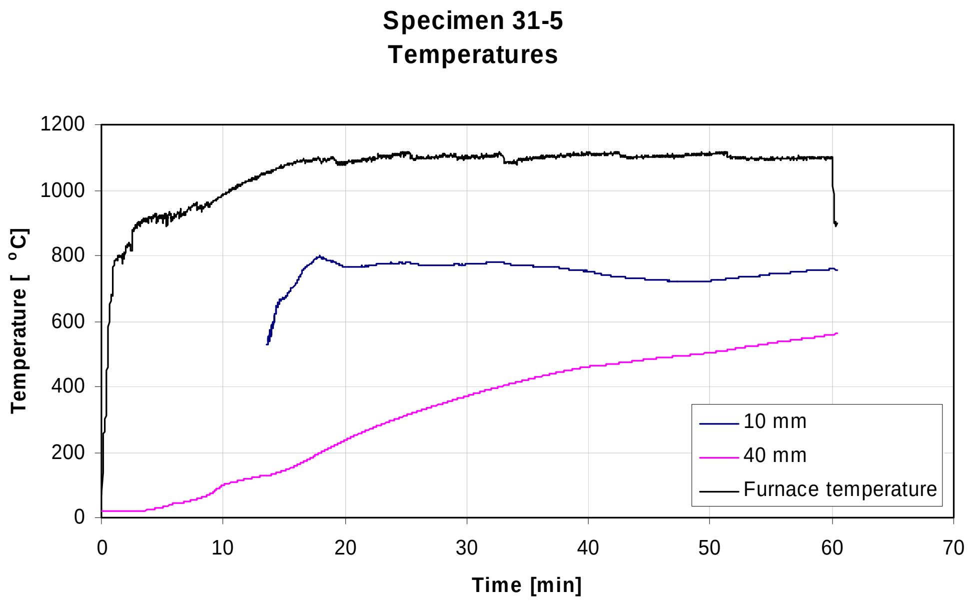


Figure A.291 Measured temperatures in furnace and in specimen 31-5.

Table A.165 Spalling measurements on specimen 31-5.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	6	12	8	5	0
200	0	6	16	9	9	0
300	0	18	17	15	14	0
400	0	20	17	18	23	0
500	0	17	13	12	20	0
600	0	4	0	0	0	0

Mean all	7
Mean inner	14
Max in diagram	23
Max measured	28

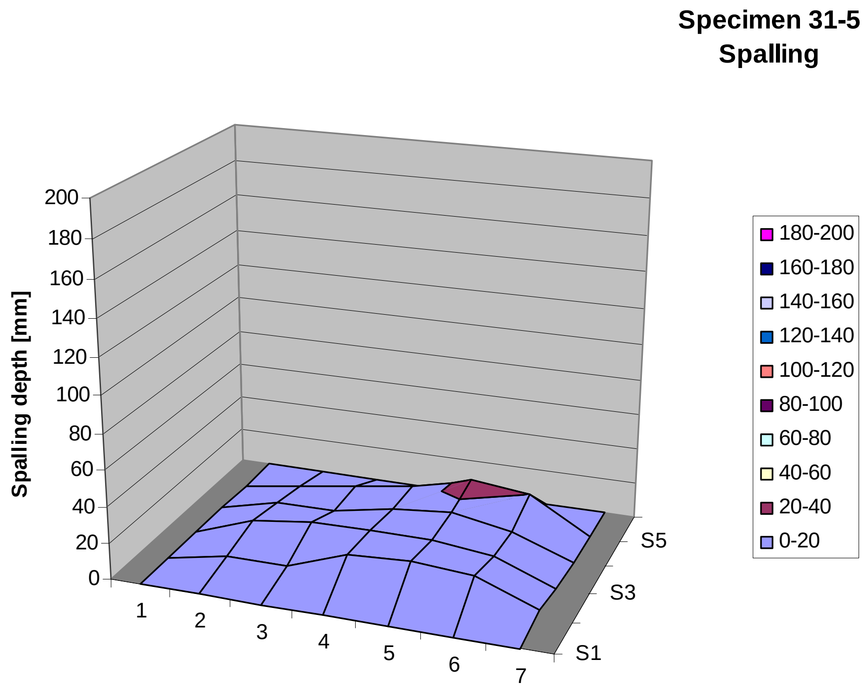


Figure A.292 Spalling measurements on specimen 31-5.

Table A.166 Observations made on specimen 31-5.

Time	Observation			
0,00	Start of test	Test date:	2006-12-28	
4,10	Two small explosions	Specimen:	31-5	
4,55	One explosion	Load level:	252	kN/bar
4,77	Two explosions	Weight loss:	8,2	kg
5,00	One explosion			
5,33	Some explosions			
5,75	One explosion			
5,80	One explosion			
6,33	One explosion			
6,53	One small explosion			
6,83	One explosion			
7,17	One small explosion			
7,83	One small explosion			
8,80	One small explosion			
9,42	One small explosion			
24,17	Small horizontal cracks on back and front face			
60,00	Test terminates			

Figure A.293 Specimen 31-5 after test.

Specimen 31-8

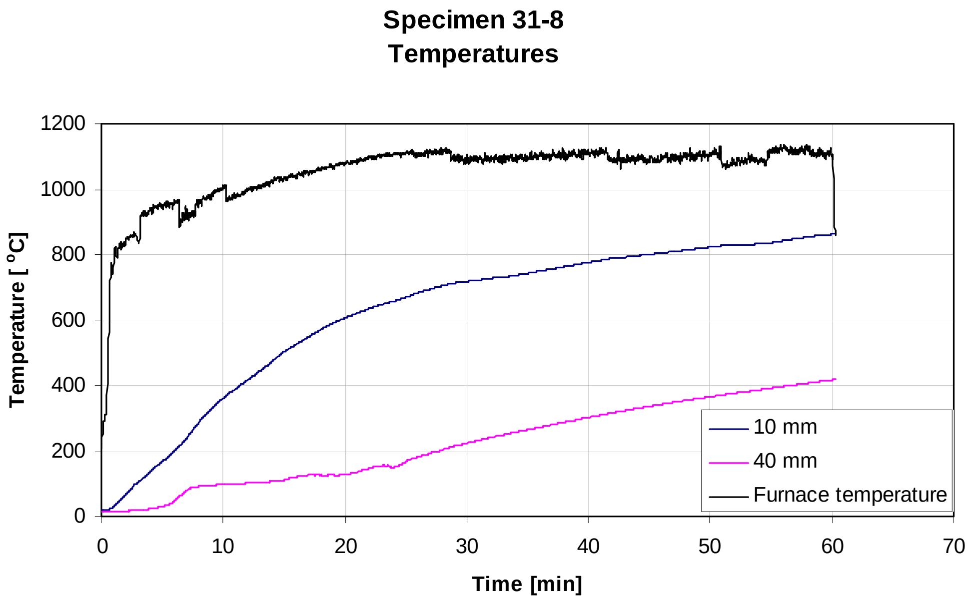


Figure A.294 Measured temperatures in furnace and in specimen 31-8.

Table A.167 Spalling measurements on specimen 31-8.

Position	0	100	200	300	400	500
0	0	0	0	0	14	0
100	0	0	1	20	23	5
200	0	1	0	15	19	8
300	0	1	0	8	11	1
400	0	2	8	15	7	2
500	0	7	13	14	4	2
600	0	4	3	1	0	0

Mean all	5
Mean inner	8
Max in diagram	23
Max measured	28

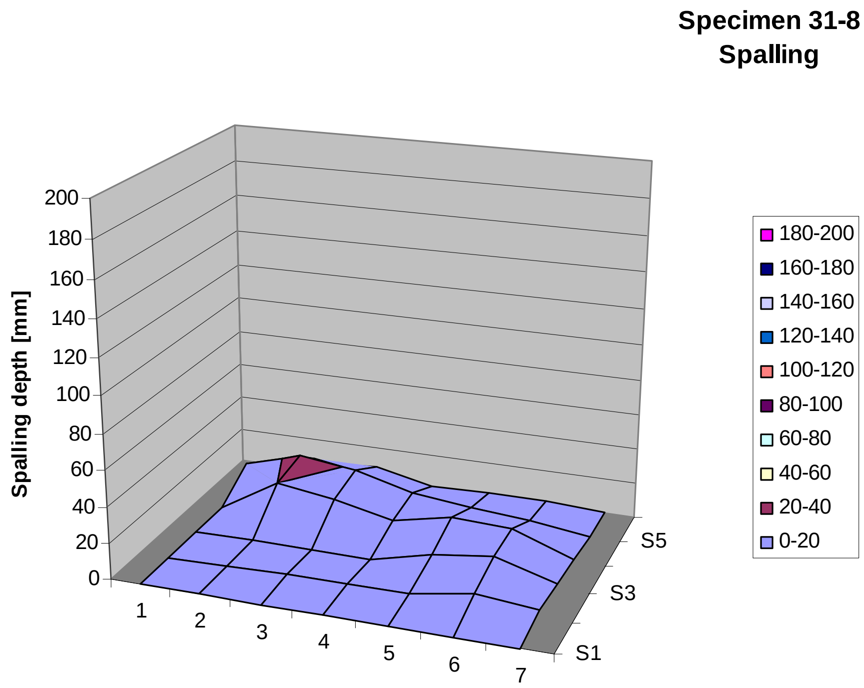


Figure A.295 Spalling measurements on specimen 31-8.

Table A.168 Observations made on specimen 31-8.

Time	Observation			
0,00	Start of test	Test date:	2006-12-27	
6,42	Two loud explosions	Specimen:	31-8	
7,07	One small explosion	Load level:	0	kN/bar
7,23	One small explosion	Weight loss:	5,2	kg
7,68	One explosion			
8,25	Two small explosions			
10,25	One explosion			
10,55	One explosion			
11,27	One explosion			
15,00	Vertical cracks on front and back side			
60,02	Test terminates			

Figure A.296 Specimen 31-8 after test.

Specimen 31-9

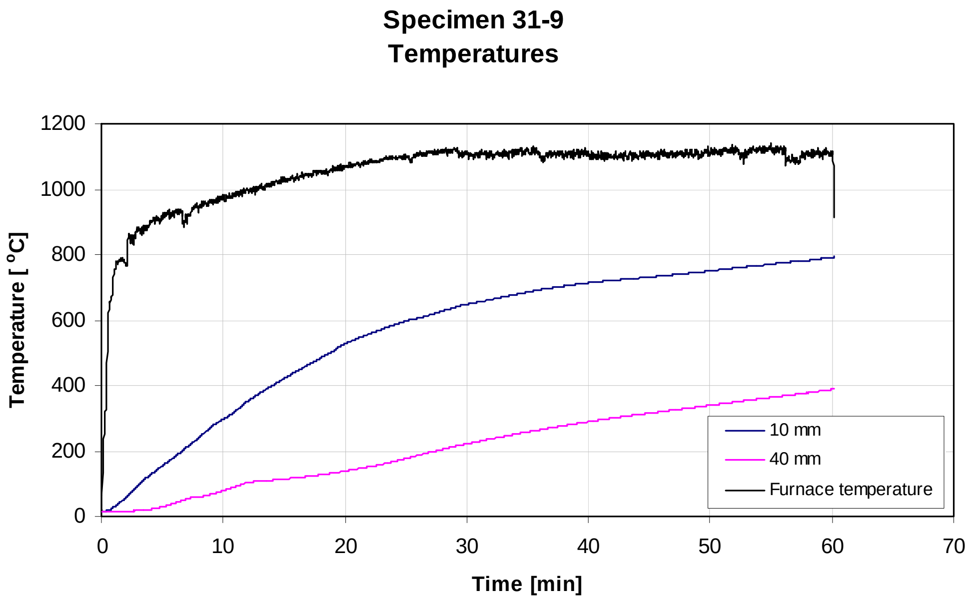


Figure A.297 Measured temperatures in furnace and in specimen 31-9.

Table A.169 Spalling measurements on specimen 31-9.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	10	10	0
200	0	0	0	11	4	0
300	0	2	0	1	0	0
400	0	2	0	14	9	0
500	0	2	1	7	8	0
600	0	0	0	0	0	0

Mean all	2
Mean inner	4
Max in diagram	14
Max measured	13

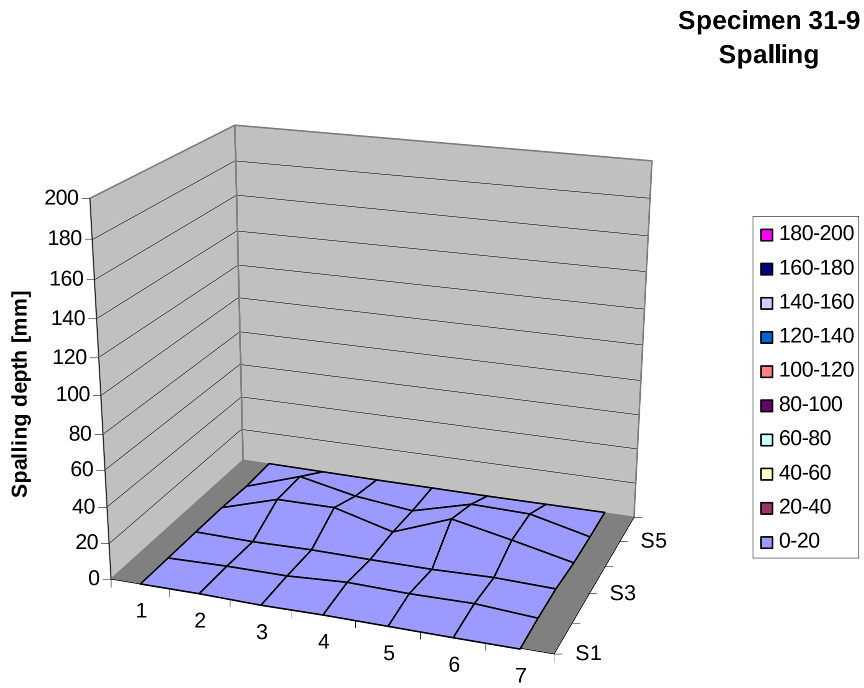


Figure A.298 Spalling measurements on specimen 31-9.

Table A.170 Observations made on specimen .

Time	Observation			
0,00	Start of test	Test date:	2006-12-28	
5,52	One small explosion	Specimen:	31-9	
6,67	One explosion	Load level:	0	kN/bar
7,32	One explosion	Weight loss:	8,4	kg
7,98	One small explosion			
10,10	One small explosion			
13,62	Vertical cracks on all sides			
60,02	Test terminates			

Figure A.299 Specimen 31-9 after test.

Concrete 32

Table A.171 Concrete admixture recipe 32.

Recipe	**32**
Water (kg/m^3)	170
CEM I 42,5N BV/LA/SR (kg/m^3)	430
Limestone filler, Limus 25 (kg/m^3)	143
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	7,0
Sikament 20HE 50 (% of cement weight)	1,63
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	700
T50 (s)	7
Air (%)	3.0
Compressive strength, 28 days (MPa)	71.2

Specimen 32-2

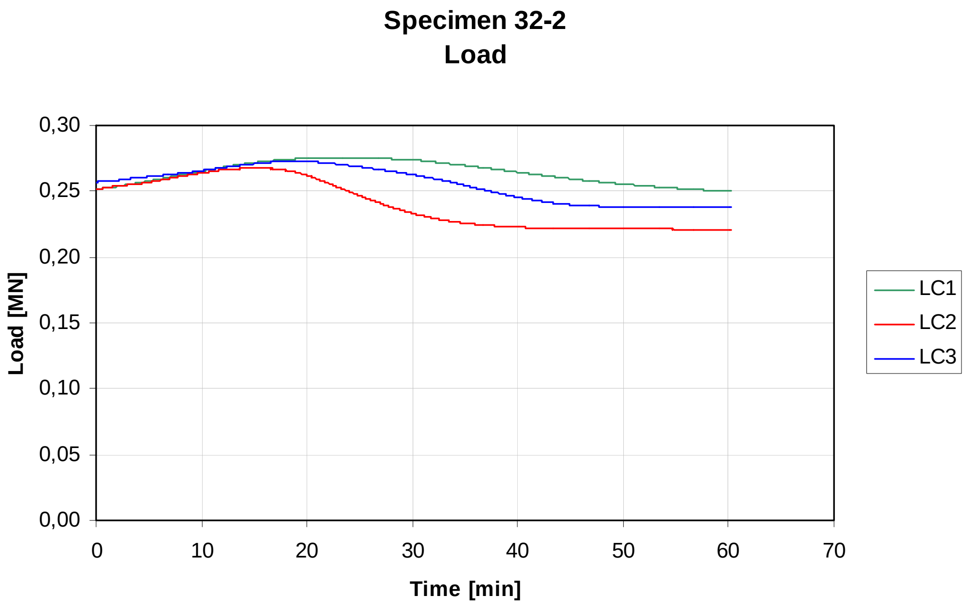


Figure A.300 Load measurements on specimen 32-2.

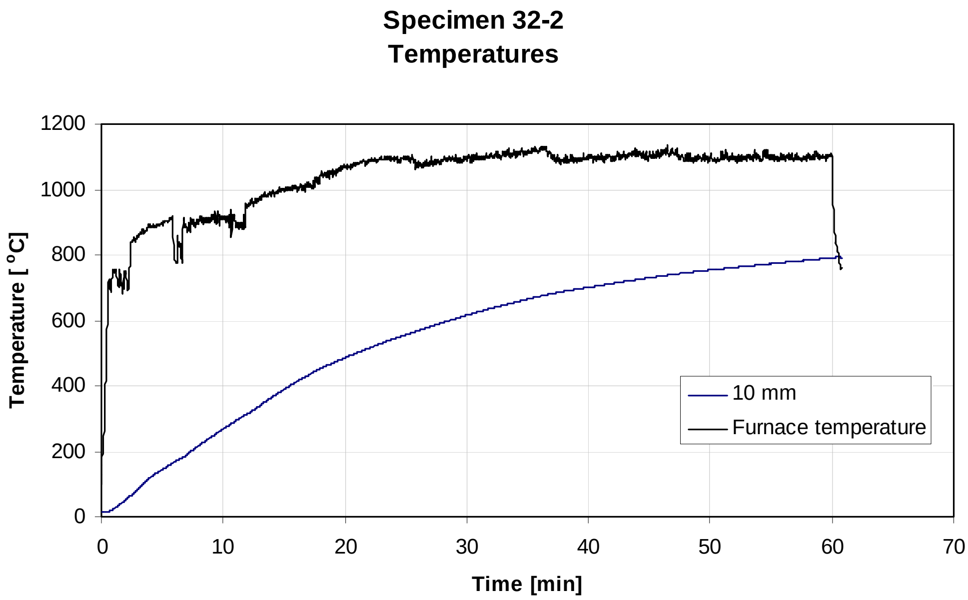


Figure A.301 Measured temperatures in furnace and in specimen 32-2.

Table A.172 Spalling measurements on specimen 32-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

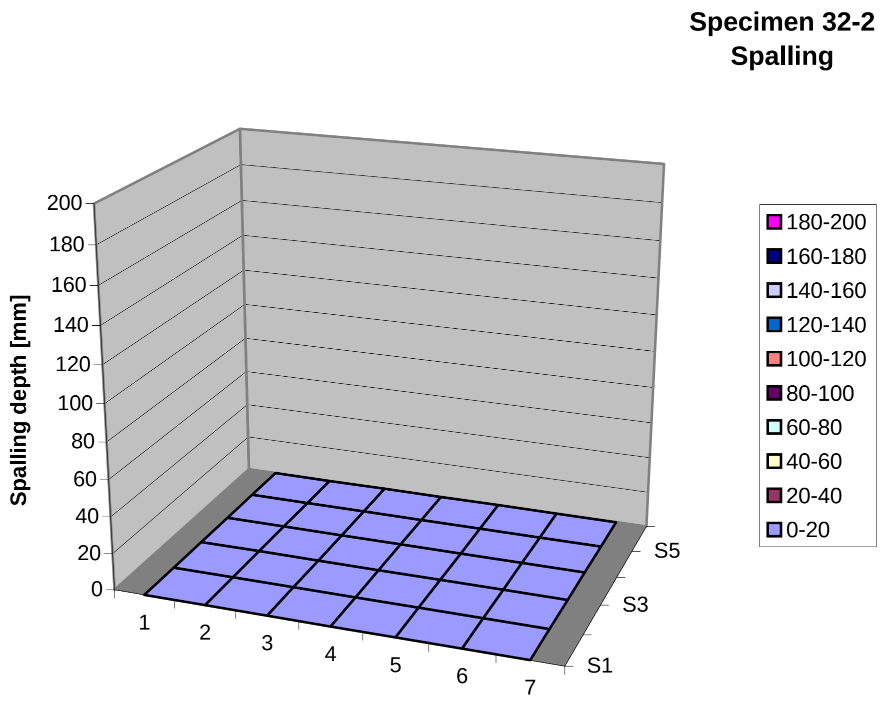


Figure A.302 Spalling measurements on specimen 32-2.

Table A.173 Observations made on specimen 32-2.

Time	Observation			
0,00	Start of test	Test date:	2007-01-11	
20,58	Horizontal crack on front side, water comes out	Specimen:	32-2	
33,67	Cracks on top face	Load level:	253	kN/bar
60,00	Test terminates	Weight loss:	3,7	kg

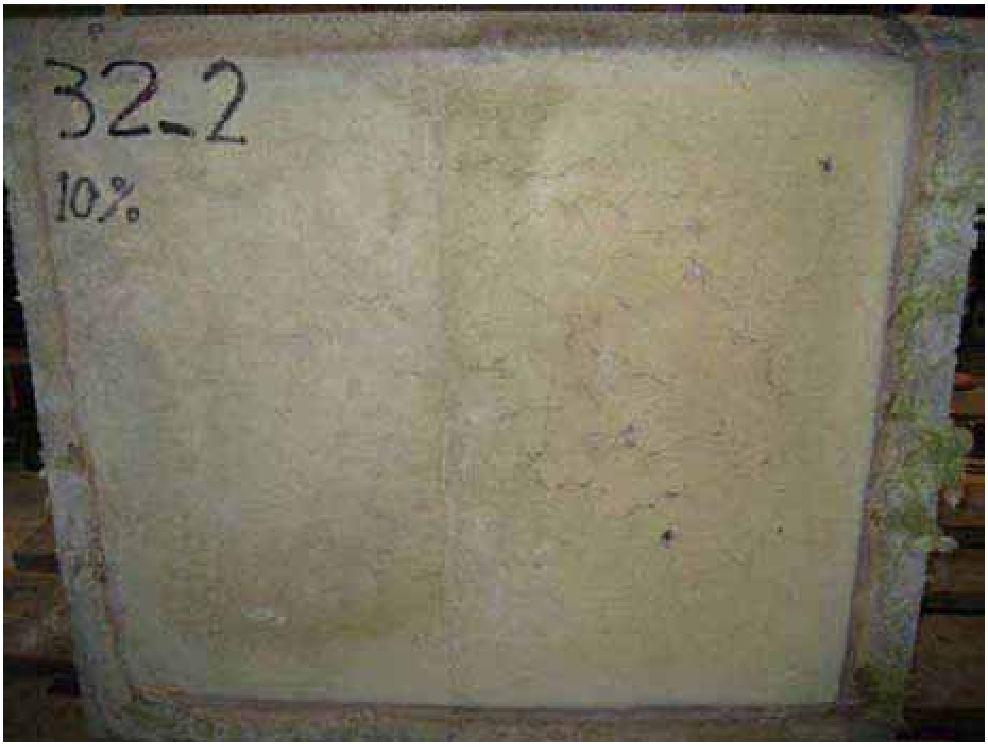


Figure A.303 Specimen 32-2 after test.

Specimen 32-3

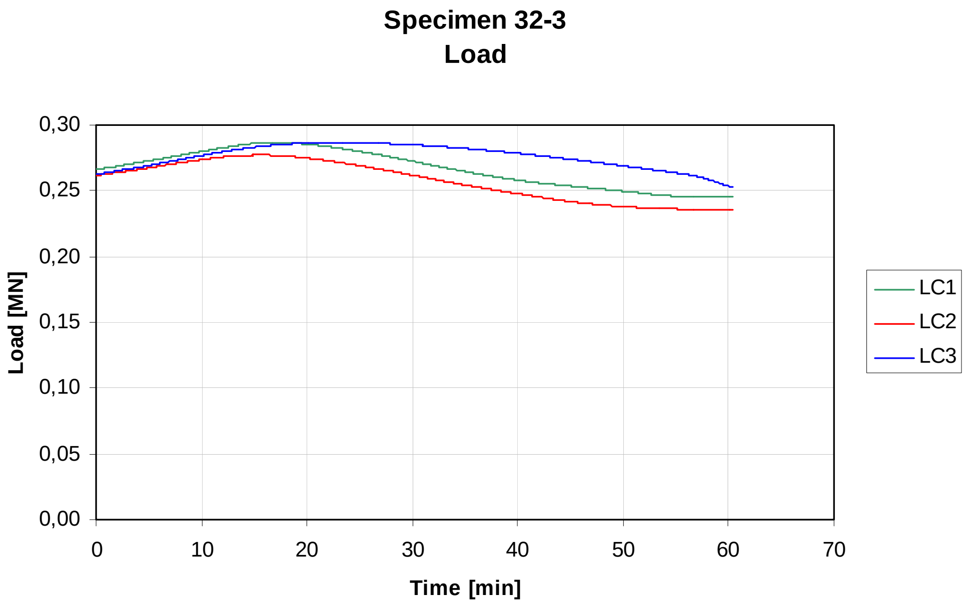


Figure A.304 Load measurements on specimen 32-3.

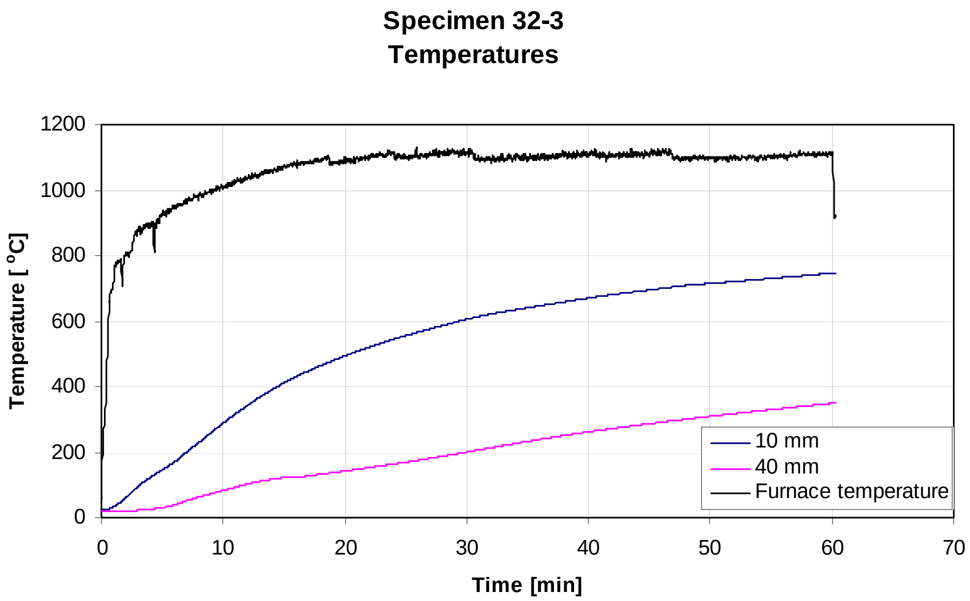


Figure A.305 Measured temperatures in furnace and in specimen 32-3.

Table A.174 Spalling measurements on specimen 32-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

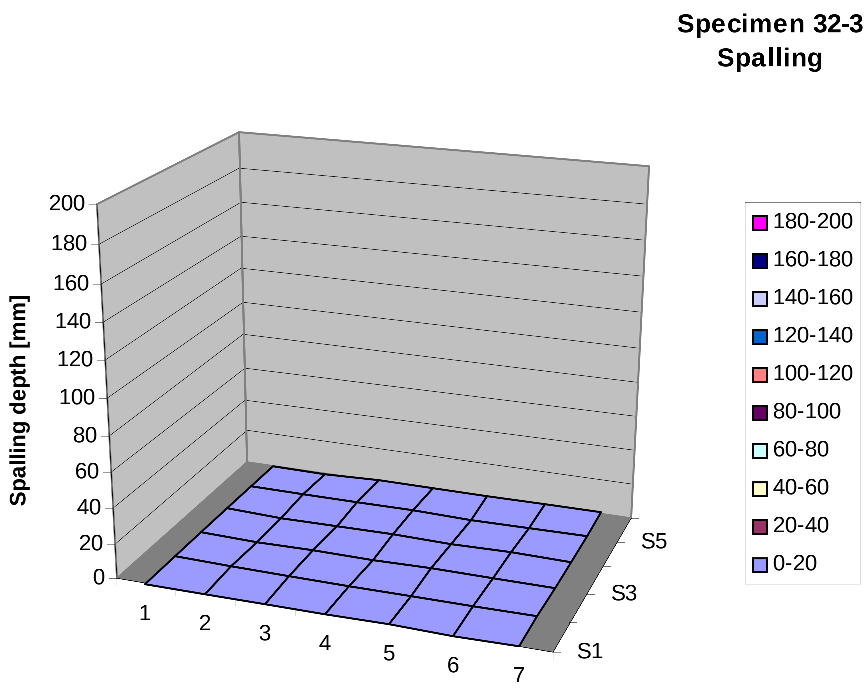


Figure A.306 Spalling measurements on specimen 32-3.

Table A.175 Observations made on specimen 32-3.

Time	Observation			
0,00	Start of test	Test date:	2006-12-29	
10,72	Stream of water on front side	Specimen:	32-3	
60,00	Test terminates	Load level:	264	kN/bar
		Weight loss:	1,9	kg

Figure A.307 Specimen 32-3 after test.

Concrete 33

Table A.176 Concrete admixture recipe 33.

Recipe	**33**
Water (kg/m^3)	170
CEM I 42,5N BV/LA/SR (kg/m^3)	430
Limestone filler, Limus 25 (kg/m^3)	143
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	9,5
Sikament 20HE 50 (% of cement weight)	2,21
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	2,0
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	600
T50 (s)	6-7
Air (%)	3.3
Compressive strength, 28 days (MPa)	68.4

Specimen 33-1

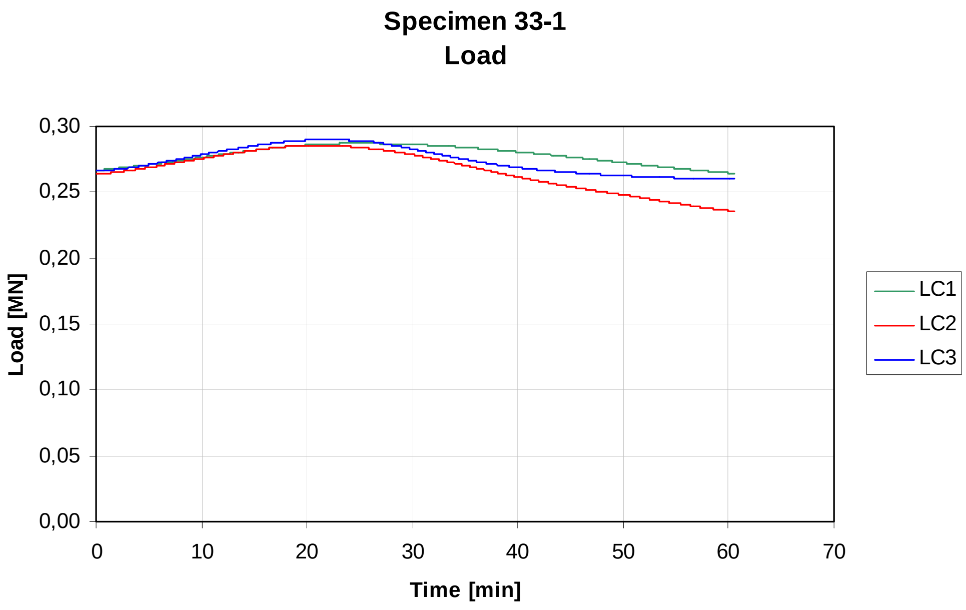


Figure A.308 Load measurements on specimen 33-1

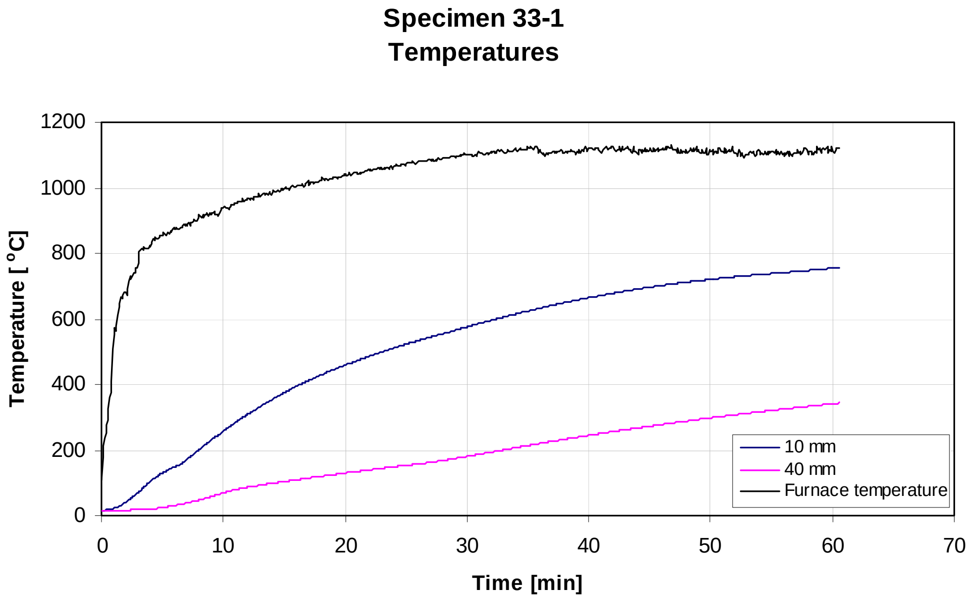


Figure A.309 Measured temperatures in furnace and in specimen 33-1.

Table A.177 Spalling measurements on specimen 33-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

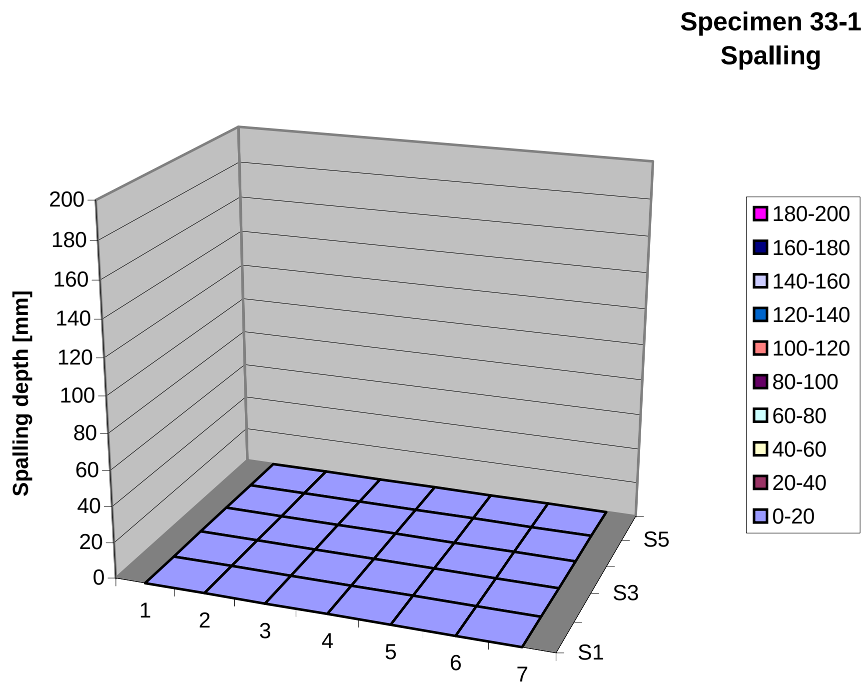


Figure A.310 Spalling measurements on specimen 33-1.

Table A.178 Observations made on specimen 33-1.

Time	Observation			
0,0	Start of test	Test date:	2007-01-22	
15,0	Some water on the top, non on the sides	Specimen:	33-1	
35,0	Horizontal crack on back side	Load level:	266	kN/bar
60,5	Test terminates	Weight loss:	1,0	kg

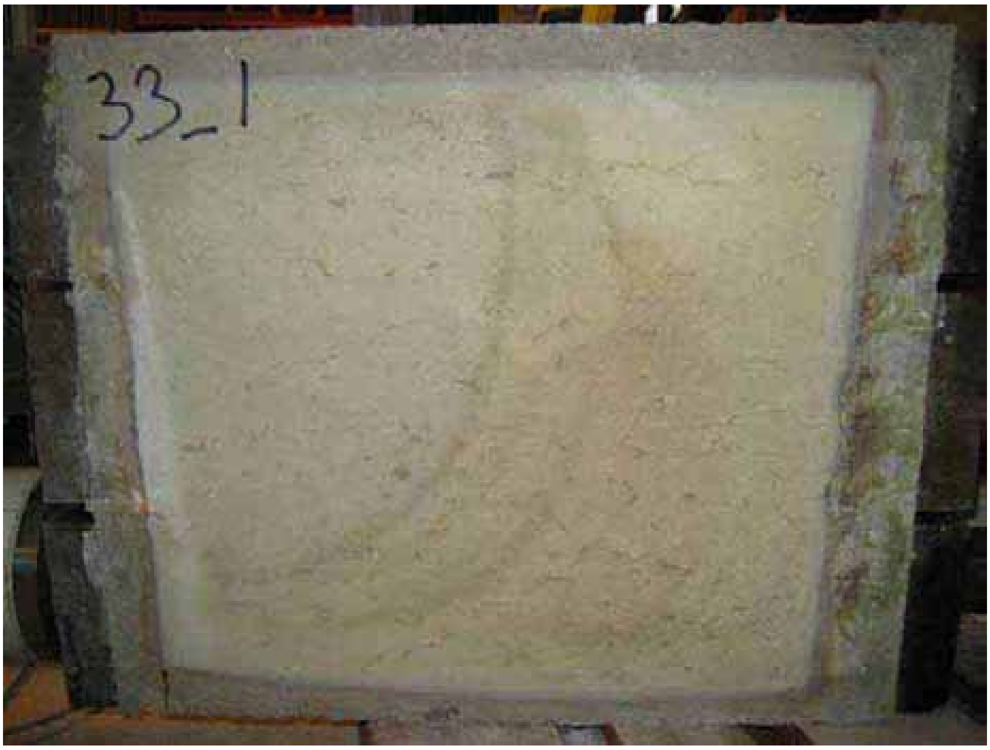


Figure A.311 Specimen 33-1 after test.

Specimen 33-4

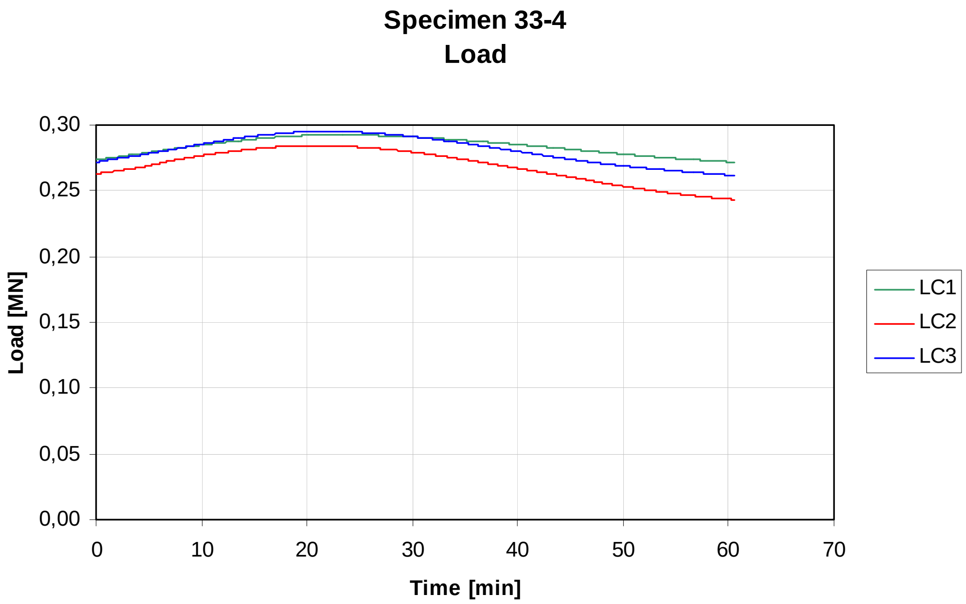


Figure A.312 Load measurements on specimen 33-4.

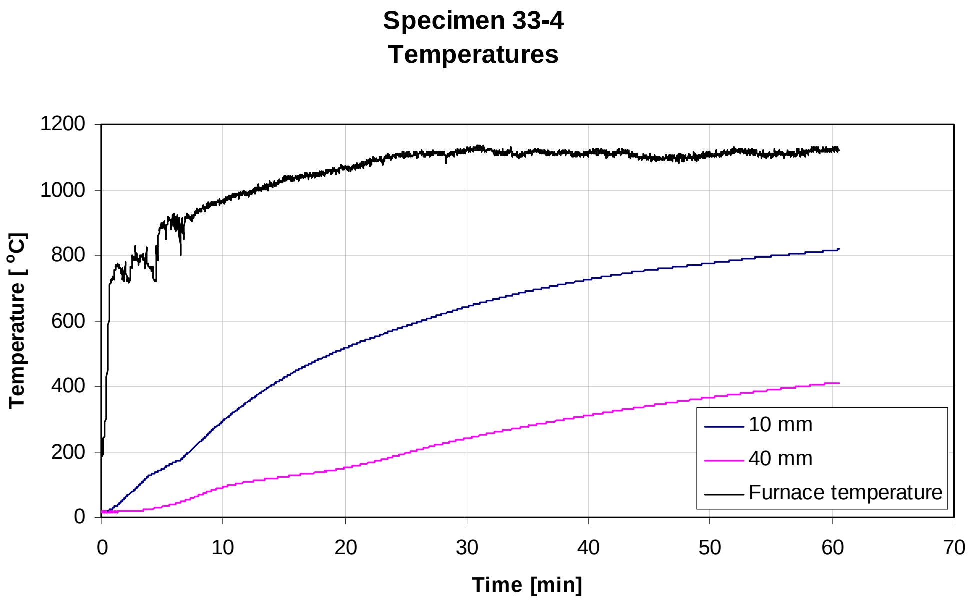


Figure A.313 Measured temperatures in furnace and in specimen 33-4.

Table A.179 Spalling measurements on specimen 33-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

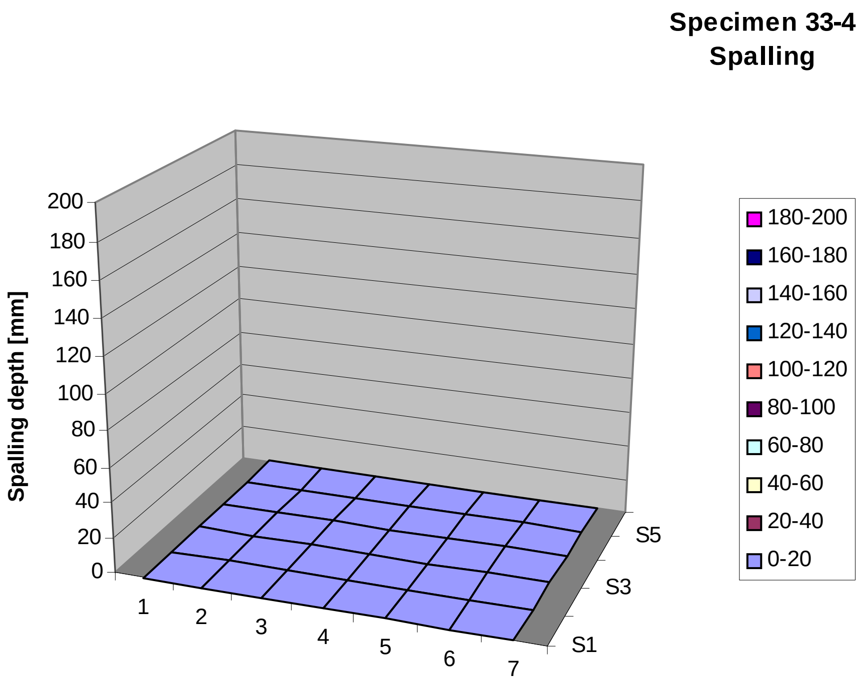


Figure A.314 Spalling measurements on specimen 33-4.

Table A.180 Observations made on specimen 33-4.

Time	Observation
0,0	Start of test
16,0	Some water on the top, non on the sides
16,1	Horizontal crack on both front and back side
60,5	Test terminates

Test date:	2007-01-16	
Specimen:	33-4	
Load level:	270	kN/bar
Weight loss:	2,7	kg

Figure A.315 Specimen 33-4 after test.

Concrete 34

Table A.181 Concrete admixture recipe 34.

Recipe	**34**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	252
Water-powder ratio, w/p	0,25
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	7,0
Sikament 20HE 50 (% of cement weight)	1,67
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	735
T50 (s)	5
Air (%)	1.6
Compressive strength, 28 days (MPa)	59.6

Specimen 34-1

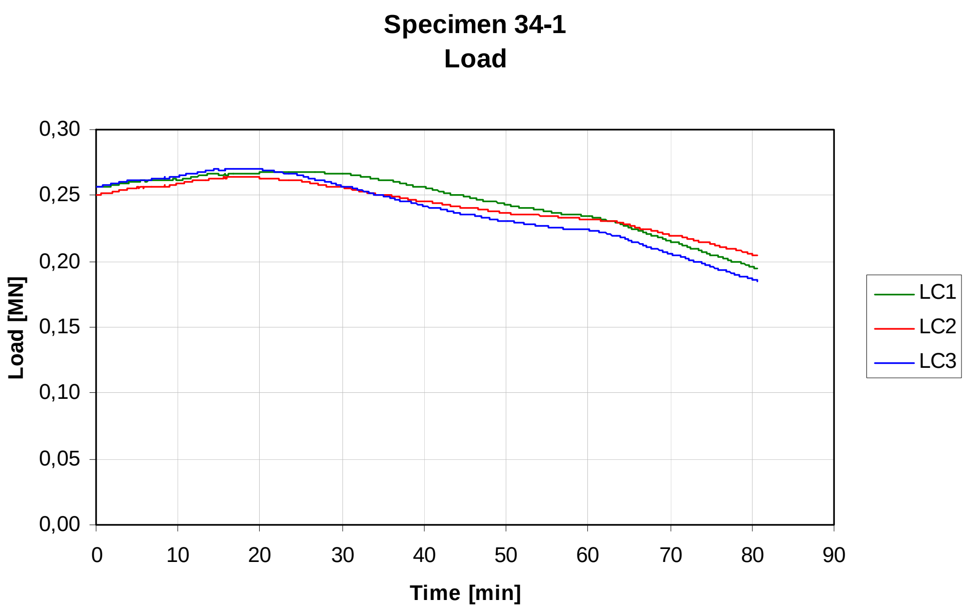


Figure A.316 Load measurements on specimen 34-1.

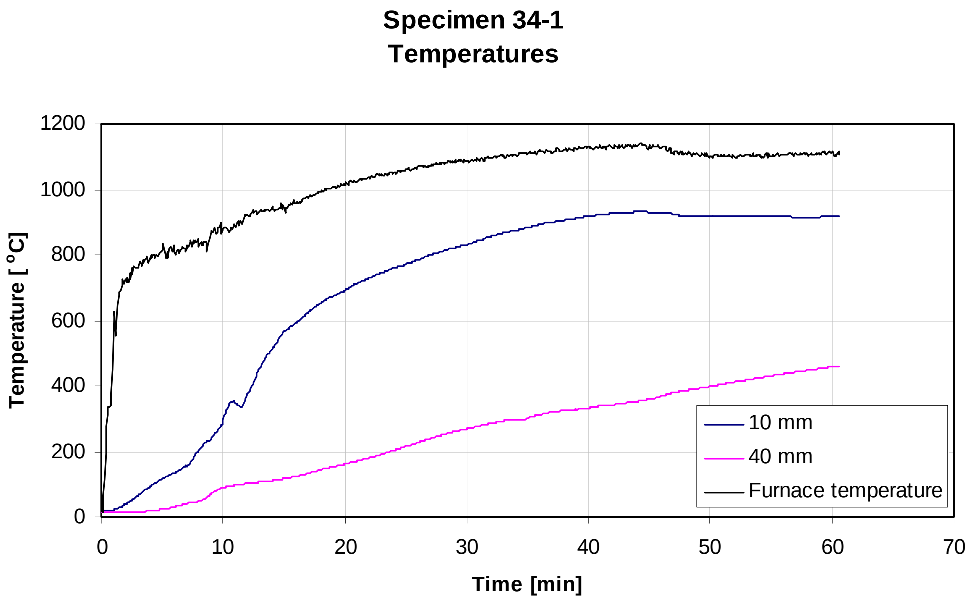


Figure A.317 Measured temperatures in furnace and in specimen 34-1.

Table A.182 Spalling measurements on specimen 34-1.

Position	0	100	200	300	400	500
0	0	0	1	0	0	0
100	10	20	12	13	14	2
200	15	25	21	11	9	2
300	15	25	29	16	5	0
400	4	26	20	4	9	0
500	3	13	20	16	8	0
600	0	1	2	0	3	0

Mean all	9
Mean inner	16
Max in diagram	29
Max measured	38

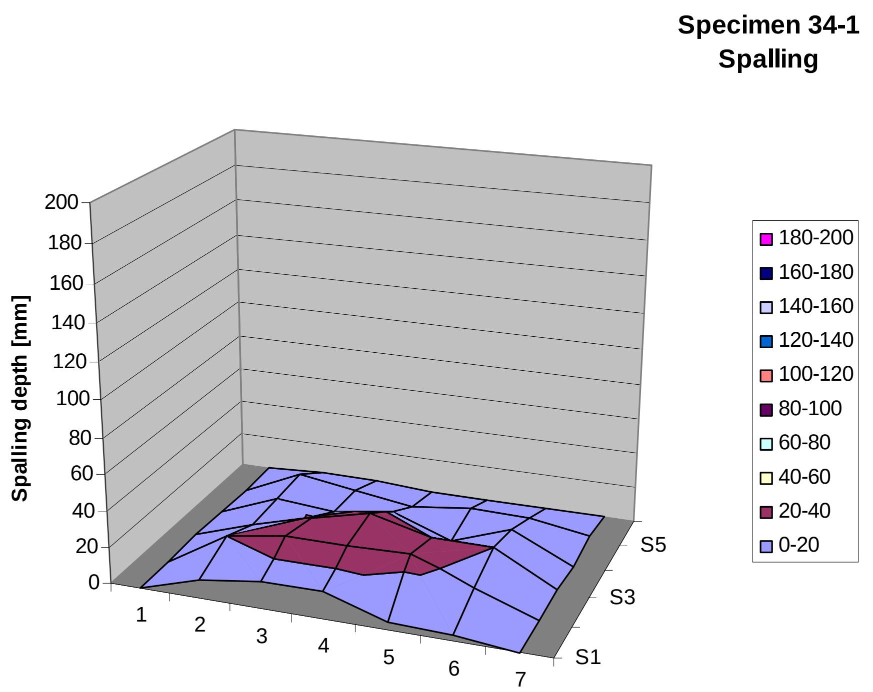


Figure A.318 Spalling measurements on specimen 34-1

Table A.183 Observations made on specimen 34-1.

Time	Observation
0,00	Start of test
4,00	Three small explosions
4,42	Two small explosions
4,67	Two small explosions
5,50	One loud explosion, continuous small ones
14,00	Spalling stops
20,00	Water and cracks on sides
60,50	Test terminates

Test date:	2007-02-23	
Specimen:	34-1	
Load level:	255	kN/bar
Weight loss:	9,6	kg

Figure A.319 Specimen 34-1 after test.

Specimen 34-2

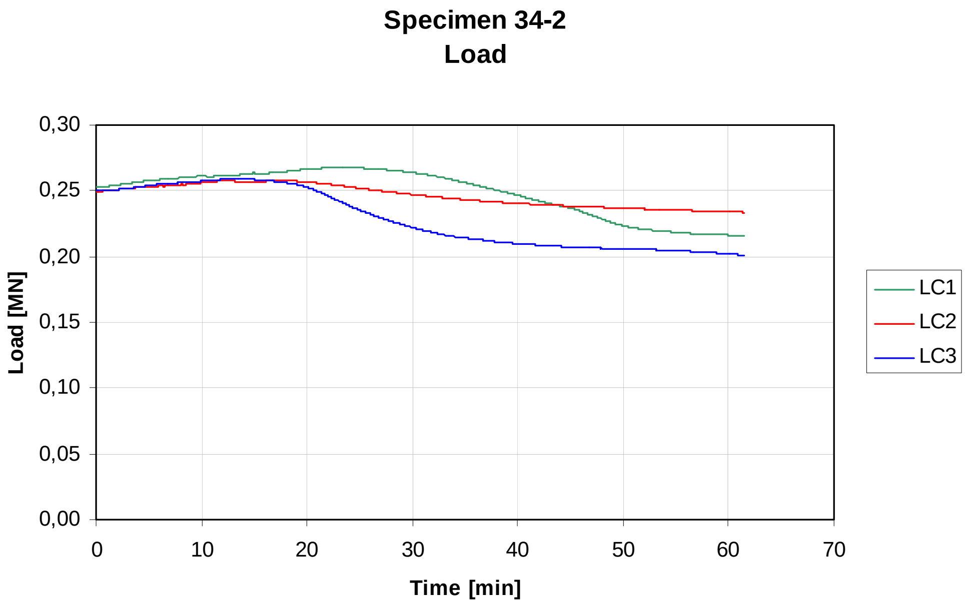


Figure A.320 Load measurements on specimen 34-2.

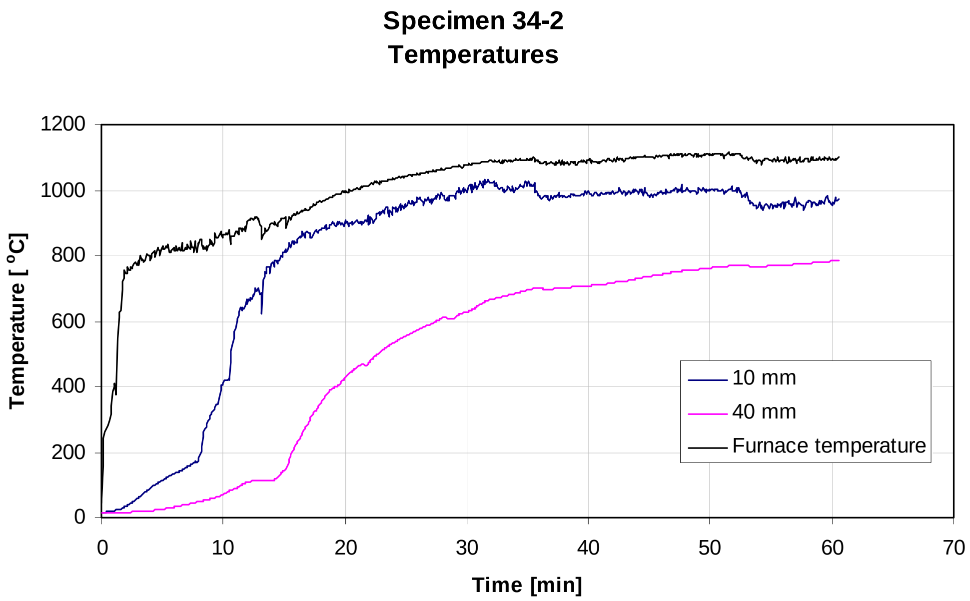


Figure A.321 Measured temperatures in furnace and in specimen 34-2.

Table A.184 Spalling measurements on specimen 34-2.

Position	0	100	200	300	400	500
0	0	2	0	0	0	0
100	0	27	24	19	10	0
200	6	35	40	38	9	0
300	1	34	41	37	11	0
400	0	36	39	20	9	1
500	1	24	14	13	17	6
600	0	0	0	0	1	0

Mean all	12
Mean inner	25
Max in diagram	41
Max measured	43

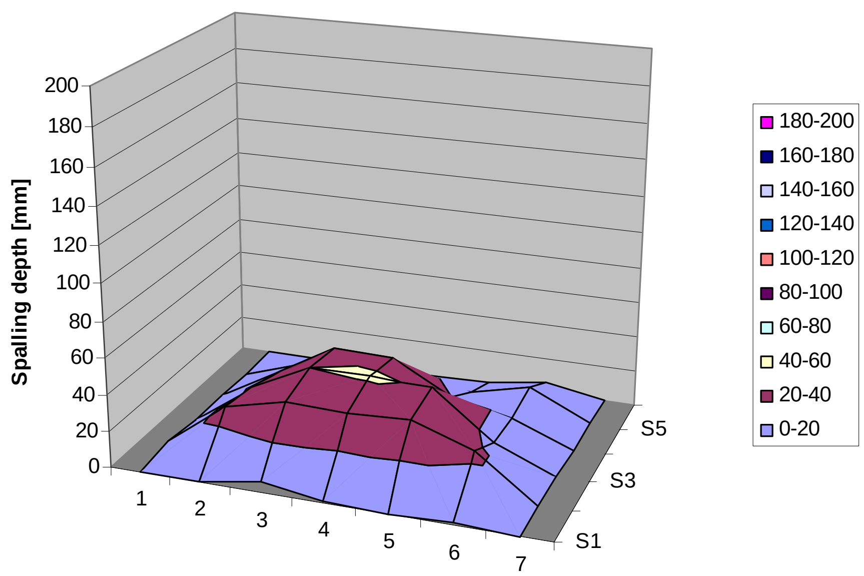


Figure A.322 Spalling measurements on specimen 34-2

Table A.185 Observations made on specimen 34-2.

Time	Observation
0,00	Start of test
3,33	Small sounds
4,75	One small explosion
5,17	One small explosion
5,50	Continuous small explosions
10,67	One loud explosion
15,00	Water and cracks on sides
17,00	Spalling stops
60,50	Test terminates

Test date:	2007-02-28	
Specimen:	34-2	
Load level:	251	kN/bar
Weight loss:	10,8	kg

Figure A.323 Specimen 34-2 after test.

Concrete 35

Table A.186 Concrete admixture recipe 35.

Recipe	**35**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	252
Water-powder ratio, w/p	0,25
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	7,0
Sikament 20HE 50 (% of cement weight)	1,67
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	0,5
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	680
T50 (s)	6
Air (%)	2.3
Compressive strength, 28 days (MPa)	67.6

Specimen 35-1

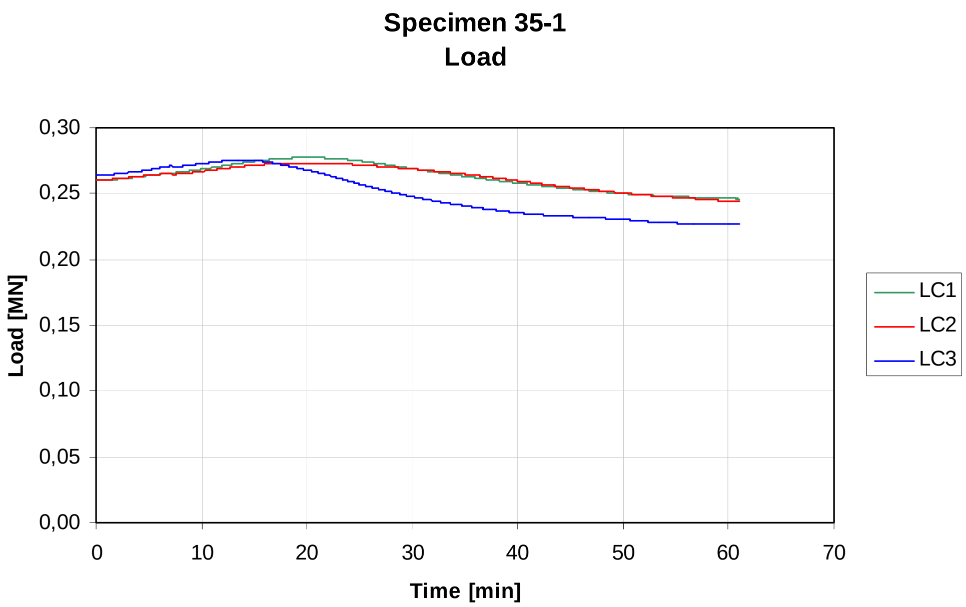


Figure A.324 Load measurements on specimen 35-1.

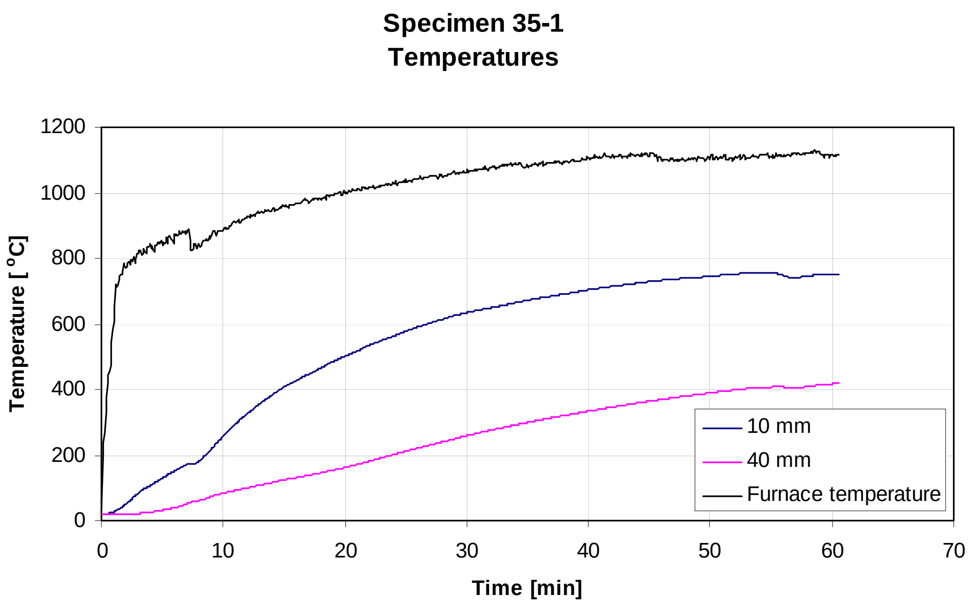


Figure A.325 Measured temperatures in furnace and in specimen 35-1.

Table A.187 Spalling observations on specimen 35-1 .

Position	0	100	200	300	400	500
0	0	0	0	1	0	0
100	0	0	2	9	9	5
200	0	0	2	8	10	5
300	0	0	1	9	13	2
400	0	0	2	7	8	1
500	0	0	0	12	5	0
600	0	0	0	3	0	0

Mean all	3
Mean inner	5
Max in diagram	13
Max measured	23

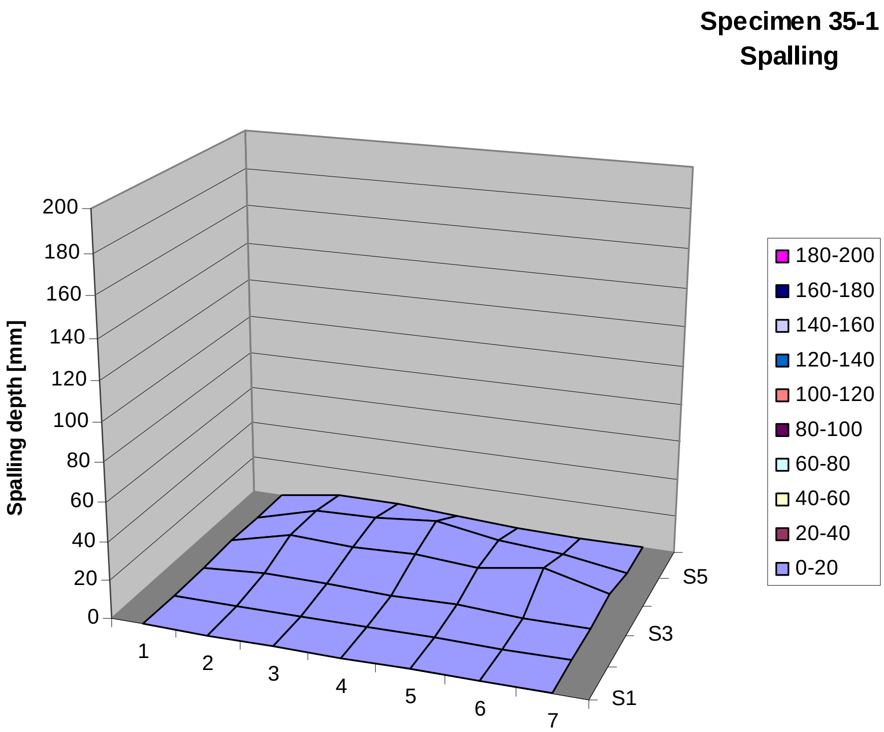


Figure A.326 Spalling observations on specimen 35-1

Table A.188 Observations made on specimen 35-1.

Time	Observation			
0,00	Start of test	Test date:	2007-03-01	
7,28	One loud explosion	Specimen:	35-1	
20,00	Water and cracks on sides	Load level:	261	kN/bar
60,50	Test terminates	Weight loss:	3,9	kg

Figure A.327 Specimen 35-1 after test

Specimen 35-2

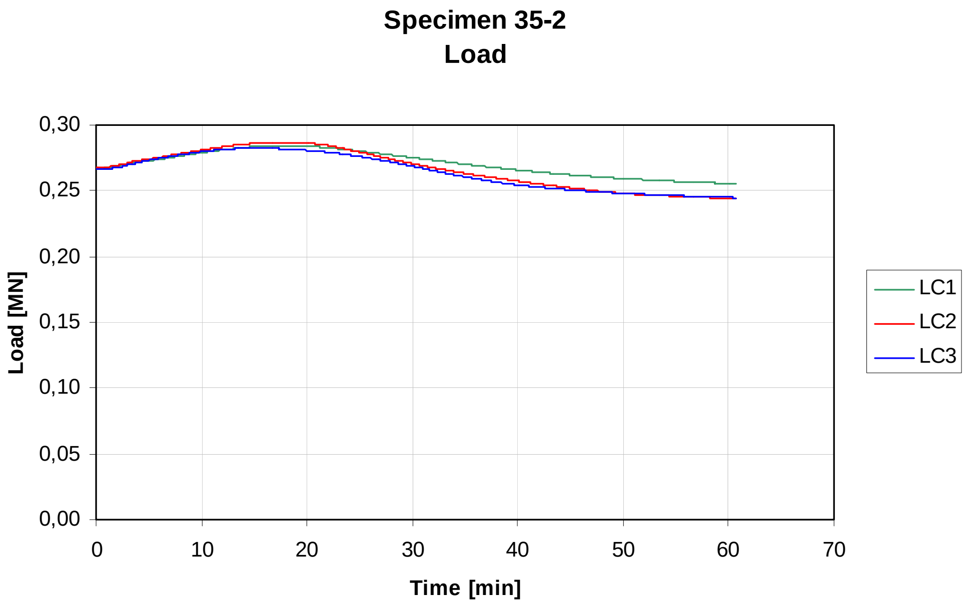


Figure A.328 Load measurements on specimen 35-2

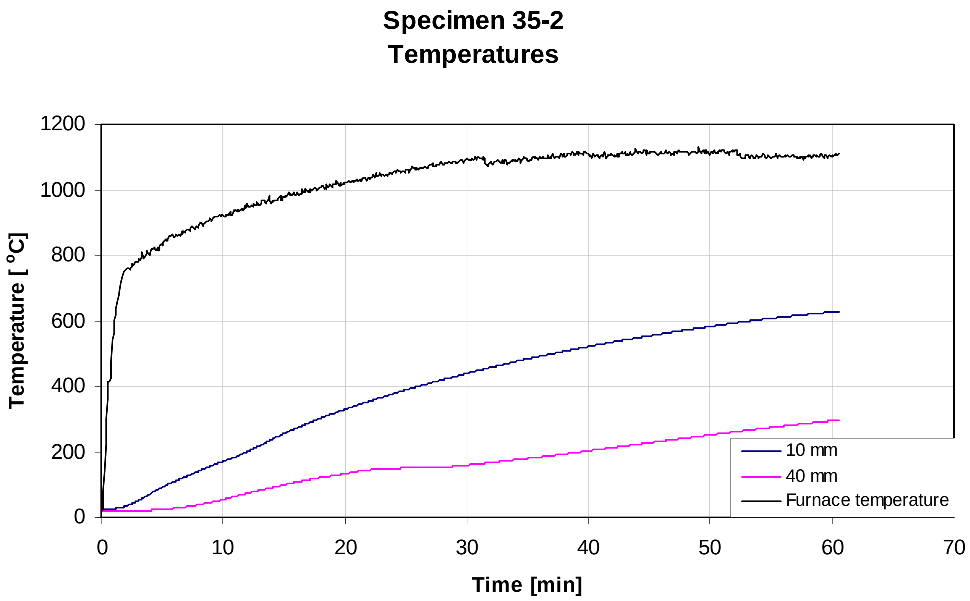


Figure A.329 Measured temperatures in furnace and in specimen 35-2

Table A.189 Spalling measurements on specimen 35-2

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

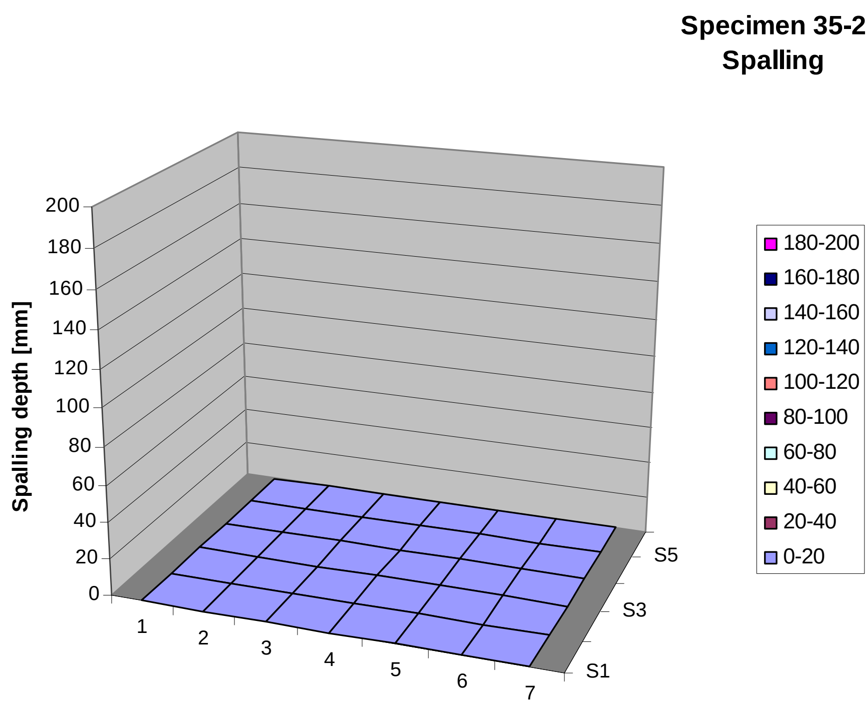


Figure A.330 Spalling measurements on specimen 35-2

Table A.190 Observations made on specimen 35-2.

Time	Observation
0,00	Start of test
20,00	Water and cracks on sides
60,50	Test terminates

Test date:	2007-03-01	
Specimen:	35-2	
Load level:	267	kN/bar
Weight loss:	2,7	kg

Figure A.331 Specimen 35-2 after test

Concrete 38

Table A.191 Concrete admixture recipe 38.

Recipe	**38**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	140
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	8,00
Sikament 20HE 50 (% of cement weight)	1,90
Fiber, Sika Crackstop, ϕ=18 µm, l=6 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	620
T50 (s)	6
Air (%)	3.5
Compressive strength, 28 days (MPa)	55.3

Specimen 38-3

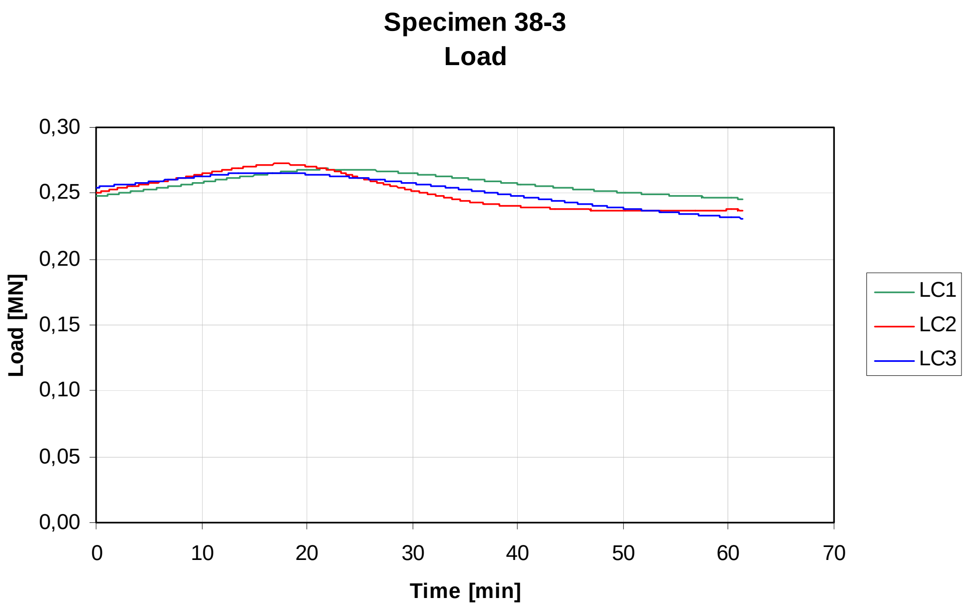


Figure A.332 Load measurements on specimen 38-3.

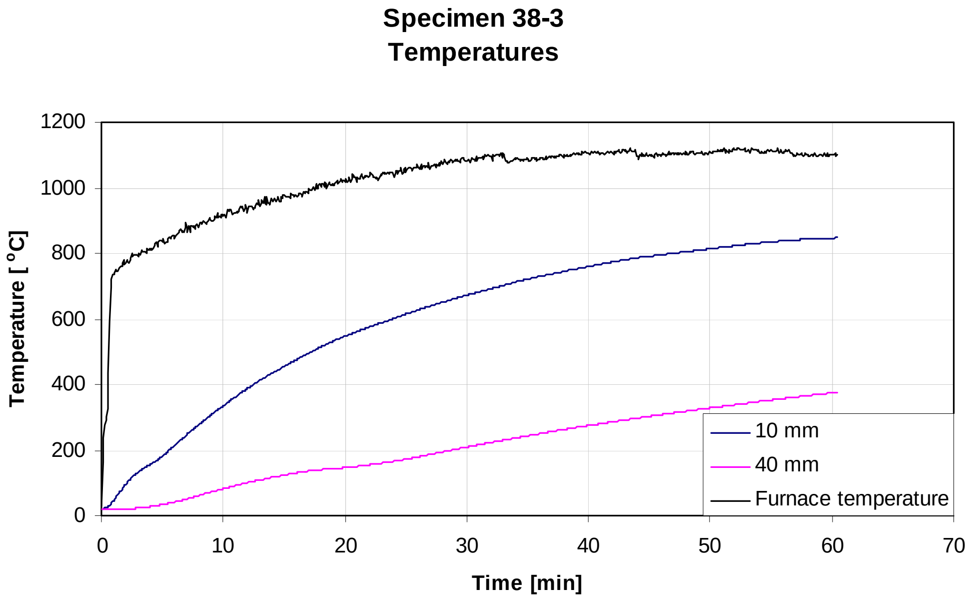


Figure A.333 Measured temperatures in furnace and in specimen 38-3.

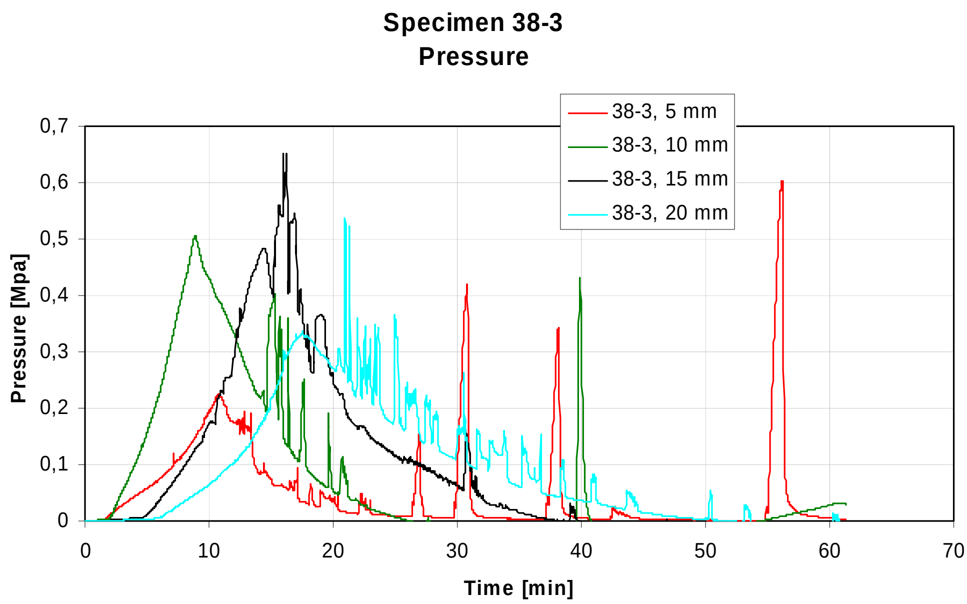


Figure A.334 Measured vapour pressure in specimen 38-3.

Table A.192 Spalling measurements on specimen 38-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

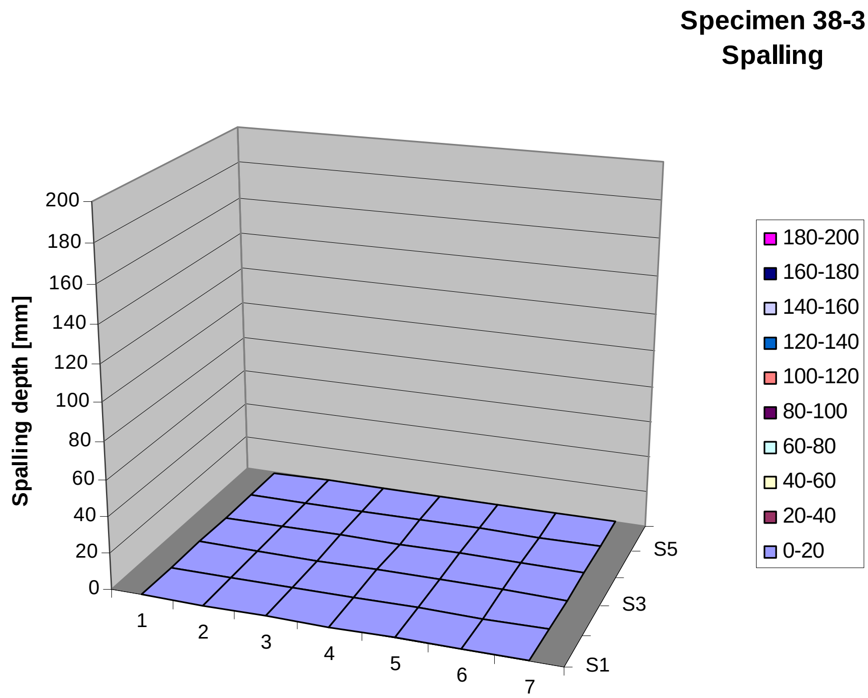


Figure A.335 Spalling measurements on specimen 38-3.

Table A.193 Observations made on specimen 38-3.

Time	Observation
0,00	Start of test
20,00	Water and cracks on sides
60,50	Test terminates

Test date:	2007-03-09	
Specimen:	38-3	
Load level:	251	kN/bar
Weight loss:	1,3	kg

Figure A.336 Specimen 38-3 after test.

Specimen 38-4

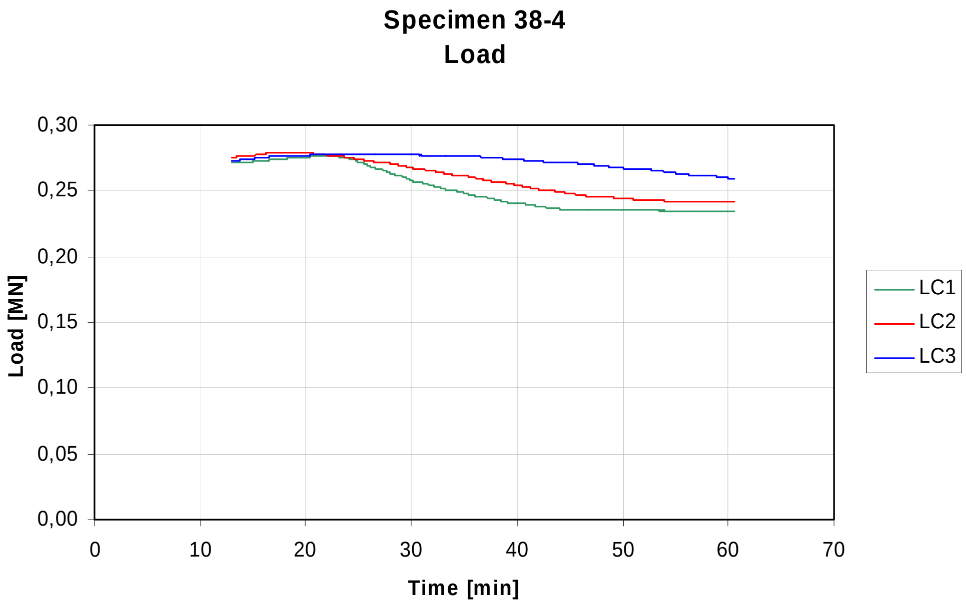


Figure A.337 Load measurements on specimen 38-4. First 13 minutes missing.

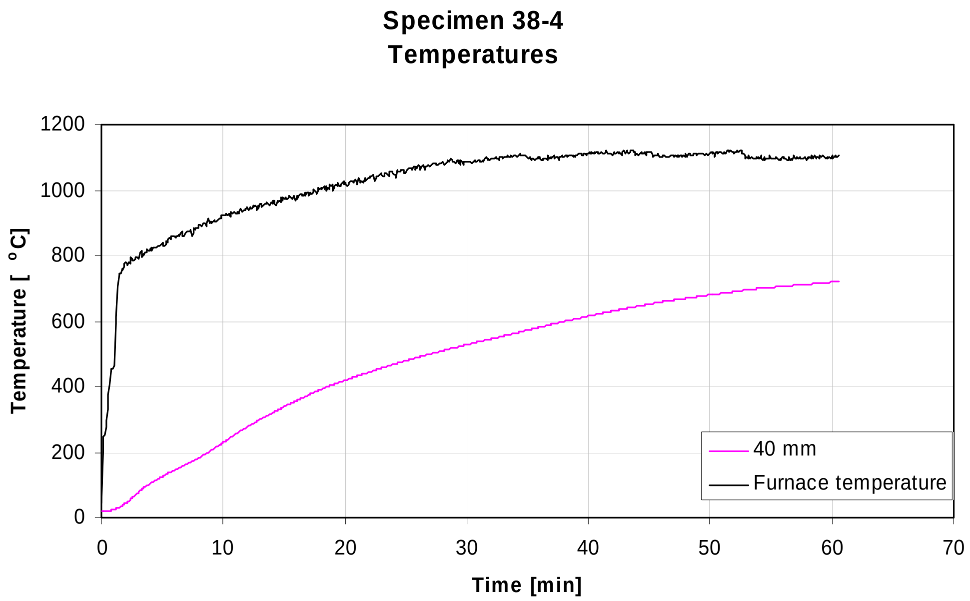


Figure A.338 Measured temperatures in furnace and in specimen 38-4.

Table A.194 Spalling measurements on specimen 38-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

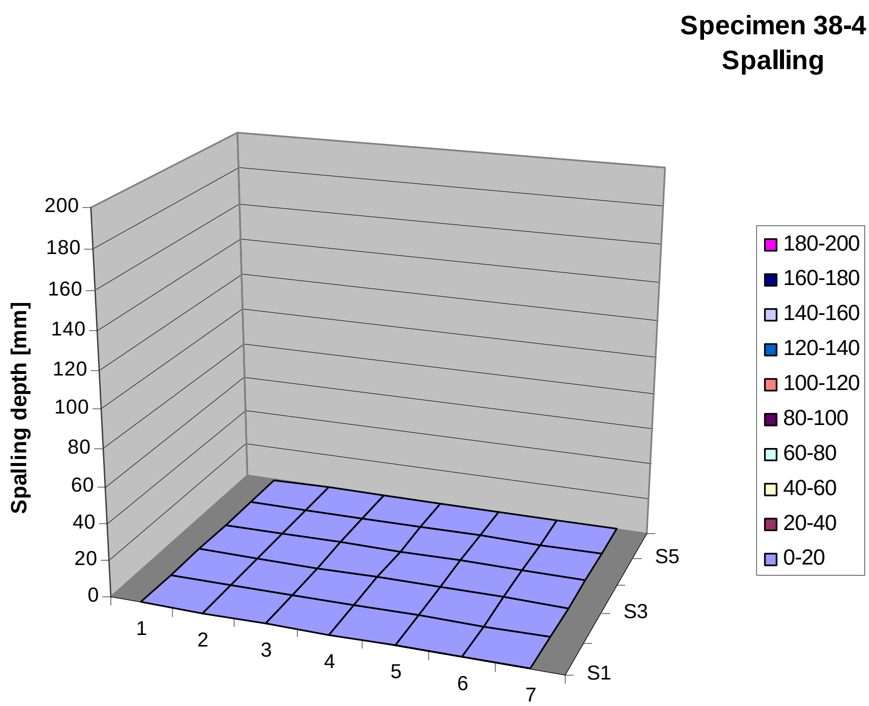


Figure A.339 Spalling measurements on specimen 38-4.

Table A.195 Observations made on specimen 38-4.

Time	Observation
0,00	Start of test
22,00	Water and cracks on sides
60,50	Test terminates

Test date:	2007-03-13	
Specimen:	38-4	
Load level:	273	kN/bar
Weight loss:	1,3	kg

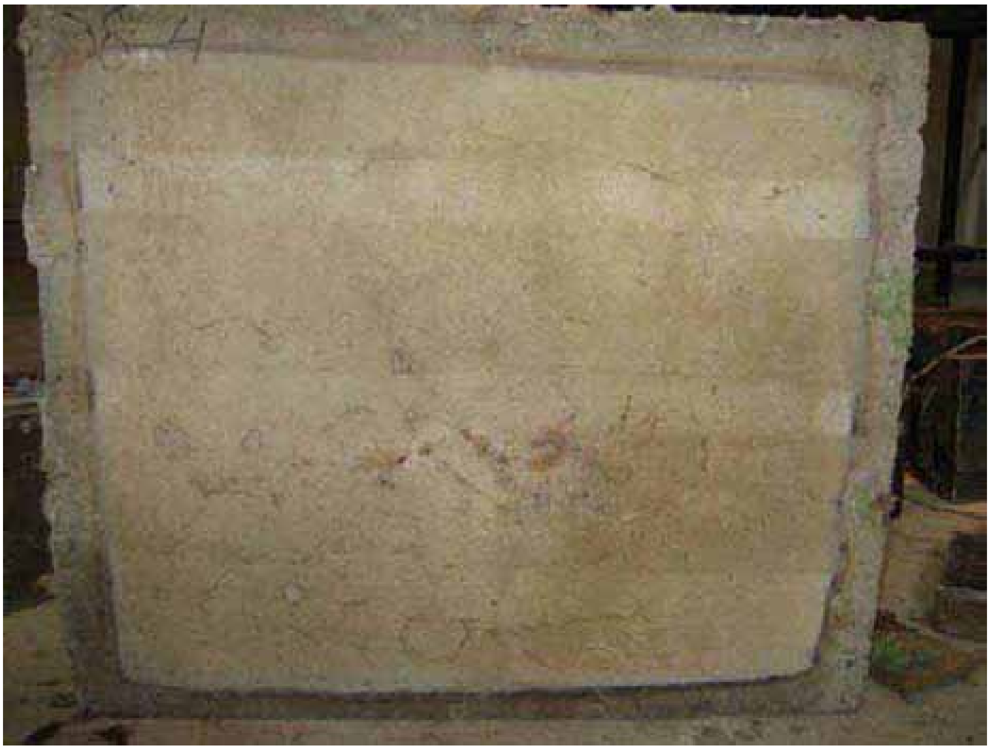


Figure A.340 Specimen 38-4 after test.

Concrete 39

Table A.196 Concrete admixture recipe 39.

Recipe	**39**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	140
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	6,3
Sikament 20HE 50 (% of cement weight)	1,50
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	730
T50 (s)	5
Air (%)	2.7
Compressive strength, 28 days (MPa)	71.5

Specimen 39-12

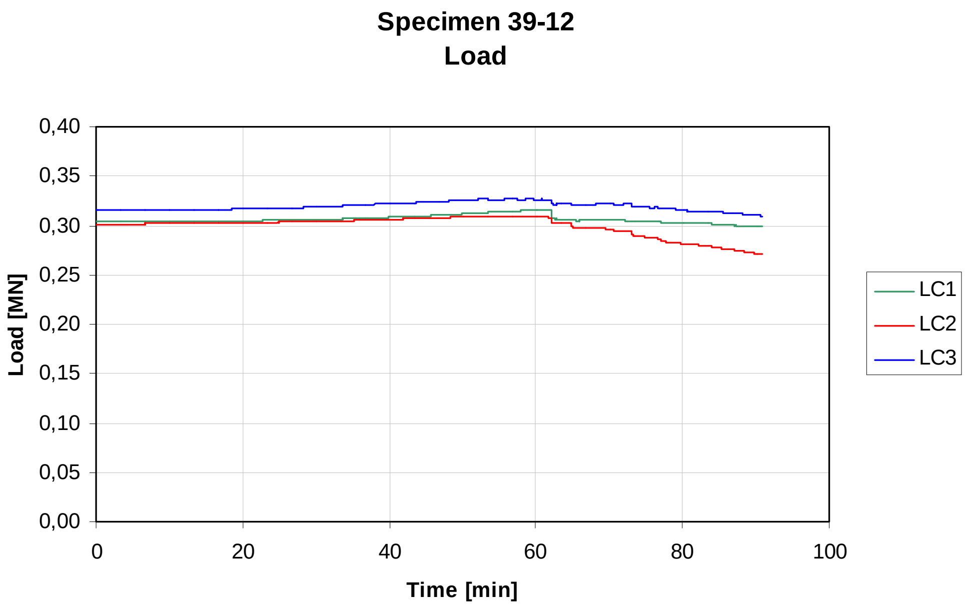


Figure A.341 Load measurements on specimen 39-12, heated at 10 degrees per minute.

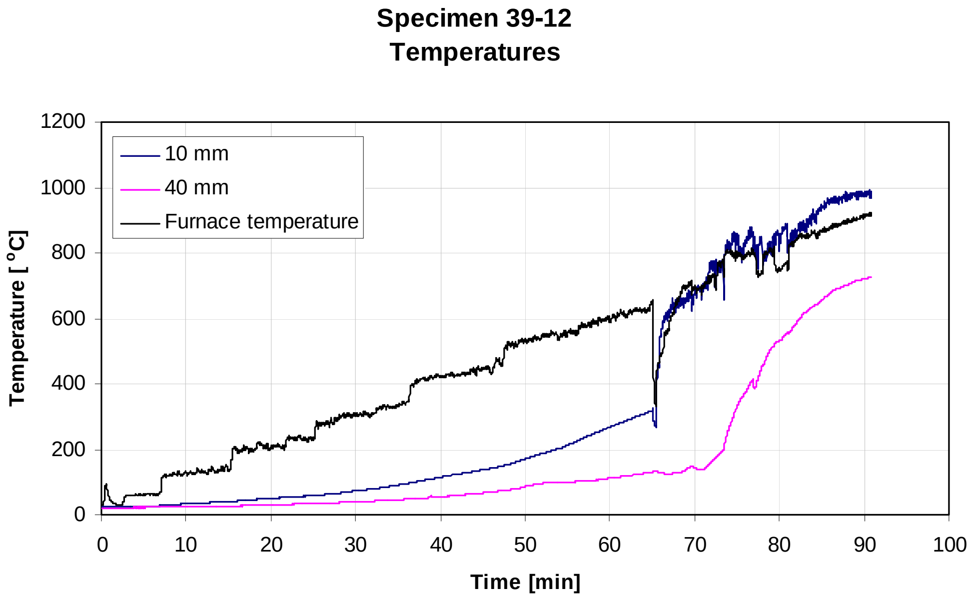


Figure A.342 Measured temperatures in furnace and in specimen 39-12, heated at 10 degrees per minute.

Table A.197 Spalling measurements on specimen 39-12.

Position	0	100	200	300	400	500
0	0	0	0	3	3	0
100	18	44	37	34	47	11
200	27	46	39	48	50	19
300	38	38	40	56	49	22
400	39	37	40	50	47	12
500	33	29	29	45	31	2
600	0	13	10	19	4	0

Mean all	26
Mean inner	42
Max in diagram	56
Max measured	59

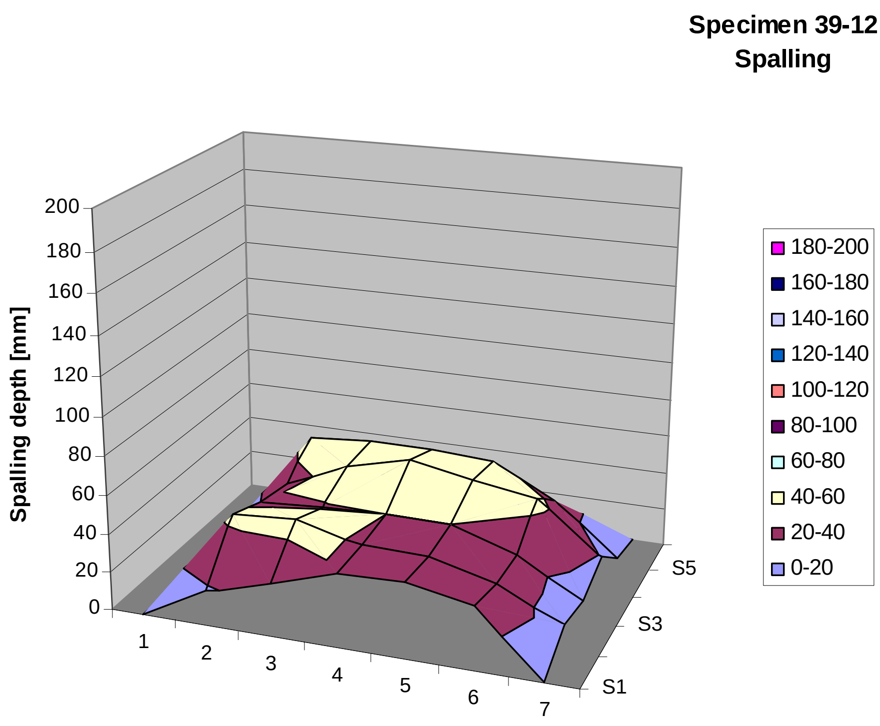


Figure A.343 Spalling measurements on specimen 39-12

Table A.198 Observations made on specimen 39-12.

Time	Observation			
0,00	Start of test	Test date:	2007-06-08	
53,75	One explosion	Specimen:	39-12	
55,42	One small explosion	Load level:	307	kN/bar
57,00	One explosion	Weight loss:	22,6	kg
57,67	One explosion			
60,00	One explosion			
65,00	One loud explosion			
67,83	Two small explosions			
68,17	Two small explosions			
68,75	Two small explosions			
69,67	One explosion			
70,00	One small explosion			
70,17	One explosion			
70,75	Three small explosions			
72,00	Cracks on sides			
73,33	One loud explosion			
77,17	One loud explosion			
84,25	One loud explosion			
85,00	Spalling stoped			
90,83	Test terminated			

Figure A.344 Specimen 39-12 during the test. It has spalled through the side.

Figure A.345 Specimen 39-12 after test.

Specimen 39-13

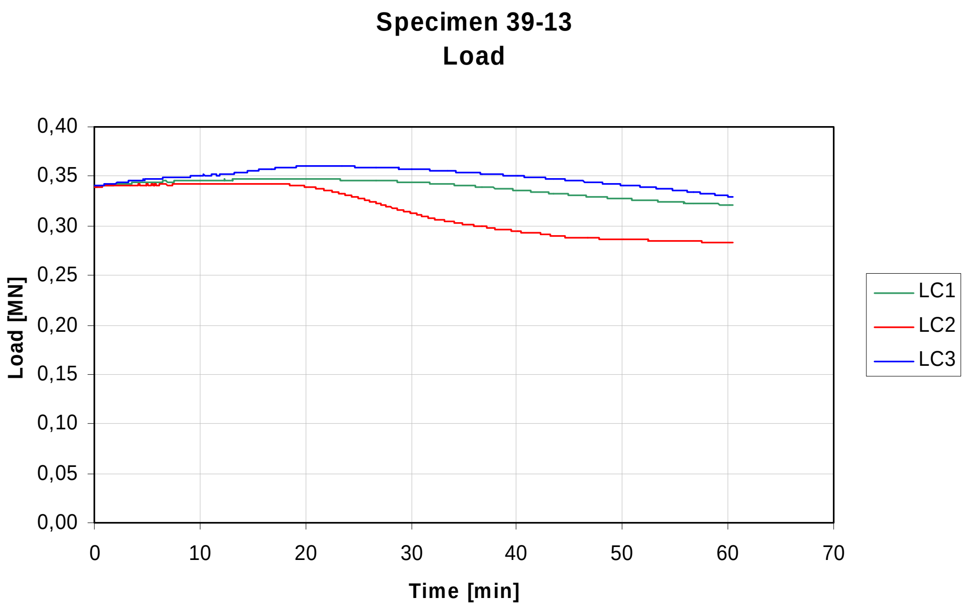


Figure A.346 Load measurements on specimen 39-13.

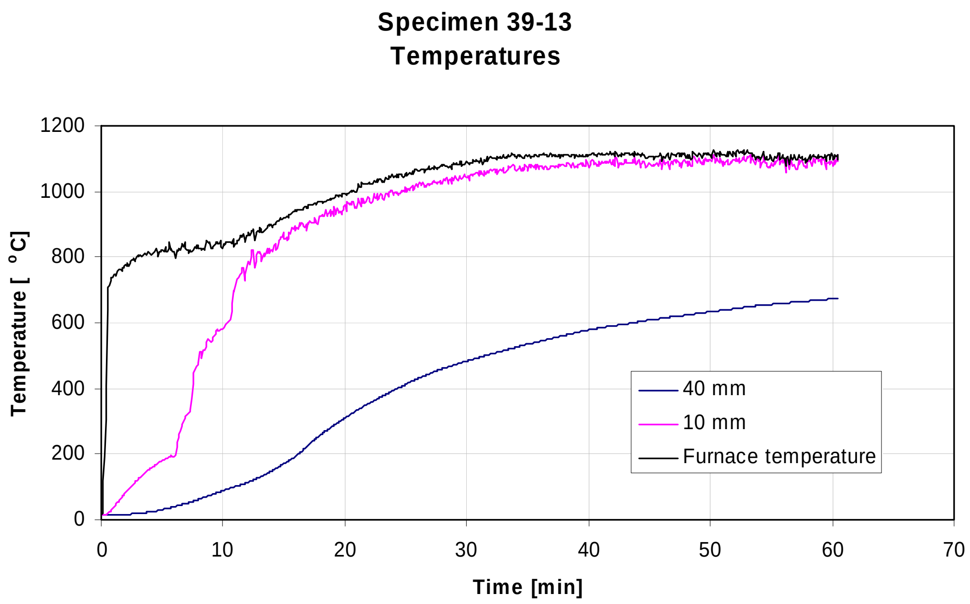


Figure A.347 Measured temperatures in furnace and in specimen 39-13.

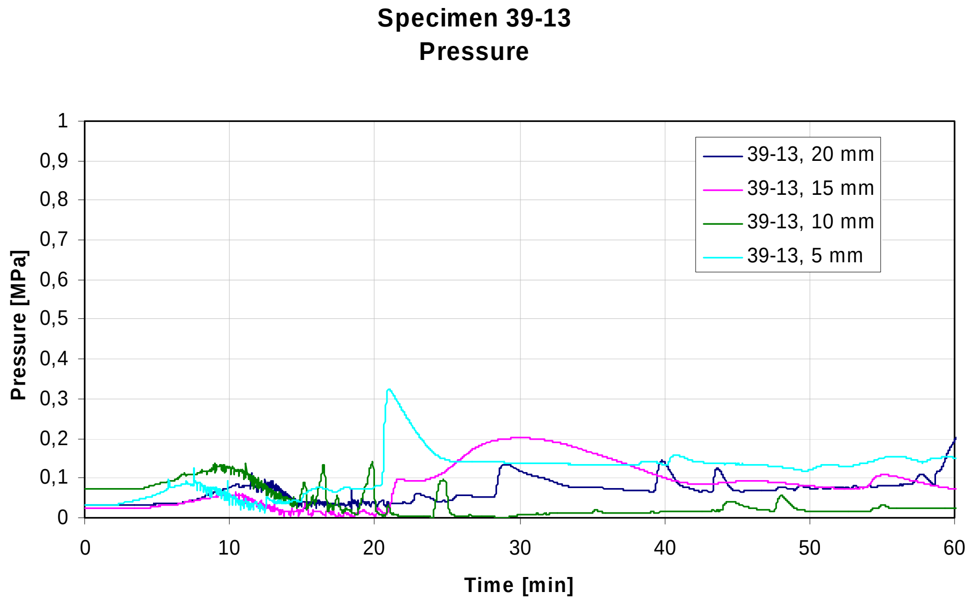


Figure A.348 Measured vapour pressure in specimen 39-13.

Table A.199 Spalling measurements on specimen 39-13.

Position	0	100	200	300	400	500
0	0	1	3	10	7	1
100	0	9	24	21	28	11
200	2	16	19	24	30	6
300	1	20	23	18	30	9
400	3	24	28	16	25	8
500	3	17	14	13	12	3
600	0	2	1	2	1	1

Mean all	12
Mean inner	21
Max in diagram	30
Max measured	41

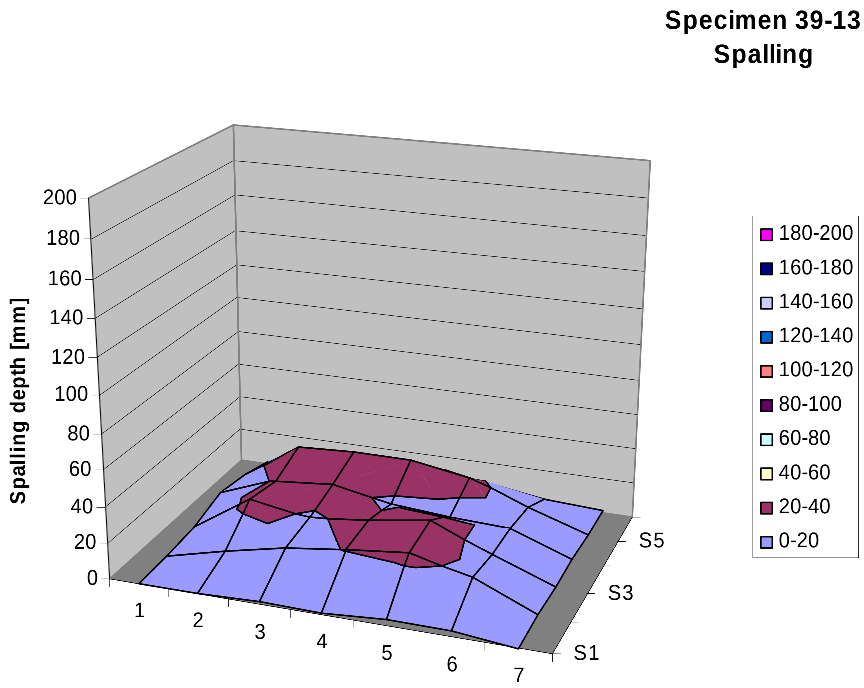


Figure A.349 Spalling measurements on specimen 39-13.

Table A.200 Observations made on specimen 39-13.

Time	Observation
0,00	Start of test
2,83	One small explosion
3,03	One small explosion
3,23	One small explosion
4,50	One explosion, continuous spalling
14,50	Spalling stoped
20,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-11-26	
Specimen:	39-13	
Load level:	340	kN/bar
Weight loss:	12,6	kg

Figure A.350 Specimen 39-13 after test.

Specimen 39-14

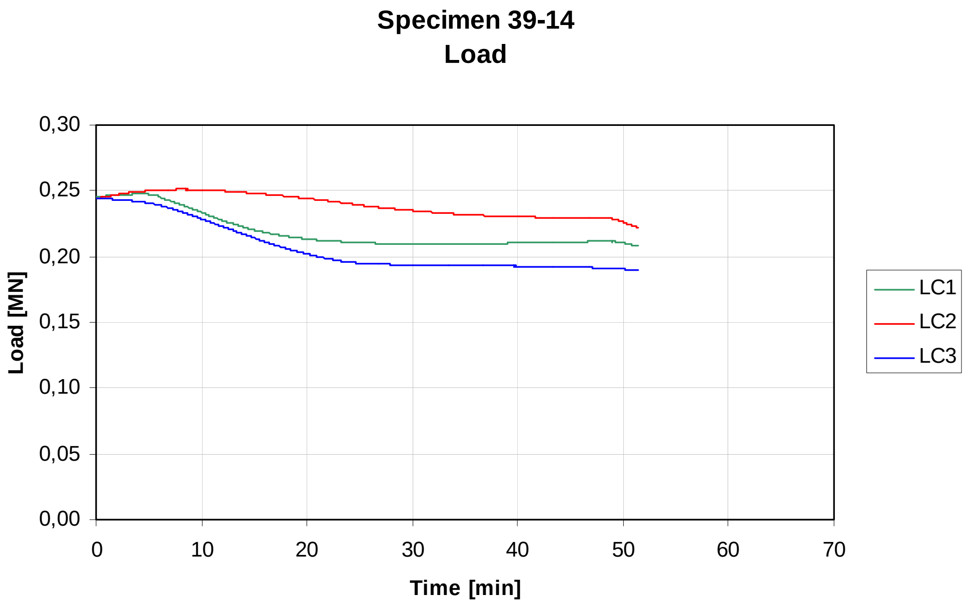


Figure A.351 Load measurements on specimen 39-14.

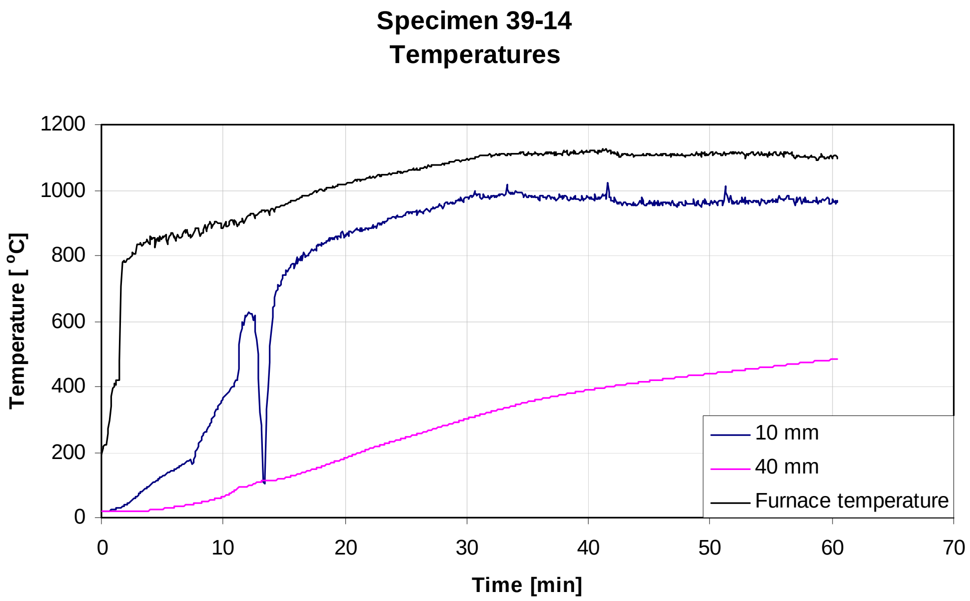


Figure A.352 Measured temperatures in furnace and in specimen 39-14.

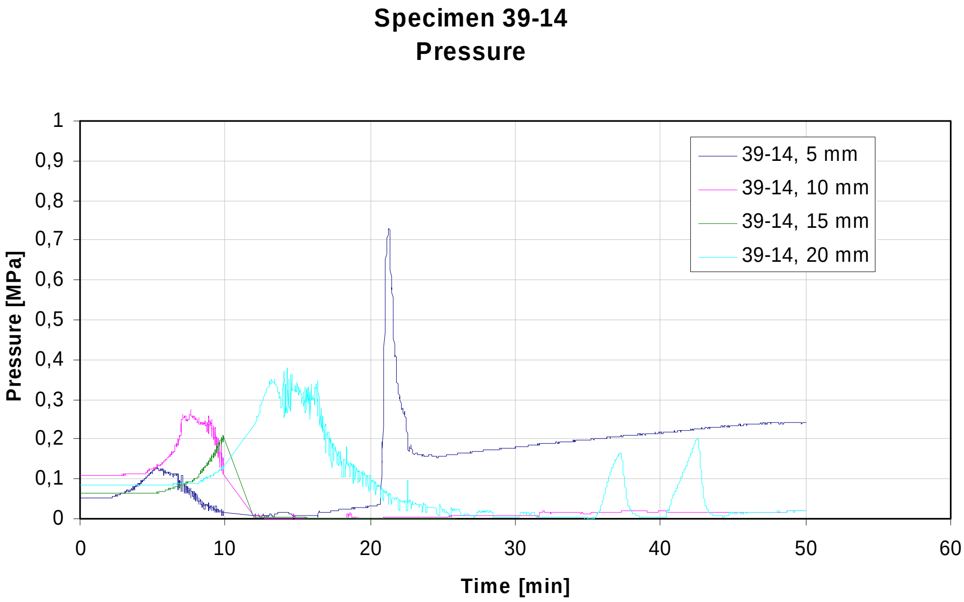


Figure A.353 Measured vapour pressure in specimen 39-14.

Table A.201 Spalling measurements on specimen 39-14.

Position	0	100	200	300	400	500
0	0	3	1	0	0	0
100	9	16	26	19	25	4
200	14	14	12	19	18	4
300	11	11	14	22	15	5
400	8	18	21	18	13	8
500	0	4	5	11	9	0
600	0	0	0	2	2	0

Mean all	9
Mean inner	16
Max in diagram	26
Max measured	31

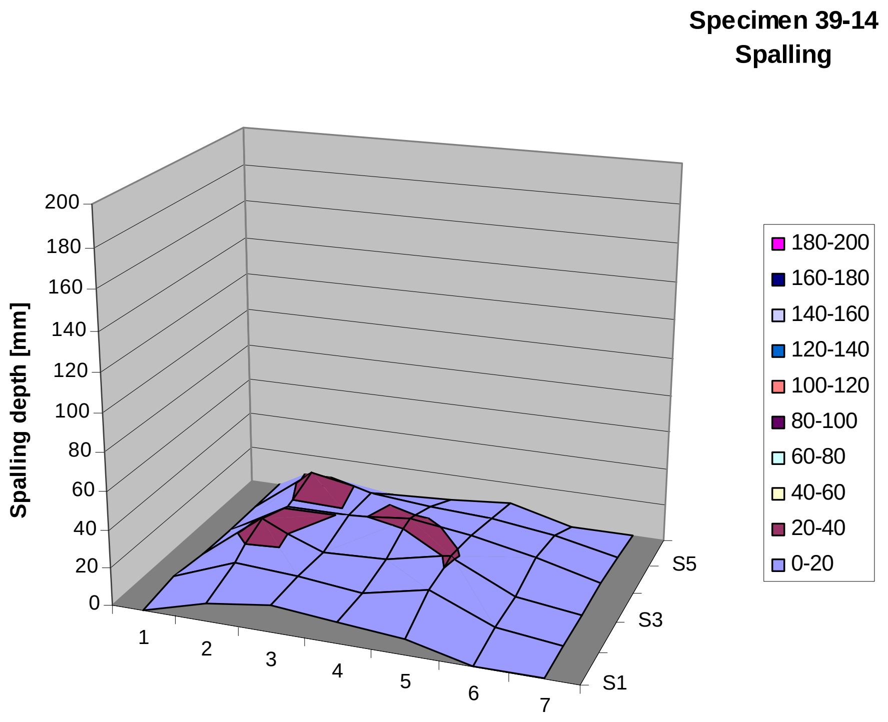


Figure A.354 Spalling measurements on specimen 39-14.

Table A.202 Observations made on specimen 39-14.

Time	Observation
0,00	Start of test
3,75	One small explosion
4,33	One explosion
4,67	Two explosions, continuous explosions
15,00	Spalling stopped, cracks and water on sides
60,50	Test teminated

Test date:	2007-02-23	
Specimen:	39-14	
Load level:	245	kN/bar
Weight loss:	6,0	kg

Figure A.355 Specimen 39-14 after test

Specimen 39-15

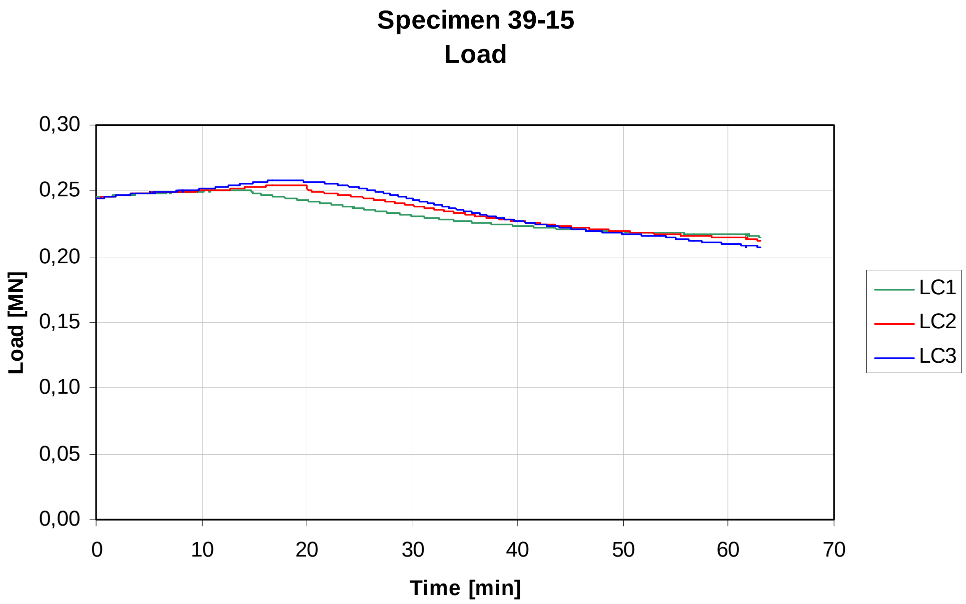


Figure A.356 Load measurements on specimen 39-15.

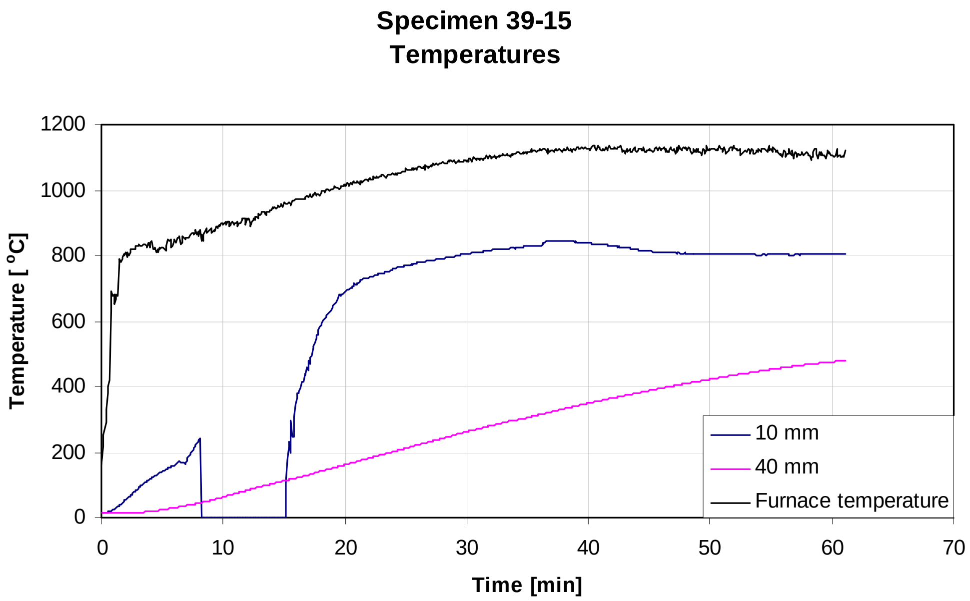


Figure A.357 Measured temperatures in furnace and in specimen 39-15.

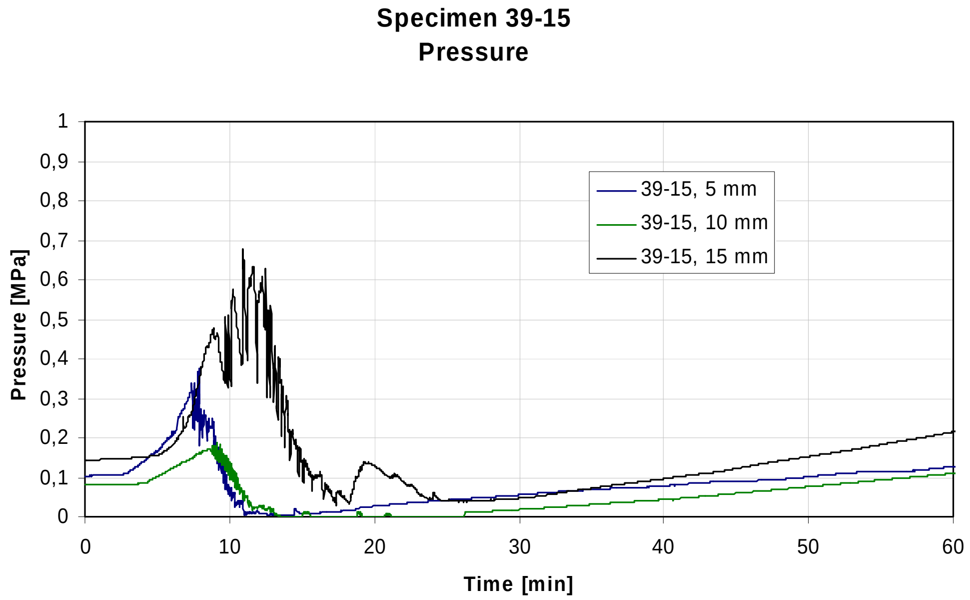


Figure A.358 Measured vapour pressure in specimen 39-15.

Table A.203 Spalling measurements on specimen 39-15.

Position	0	100	200	300	400	500
0	0	6	0	0	0	0
100	0	9	7	10	16	0
200	0	15	12	19	22	6
300	0	17	16	11	21	5
400	0	14	15	7	18	7
500	0	13	6	17	17	3
600	0	0	0	0	0	0

Mean all	7
Mean inner	14
Max in diagram	22
Max measured	35

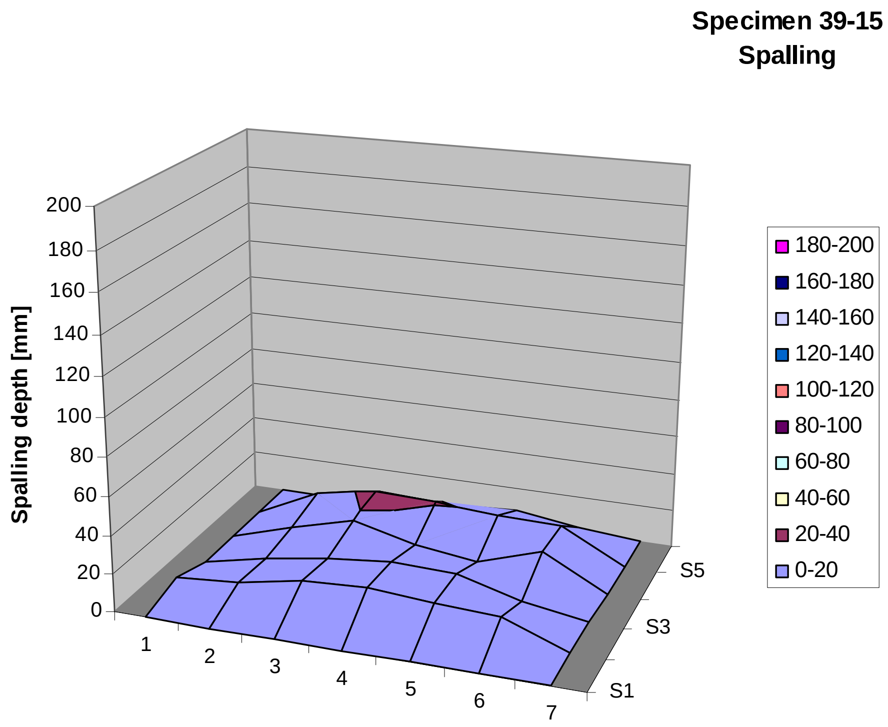


Figure A.359 Spalling measurements on specimen 39-15.

Table A.204 Observations made on specimen 39-15.

Time	Observation			
0,00	Start of test	Test date:	2007-02-22	
3,67	One small explosion	Specimen:	39-15	
4,00	Two small explosions	Load level:	245	kN/bar
4,25	One explosion	Weight loss:	3,7	kg
4,50	Continuous explosions			
13,00	Spalling stopped			
21,00	Cracks and water on sides			
61,00	Test terminated			

Figure A.360 Specimen 39-15 after test

Specimen 3-17

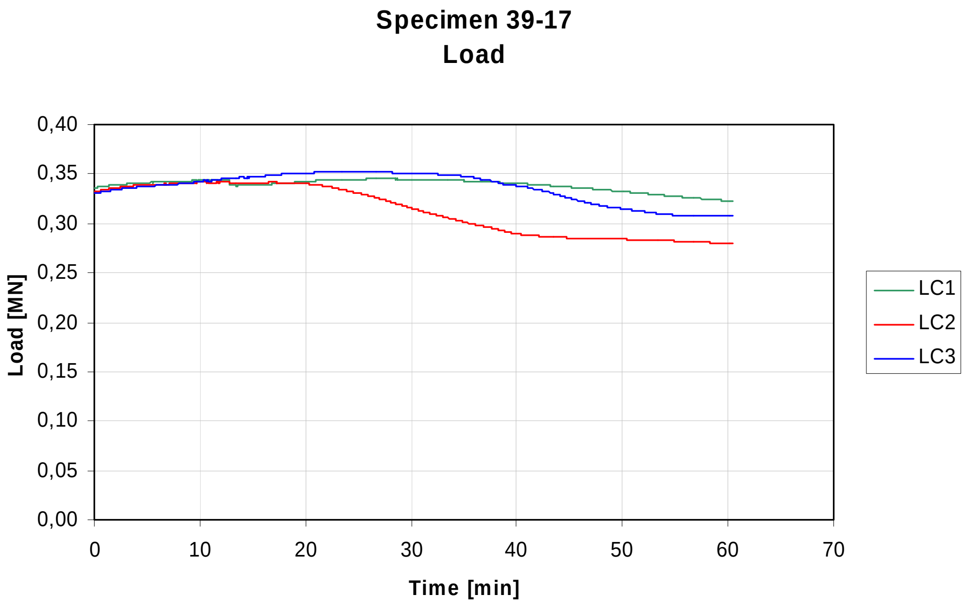


Figure A.361 Load measurements on specimen 39-17.

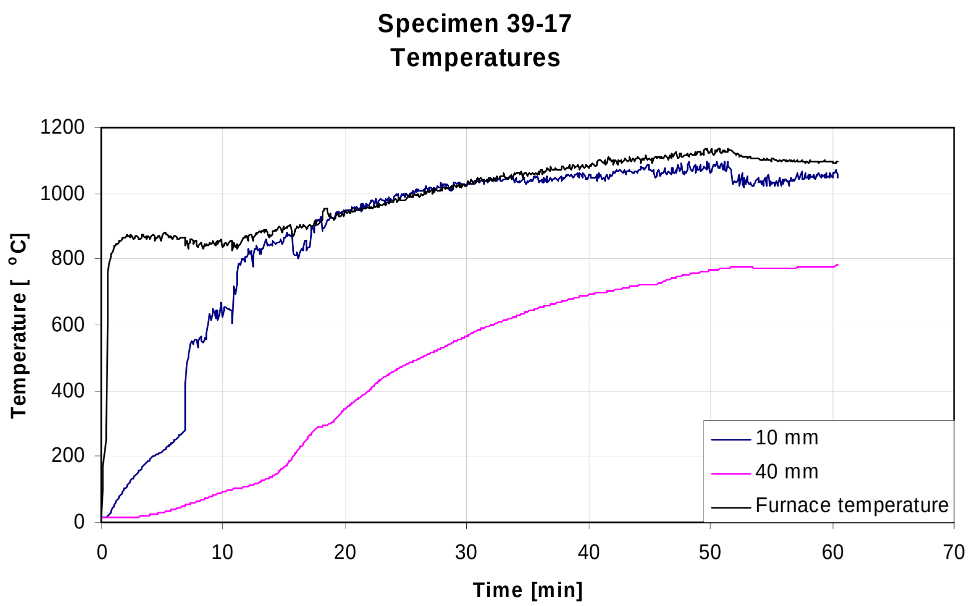


Figure A.362 Measured temperatures in furnace and in specimen 39-17.

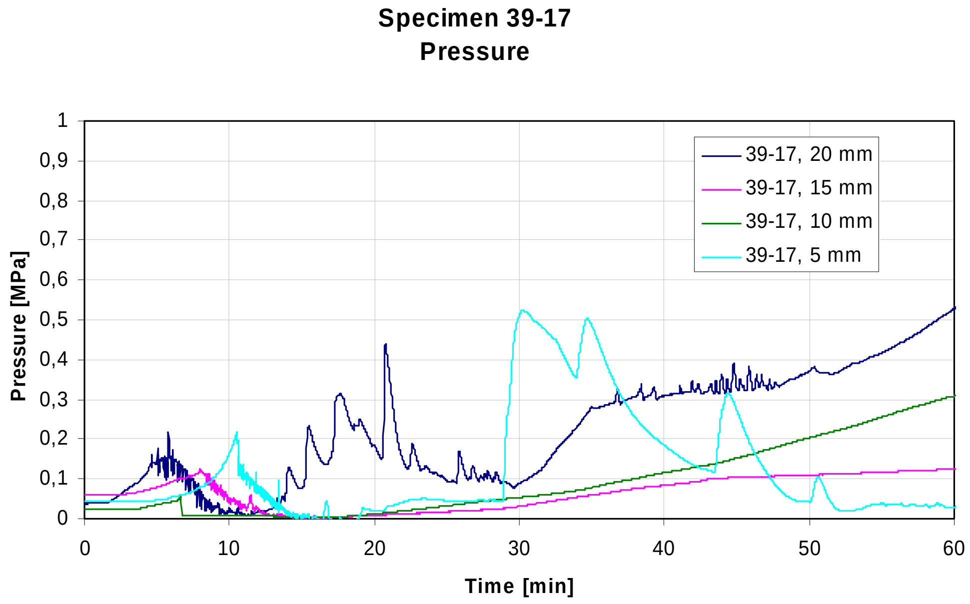


Figure A.363 Measured temperatures in furnace and in specimen 39-17.

Table A.205 Spalling measurements on specimen 39-17.

Position	0	100	200	300	400	500
0	0	0	9	18	8	1
100	11	9	31	19	19	6
200	17	15	29	27	22	3
300	13	23	26	30	19	2
400	10	34	20	22	32	3
500	6	22	13	21	12	1
600	0	2	0	3	2	0

Mean all	13
Mean inner	22
Max in diagram	34
Max measured	43

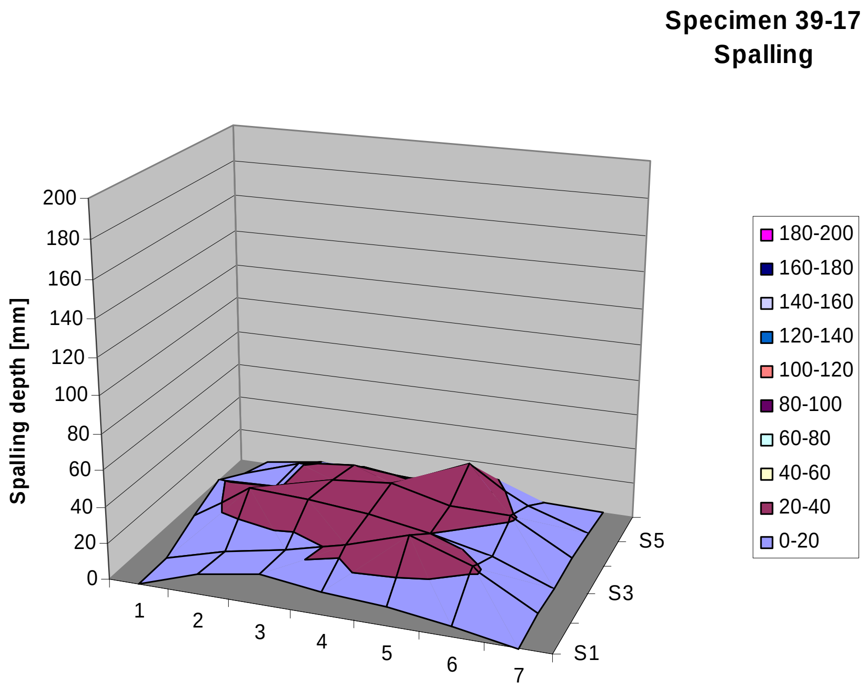


Figure A.364 Spalling measurements on specimen 39-17.

Table A.206 Observations made on specimen 39-17.

Time	Observation			
0,00	Start of test	Test date:	2007-11-28	
2,58	One small explosion	Specimen:	39-17	
3,00	Continuous explosions	Load level:	333	kN/bar
16,00	Spalling stopped	Weight loss:	14,8	kg
20,00	Cracks and water on sides			
60,50	Test terminated			

Figure A.365 Specimen 39-17 after test.

Specimen 39-18

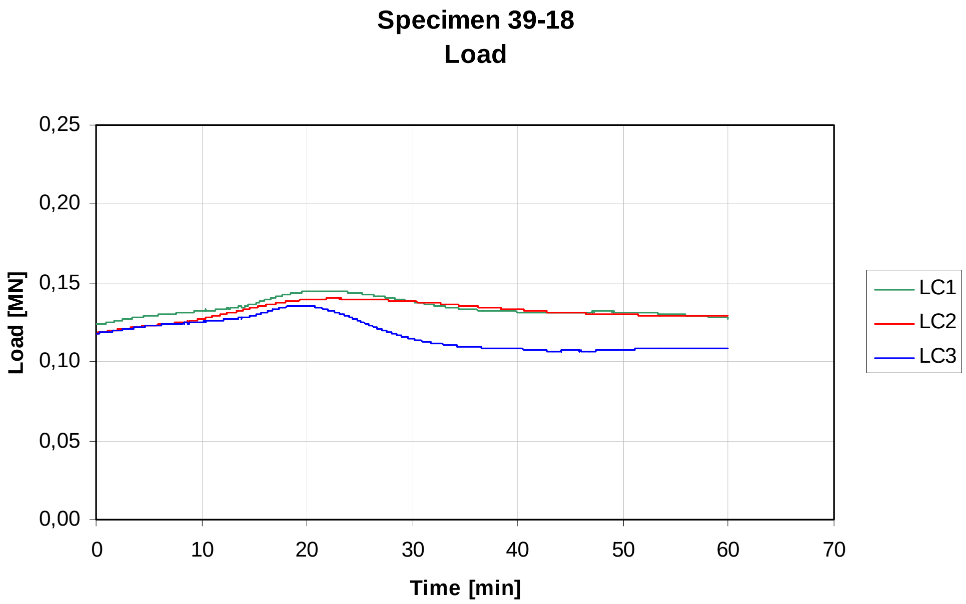


Figure A.366 Load measurements on specimen 39-18.

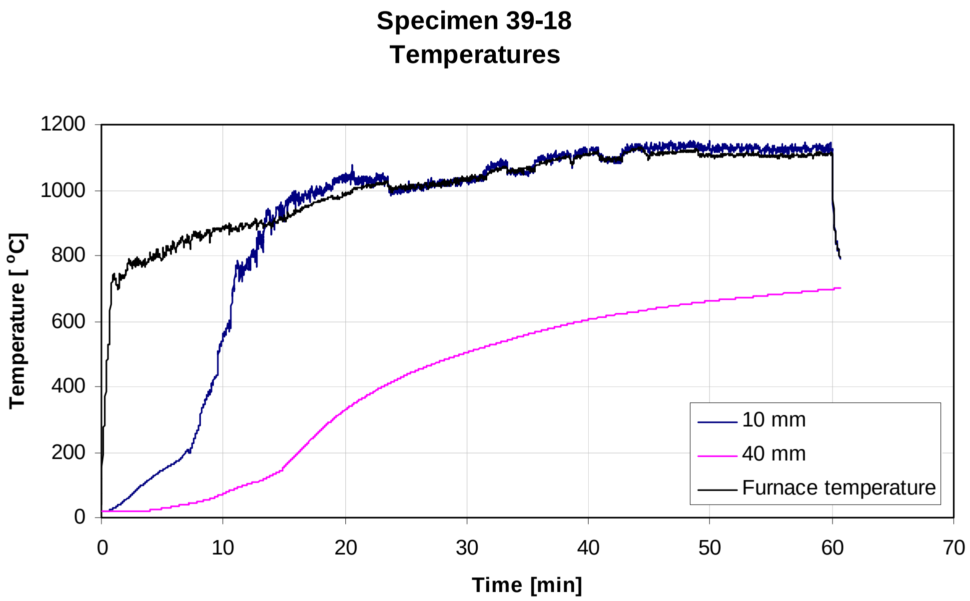


Figure A.367 Measured temperatures in furnace and in specimen 39-18.

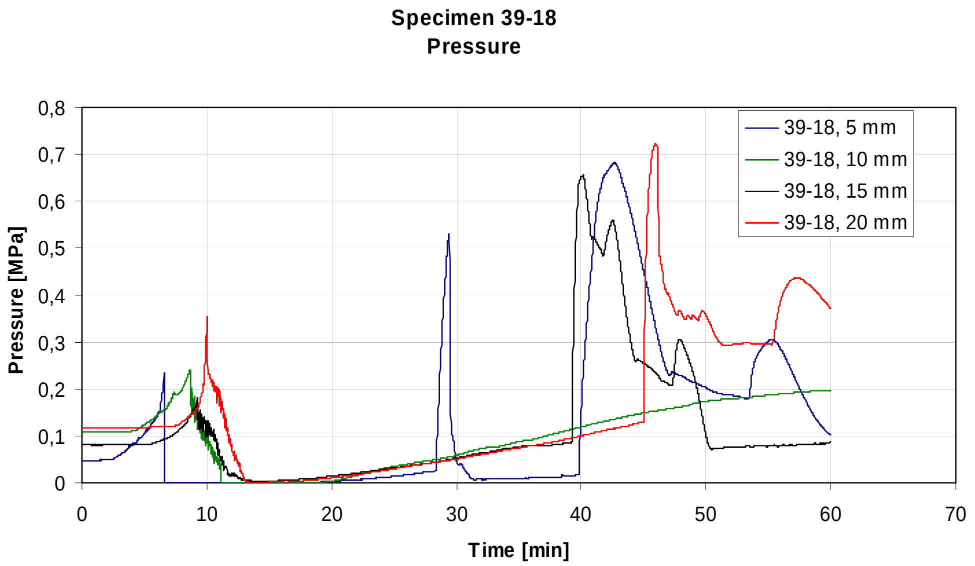


Figure A.368 Measured vapour pressure in specimen 39-18.

Table A.207 Spalling measurements on specimen 39-18

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	6	13	26	22	8	0
200	22	32	39	35	14	3
300	25	29	31	32	7	0
400	16	34	30	27	8	0
500	9	26	22	30	11	0
600	0	0	0	7	8	0

Mean all	14
Mean inner	24
Max in diagram	39
Max measured	42

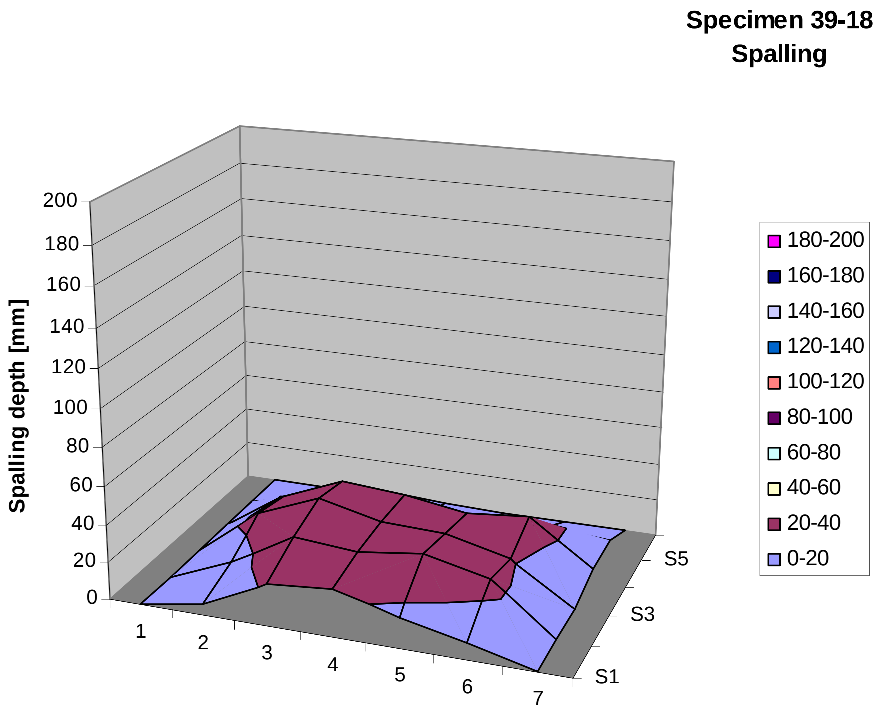


Figure A.369 Spalling measurements on specimen 39-18

Table A.208 Observations made on specimen 39-18.

Time	Observation
0,00	Start of test
2,80	One small explosion
2,95	Continuous explosions
16,33	Spalling stopped
31,00	Lots of water on sides
60,00	Test terminated

Test date:	2007-02-22	
Specimen:	39-18	
Load level:	120	kN/bar
Weight loss:	14,7	kg

Figure A.370 Specimen 39-18 after test

Specimen 39-19

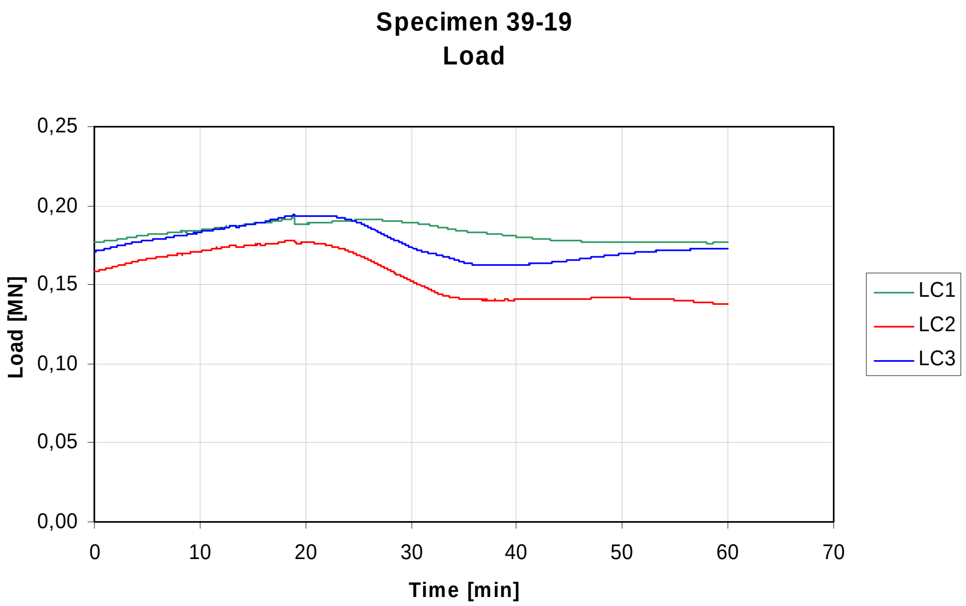


Figure A.371 Load measurements on specimen 39-19.

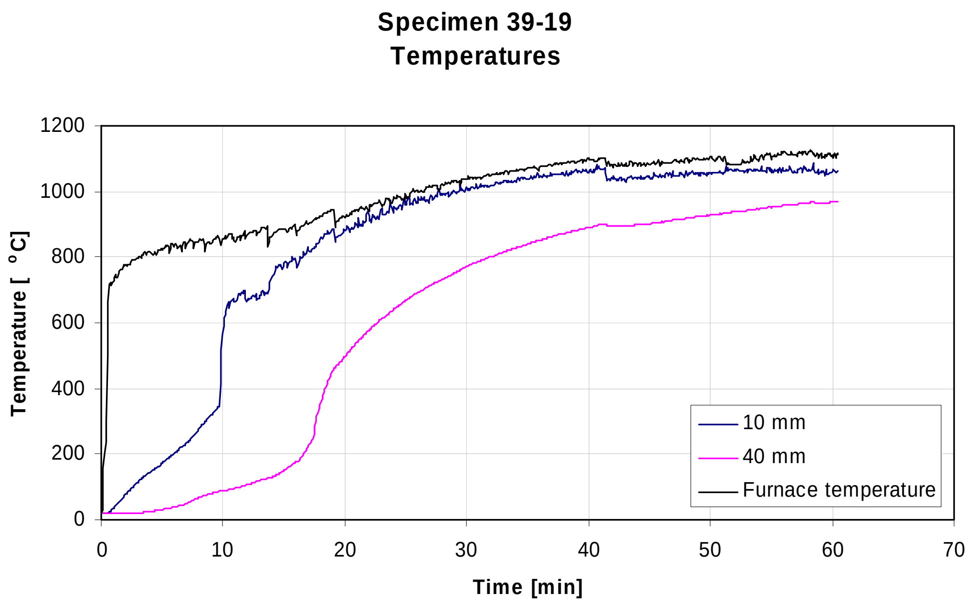


Figure A.372 Measured temperatures in furnace and in specimen 39-19.

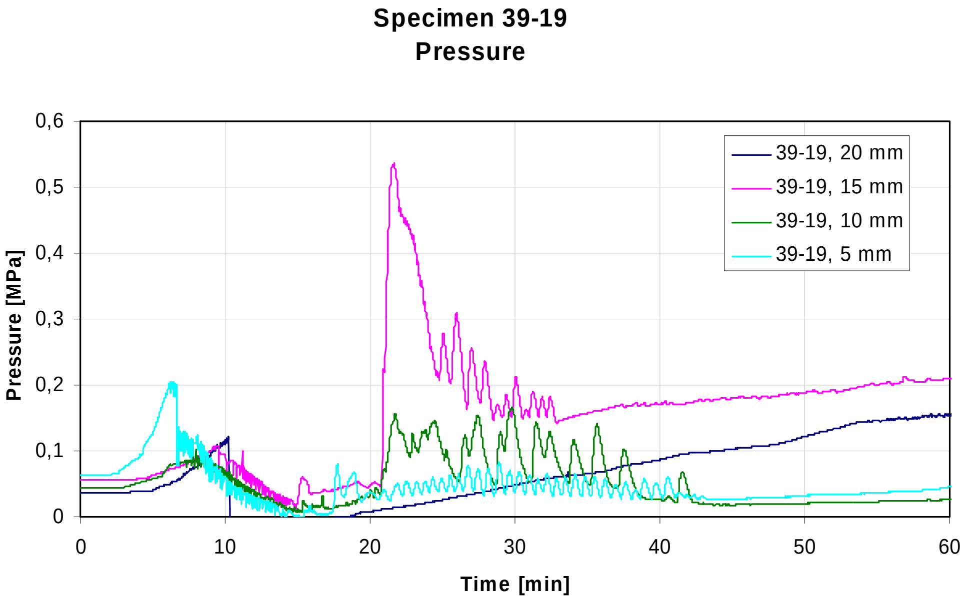


Figure A.373 Measured vapour pressure in specimen 39-19.

Table A.209 Spalling measurements on specimen 39-19.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	8	18	23	29	3
200	0	28	40	24	40	8
300	6	26	45	30	36	17
400	8	37	48	24	34	10
500	4	22	21	20	19	12
600	0	0	0	0	0	0

Mean all	15
Mean inner	29
Max in diagram	48
Max measured	64

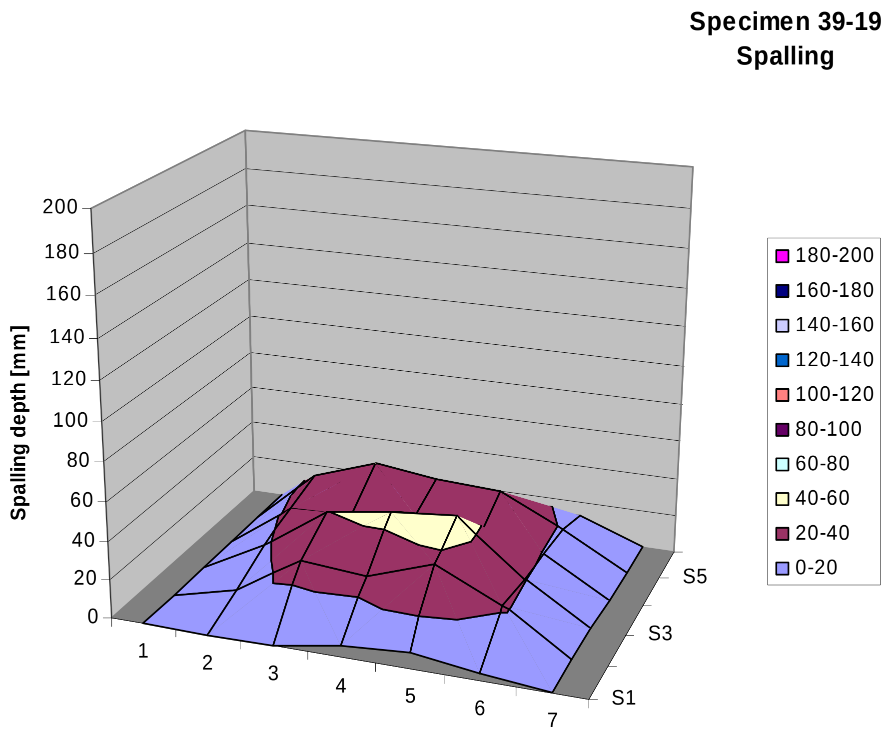


Figure A.374 Spalling measurements on specimen 39-19..

Table A.210 Observations made on specimen 39-19.

Time	Observation
0,00	Start of test
3,25	Two small explosions
4,00	Continuous spalling
20,00	Spalling stopped, cracks and water on sides
60,50	Test terminated

Test date:	2007-11-22	
Specimen:	39-19	
Load level:	169	kN/bar
Weight loss:	18,1	kg

Figure A.375 Specimen 39-19 after test.

Specimen 39-20

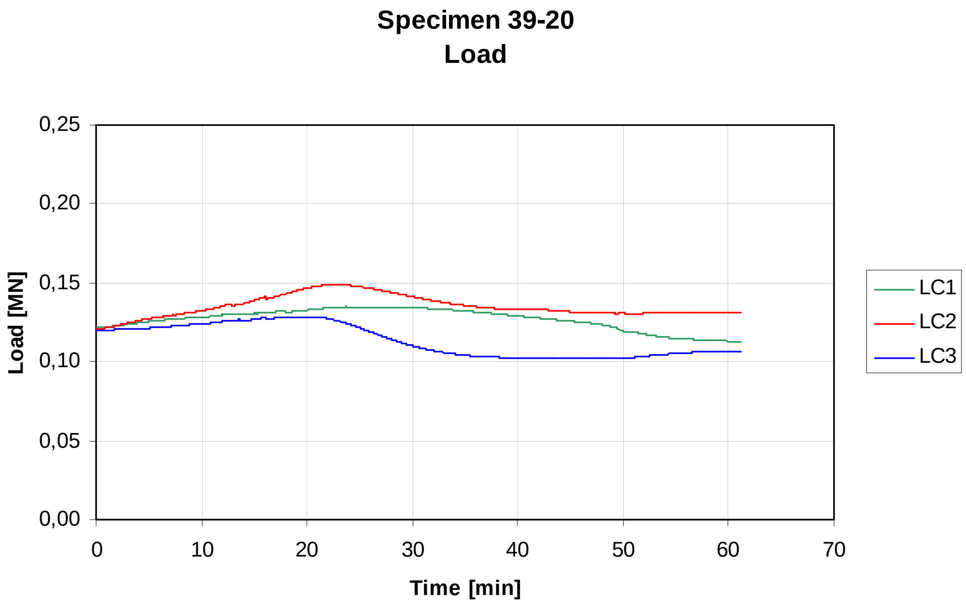


Figure A.376 Load measurements on specimen 39-20.

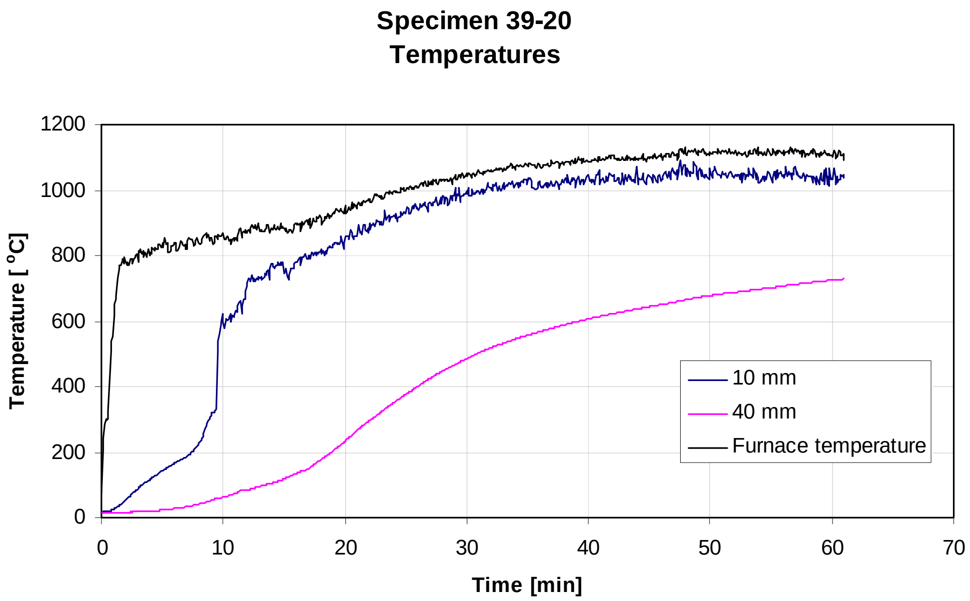


Figure A.377 Measured temperatures in furnace and in specimen 39-20.

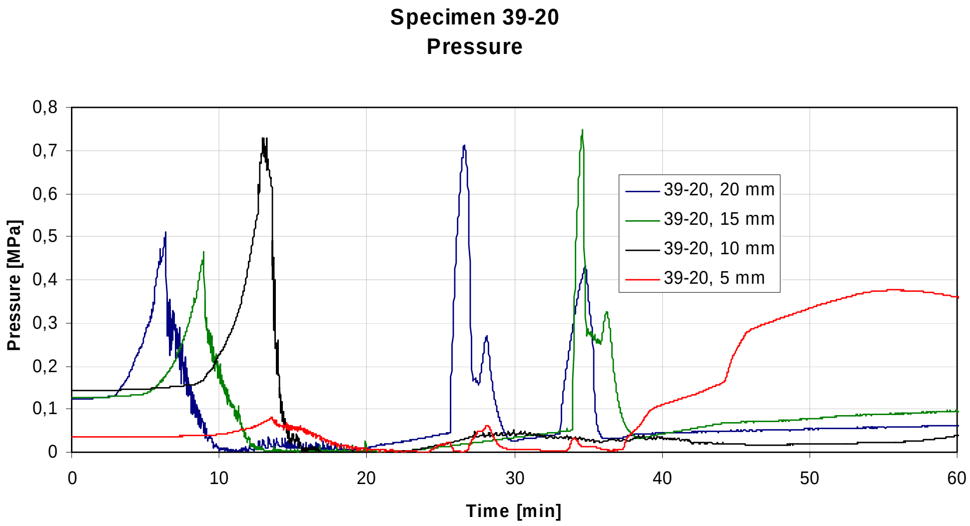


Figure A.378 Measured vapour pressure in specimen 39-20.

Table A.211 Spalling measurements on specimen 39-20.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	13	25	17	12	25	0
200	18	41	29	25	34	19
300	17	38	34	39	42	10
400	0	21	33	40	38	0
500	0	6	7	23	30	0
600	0	0	0	0	0	0

Mean all	15
Mean inner	28
Max in diagram	42
Max measured	49

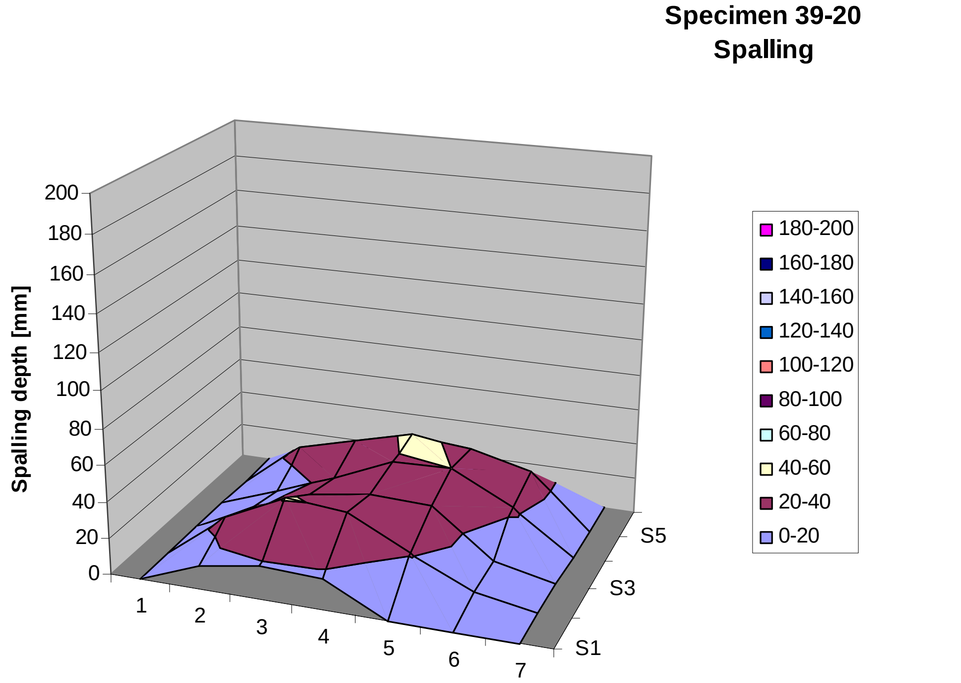


Figure A.379 Spalling measurements on specimen 39-20.

Table A.212 Observations made on specimen 39-20.

Time	Observation			
0,00	Start of test	Test date:	2007-02-19	
3,00	Small explosion	Specimen:	39-20	
3,33	Continuous spalling	Load level:	121	kN/bar
20,00	Spalling stopped, cracks and water on sides	Weight loss:	15,8	kg
61,00	Test terminated			

Figure A.380 Specimen 39-20 after test.

Specimen 39-23

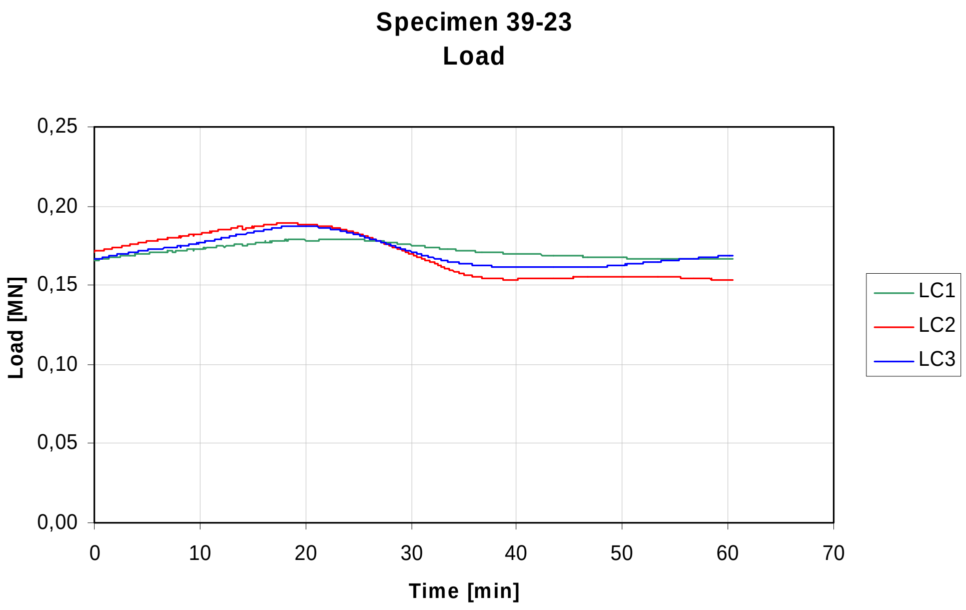


Figure A.381 Load measurements on specimen 39-23.

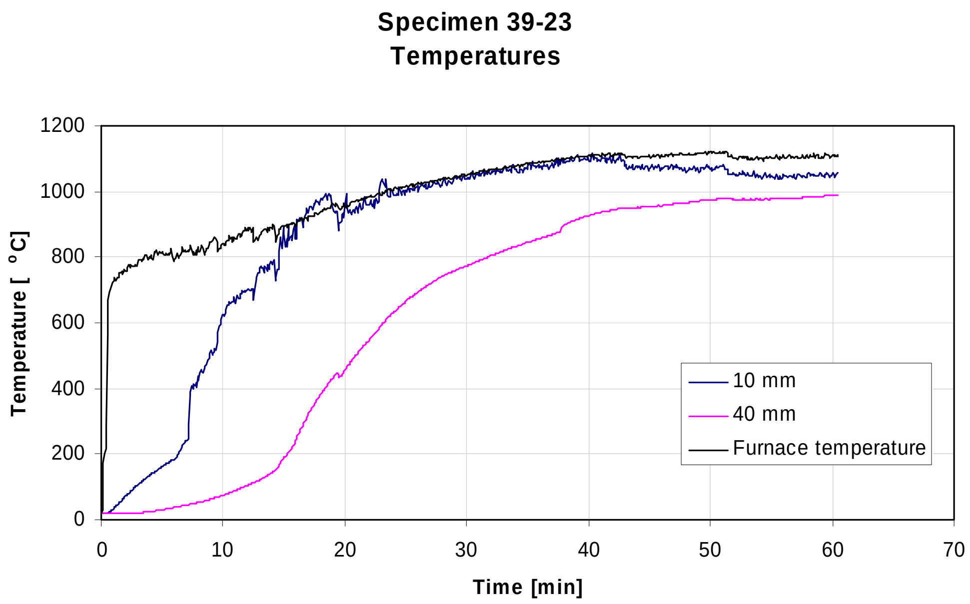


Figure A.382 Measured temperatures in furnace and in specimen 39-23.

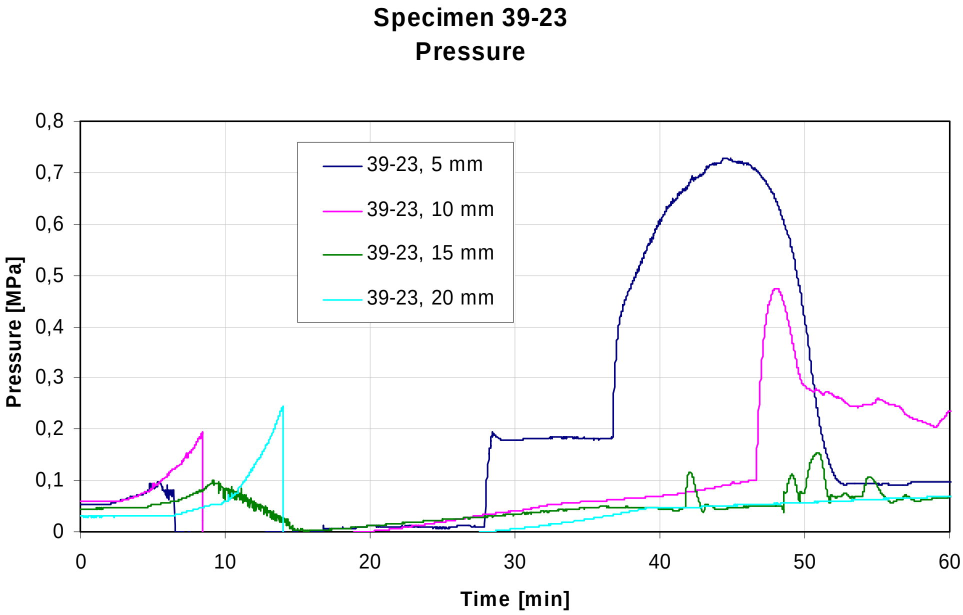


Figure A.383 Measured vapour pressure in specimen 39-23.

Table A.213 Spalling measurements on specimen 39-23.

Position	0	100	200	300	400	500
0	0	0	0	0	3	0
100	0	11	22	17	9	1
200	2	21	29	25	10	0
300	10	26	47	39	30	6
400	0	3	50	41	27	14
500	0	23	39	33	11	0
600	0	0	1	0	0	0

Mean all	13
Mean inner	26
Max in diagram	50
Max measured	63

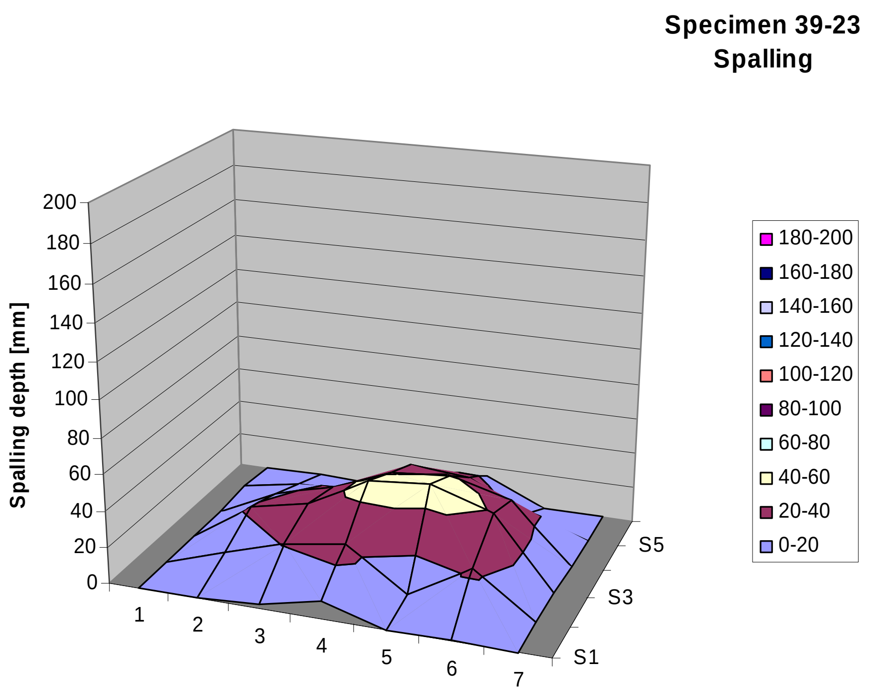


Figure A.384 Spalling measurements on specimen 39-23.

Table A.214 Observations made on specimen 39-23.

Time	Observation
0,00	Start of test
3,17	One small explosion
3,80	Two small explosions
5,00	Continuous spalling
20,00	Spalling stopped, cracks and water on sides
60,50	Test terminated

Test date:	2007-11-21	
Specimen:	39-23	
Load level:	168	kN/bar
Weight loss:	14,3	kg

Figure A.385 Specimen 39-23 after test.

Specimen 39-25

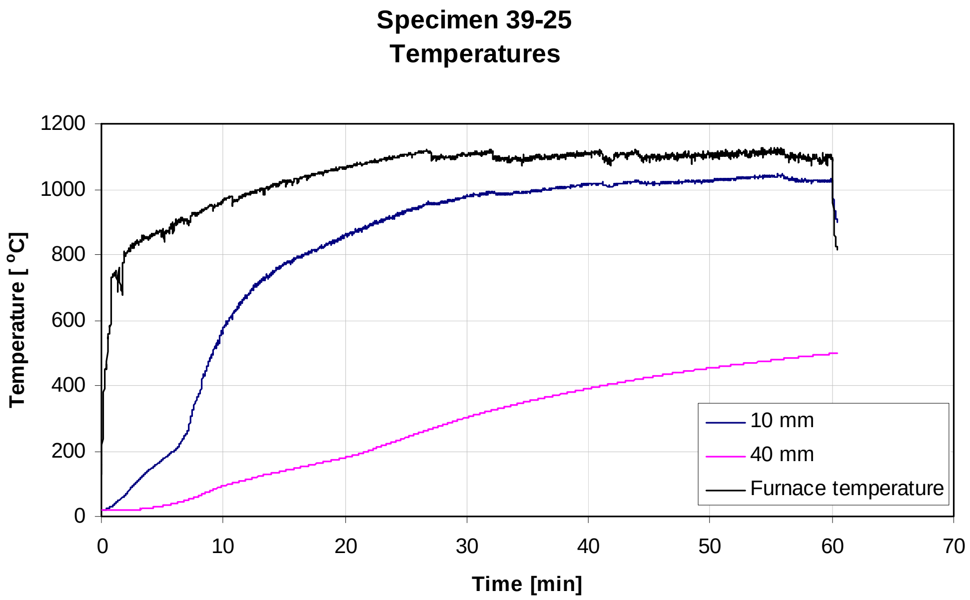


Figure A.386 Measured temperatures in furnace and in specimen 39-25, unloaded.

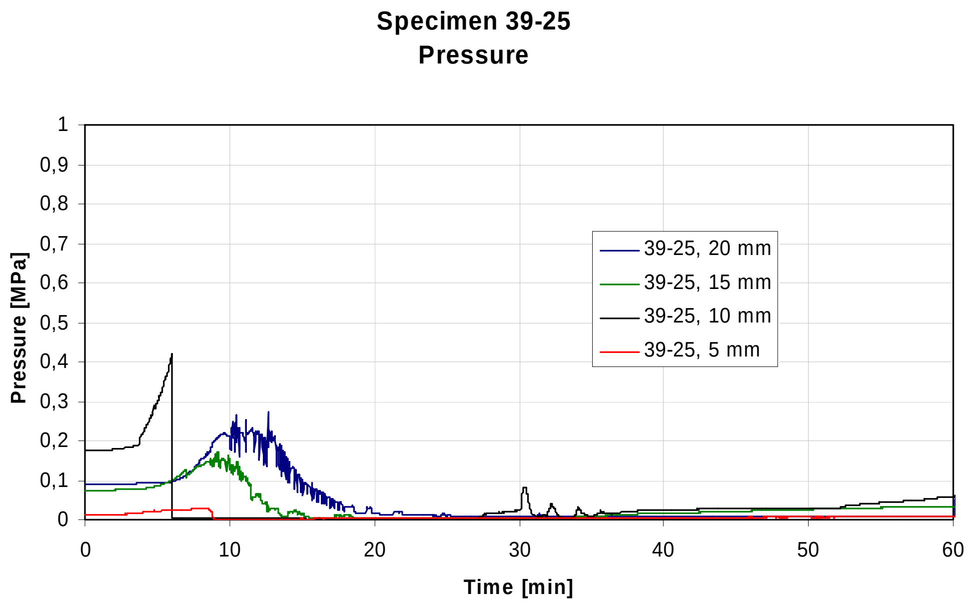


Figure A.387 Measured vapour pressure in specimen 39-25.

Table A.215 Spalling measurements on specimen 39-25

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	3	10	9	1	16	5
200	7	19	14	14	3	7
300	0	20	15	14	3	1
400	0	20	8	6	4	2
500	3	13	9	3	2	0
600	2	4	0	0	0	0

Mean all	6
Mean inner	10
Max in diagram	20
Max measured	24

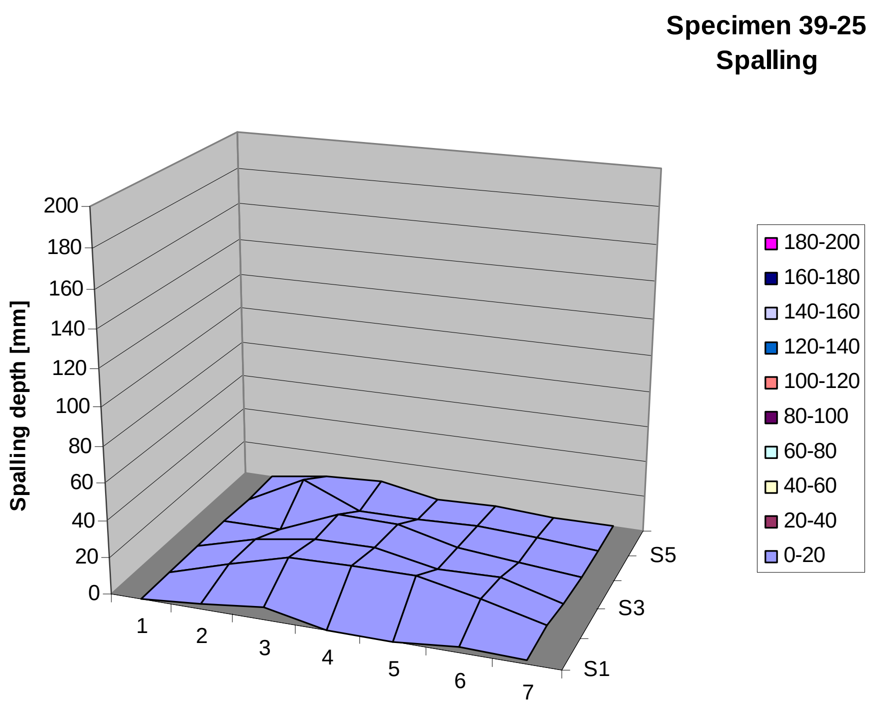


Figure A.388 Spalling measurements on specimen 39-25

Table A.216 Observations made on specimen 39-25.

Time	Observation
0,00	Start of test
3,80	Some small explosions
4,12	Continuous spalling
9,00	Spalling stopped
9,33	Cracks on sides
60,00	Test terminated

Test date:	2007-05-15	
Specimen:	39-25	
Load level:	-	kN/bar
Weight loss:	7,5	kg

Figure A.389 Specimen 39-25 after test.

Specimen 39-27

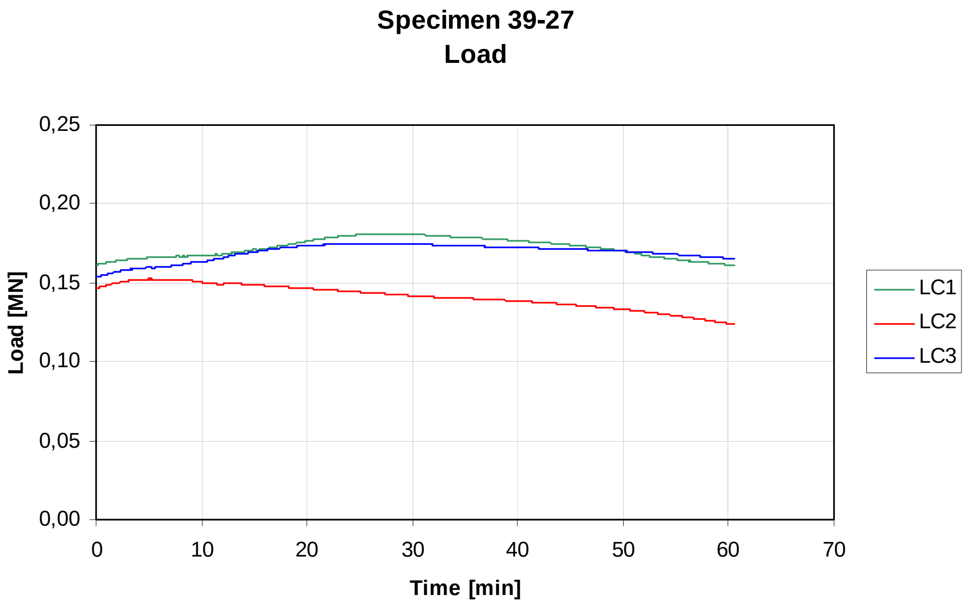


Figure A.390 Load measurements on specimen 39-27.

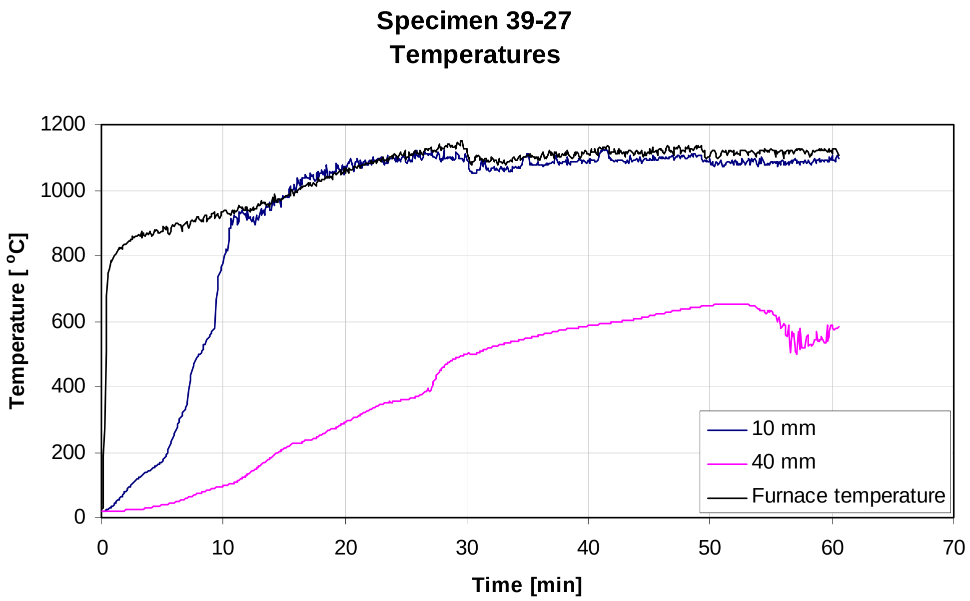


Figure A.391 Measured temperatures in furnace and in specimen 39-27.

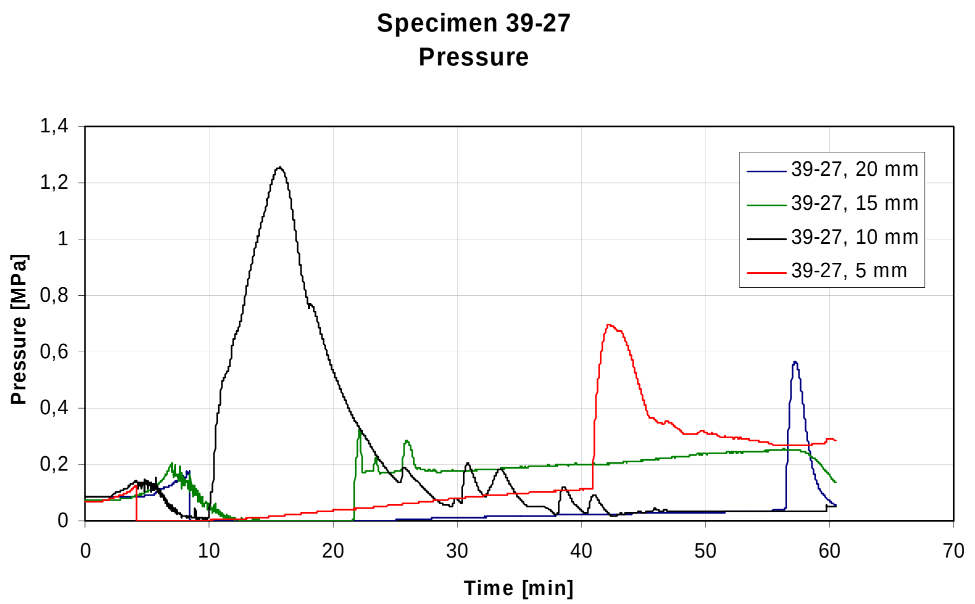


Figure A.392 Measured vapour pressure in specimen 39-27.

Table A.217 Spalling measurements on specimen 39-27.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	16	34	11	20	2
200	2	45	30	26	25	4
300	7	37	28	33	33	2
400	12	43	23	27	26	1
500	18	38	22	28	17	0
600	0	0	0	1	1	0

Mean all	15
Mean inner	28
Max in diagram	45
Max measured	53

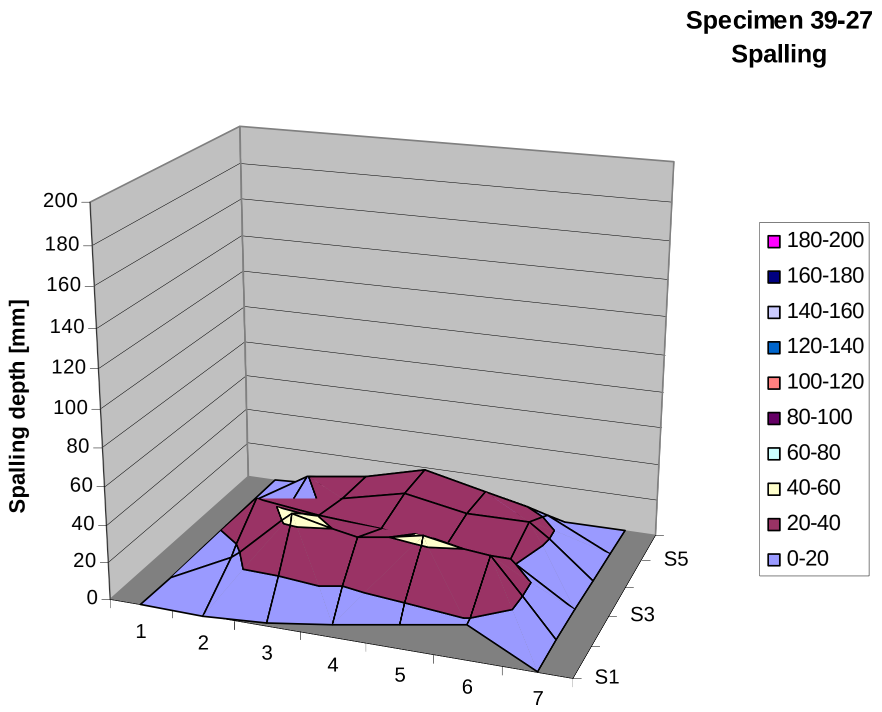


Figure A.393 Spalling measurements on specimen 39-27.

Table A.218 Observations made on specimen 39-27.

Time	Observation			
0,00	Start of test	Test date:	2007-05-23	
2,00	Two small explosions	Specimen:	39-27	
2,50	Continuous spalling	Load level:	154	kN/bar
15,00	Spalling stopped, cracks and water on sides	Weight loss:	15,5	kg
60,50	Test terminated			

Figure A.394 Specimen 39-27 after test.

Specimen 39-28

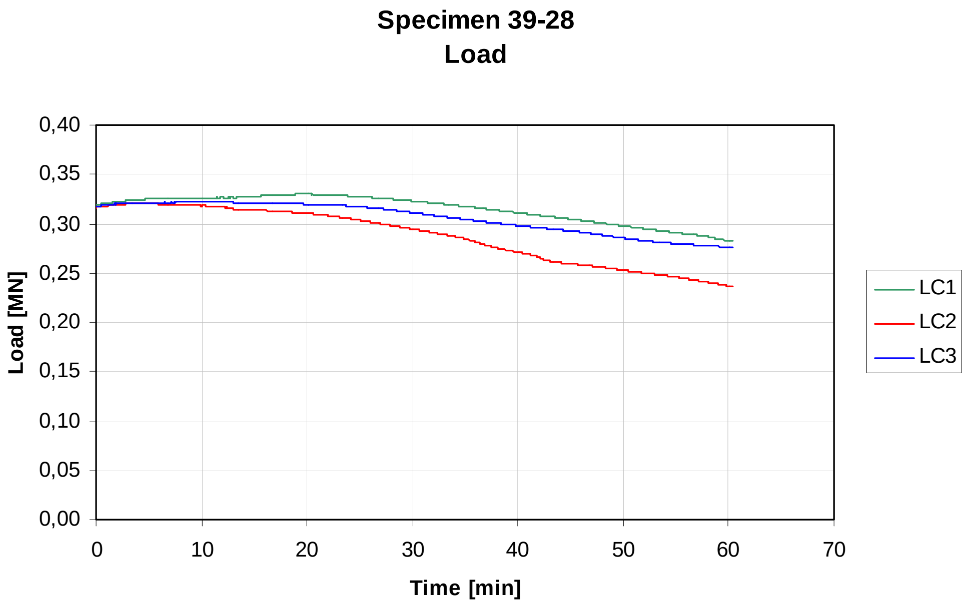


Figure A.395 Load measurements on specimen 39-28.

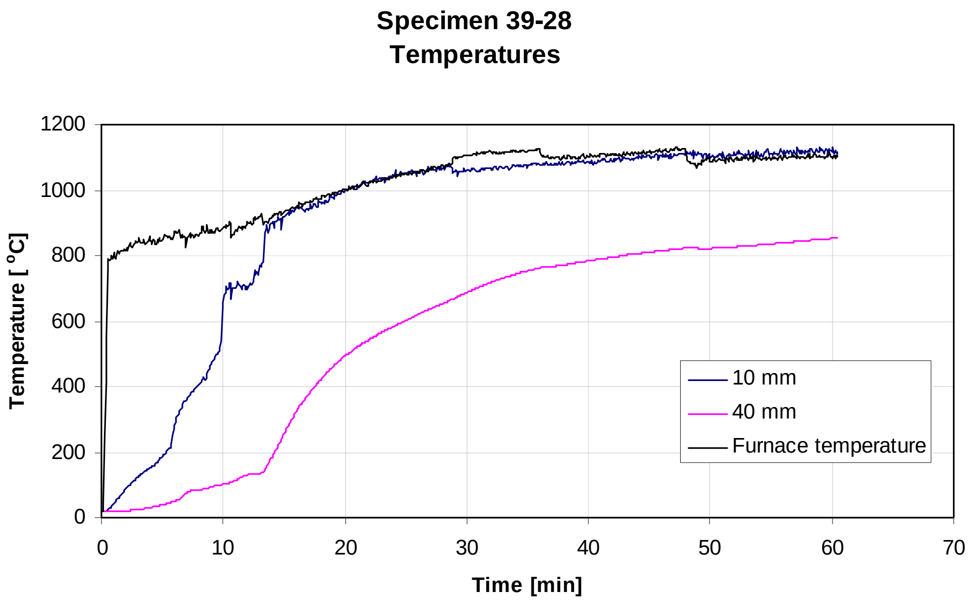


Figure A.396 Measured temperatures in furnace and in specimen 39-28.

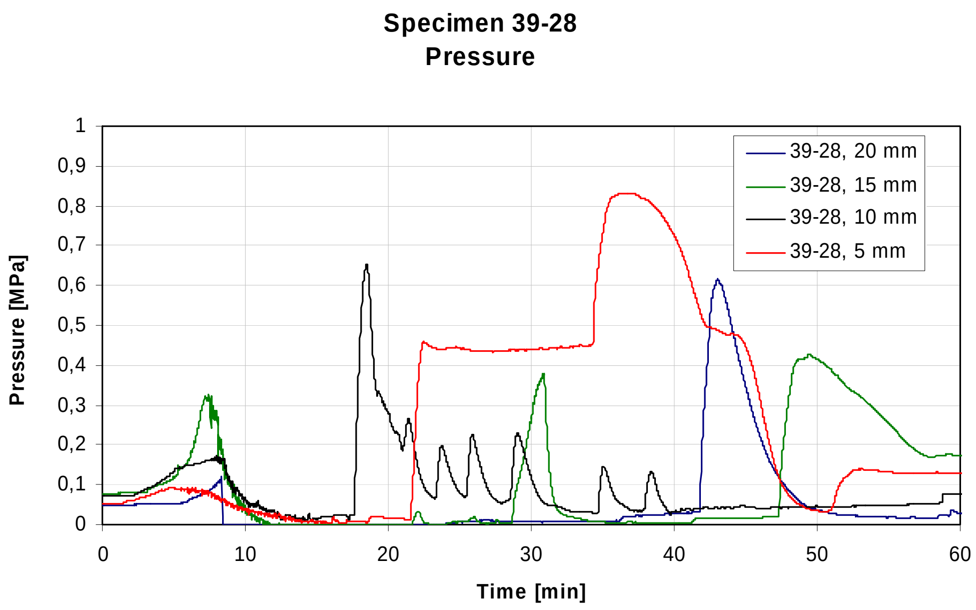


Figure A.397 Measured vapour pressure in specimen 39-28.

Table A.219 Spalling measurements on specimen 39-28.

Position	0	100	200	300	400	500
0	0	0	0	0	1	0
100	0	15	13	12	4	0
200	6	26	23	26	16	1
300	5	31	33	36	8	5
400	9	29	31	37	32	8
500	5	23	31	42	33	9
600	0	0	16	19	2	0

Mean all	14
Mean inner	25
Max in diagram	42
Max measured	48

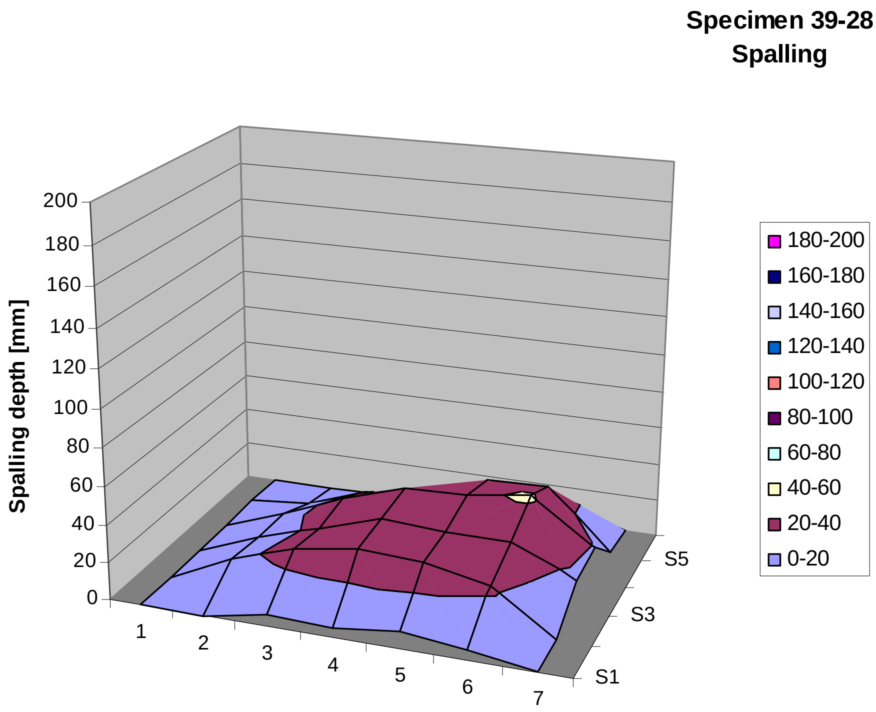


Figure A.398 Spalling measurements on specimen 39-28.

Table A.220 Observations made on specimen 39-28.

Time	Observation			
0,00	Start of test	Test date:	2007-05-11	
3,00	Two small explosions	Specimen:	39-28	
3,33	Continuous spalling	Load level:	318	kN/bar
15,00	Spalling stopped, cracks and water on sides	Weight loss:	12,1	kg
60,50	Test terminated			

Figure A.399 Specimen 39-28 after test.

Specimen 39-29

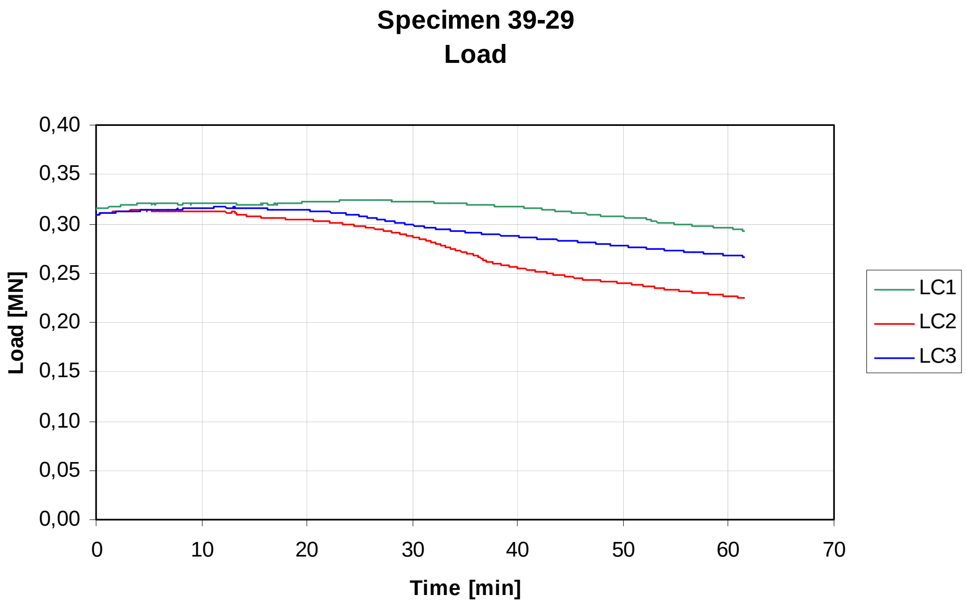


Figure A.400 Load measurements on specimen 39-29.

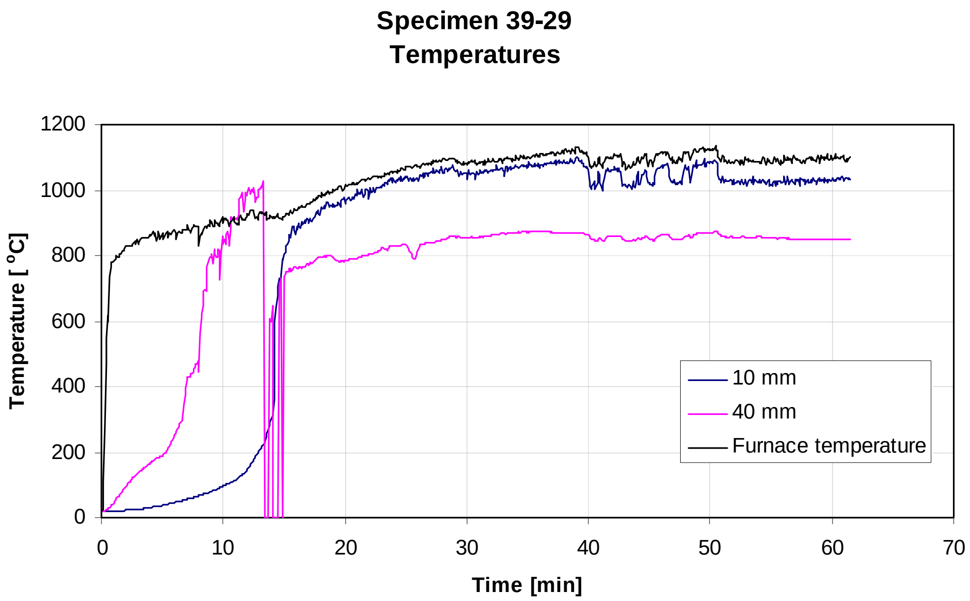


Figure A.401 Measured temperatures in furnace and in specimen 39-29.

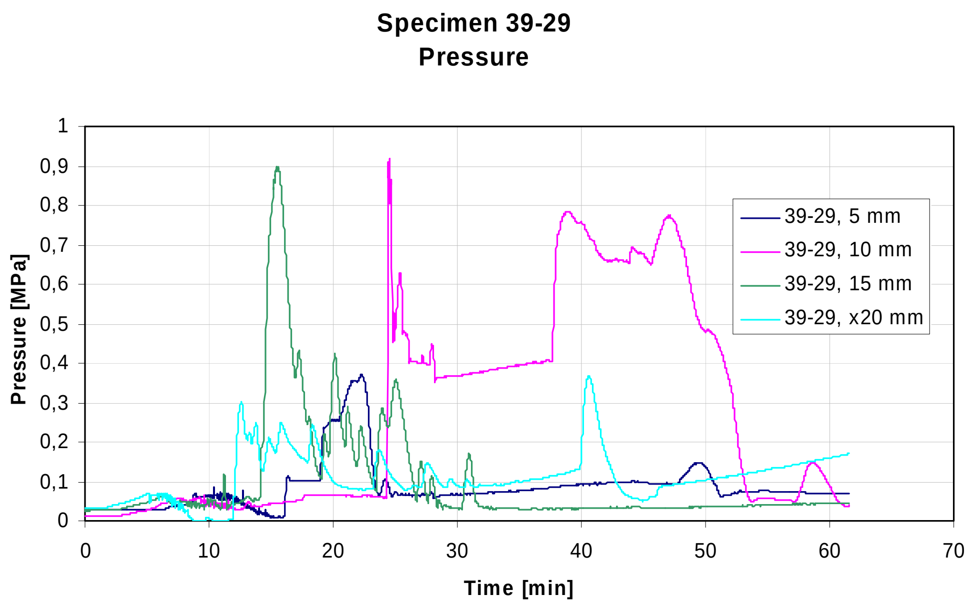


Figure A.402 Measured vapour pressure in specimen 39-29.

Table A.221 Spalling measurements on specimen 39-29.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	19	13	16	11	0
200	3	30	15	30	11	3
300	12	37	44	50	43	10
400	0	25	39	37	36	8
500	0	21	27	38	29	4
600	0	0	1	8	8	1

Mean all	15
Mean inner	29
Max in diagram	50
Max measured	64

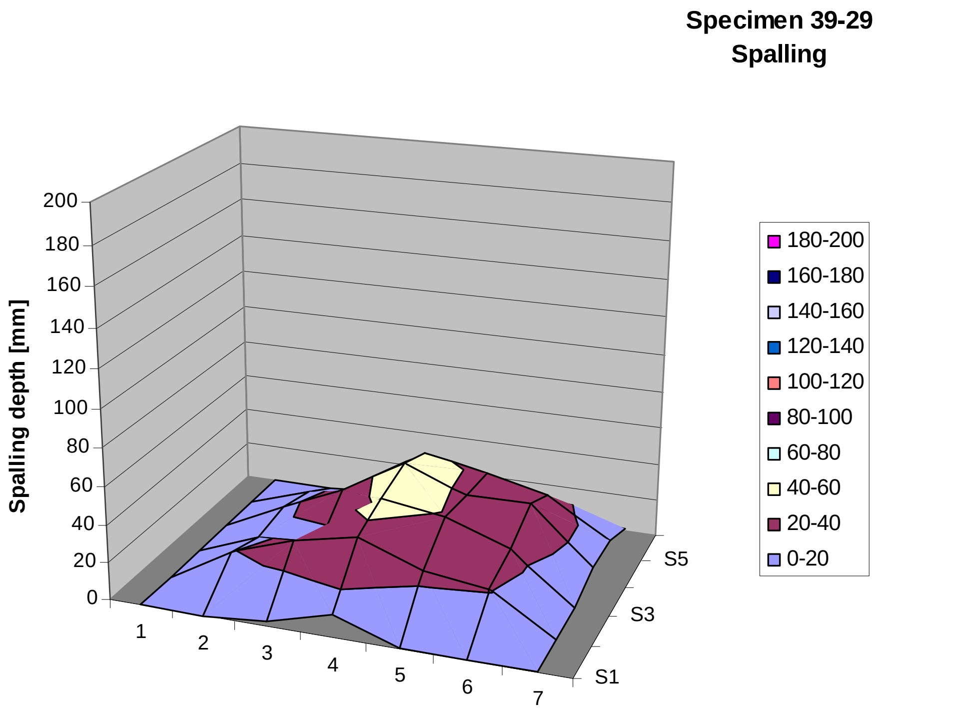


Figure A.403 Spalling measurements on specimen 39-29.

Table A.222 Observations made on specimen 39-29.

Time	Observation			
0,00	Start of test	Test date:	2007-05-21	
3,00	Four small explosions	Specimen:	39-29	
3,50	Continuous spalling	Load level:	311	kN/bar
17,00	Spalling stopped, cracks and water on sides	Weight loss:	15,2	kg
61,50	Test terminated			

Figure A.404 Specimen 39-29 after test.

Specimen 39-30

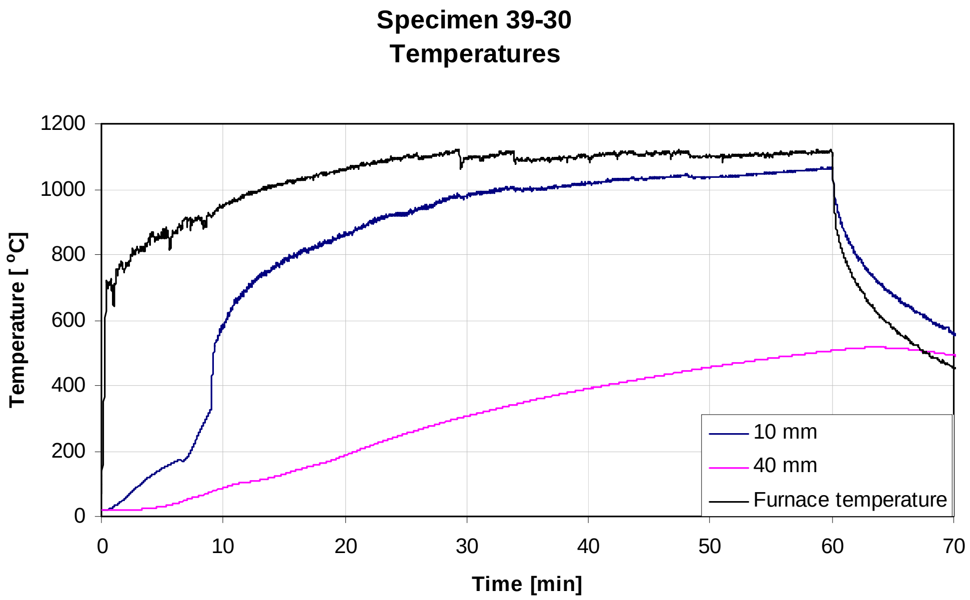


Figure A.405 Measured temperatures in furnace and in specimen 39-30, unloaded.

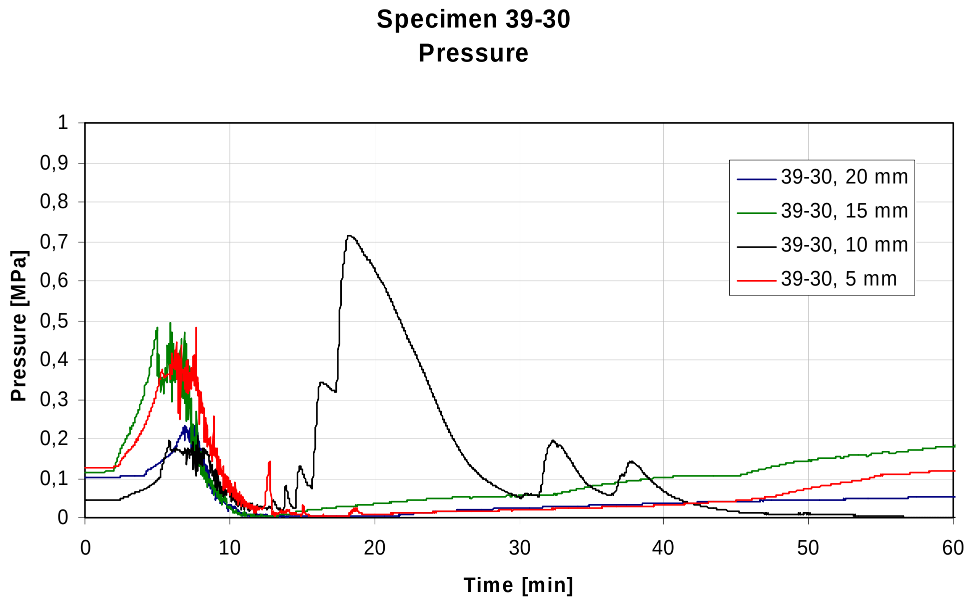


Figure A.406 Measured vapour pressure in specimen 39-30.

Table A.223 Spalling measurements on specimen 39-30

Position	0	100	200	300	400	500
0	0	0	0	0	1	0
100	0	9	18	12	14	0
200	5	8	16	9	7	0
300	6	14	16	15	14	4
400	0	13	15	14	9	1
500	0	9	7	12	9	8
600	0	0	0	0	0	0

Mean all	6
Mean inner	12
Max in diagram	18
Max measured	24

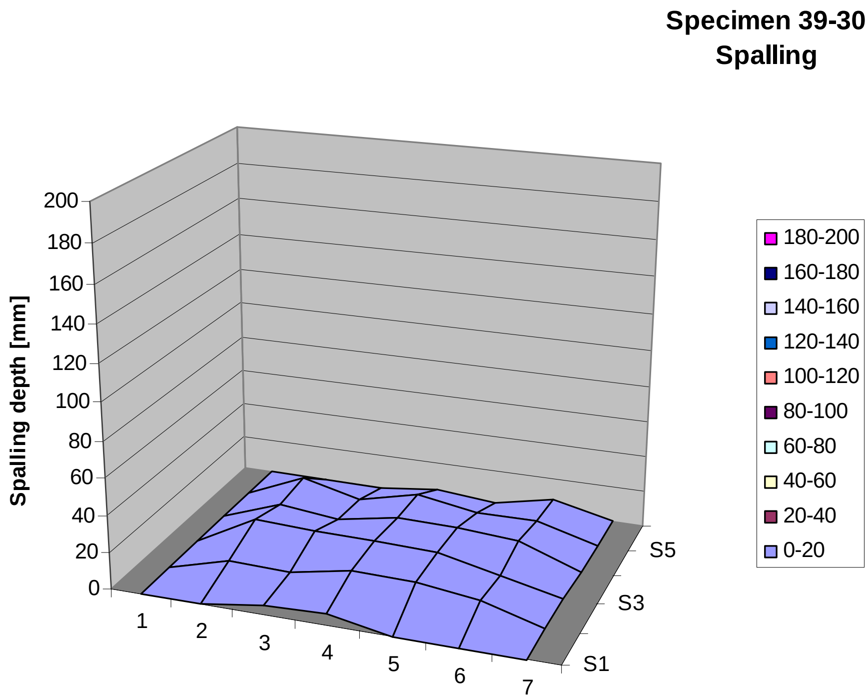


Figure A.407 Spalling measurements on specimen 39-30.

Table A.224 Observations made on specimen 39-30.

Time	Observation
0,00	Start of test
2,70	Two small explosions
3,17	Continuous spalling
8,50	Spalling stopped
12,67	Cracks and water on sides
60,00	Test terminated

Test date:	2007-05-14	
Specimen:	39-30	
Load level:	-	kN/bar
Weight loss:	7,5	kg

Figure A.408 Specimen 39-30 after test.

Specimen 39-31

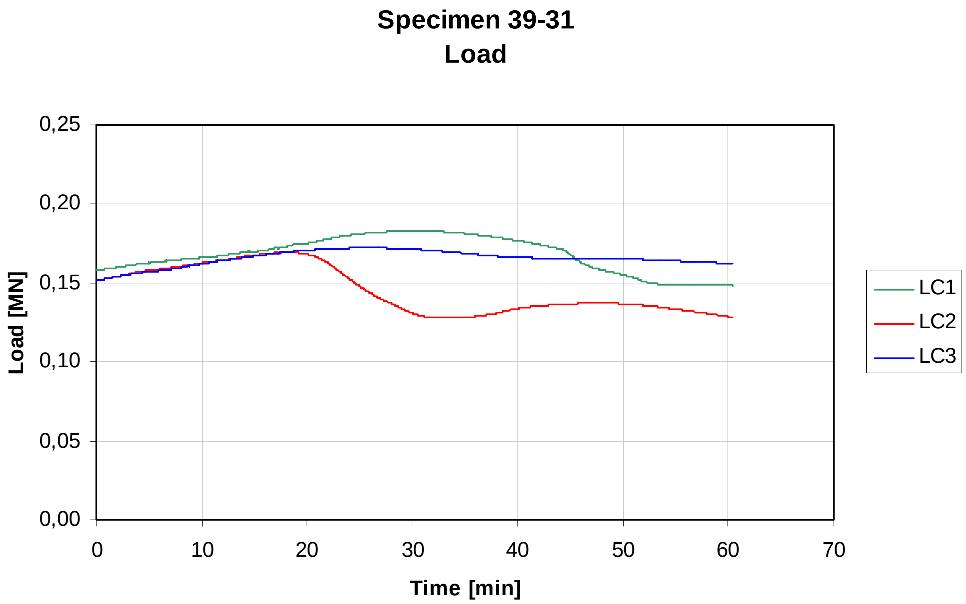


Figure A.409 Load measurements on specimen 39-31.

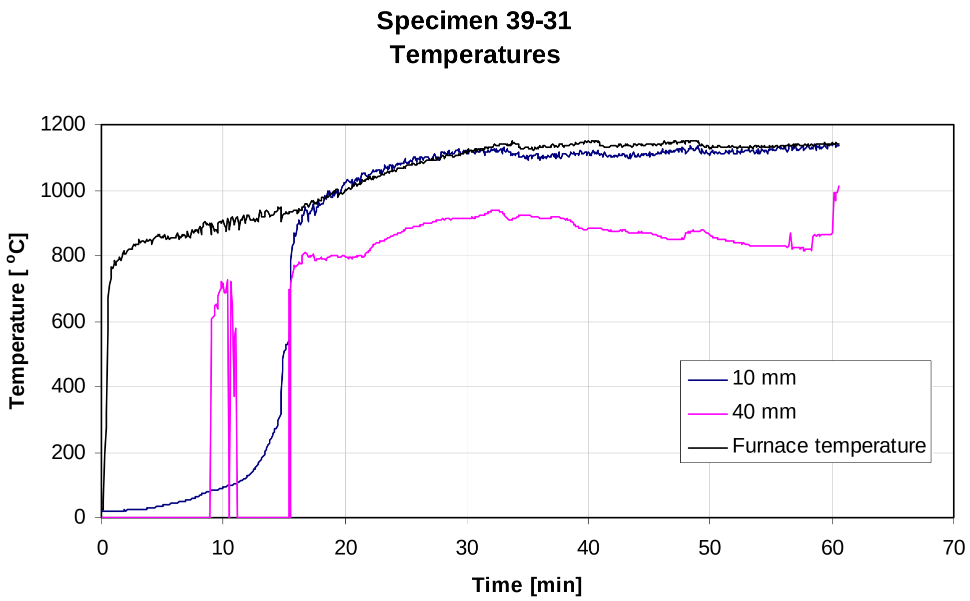


Figure A.410 Measured temperatures in furnace and in specimen 39-31.

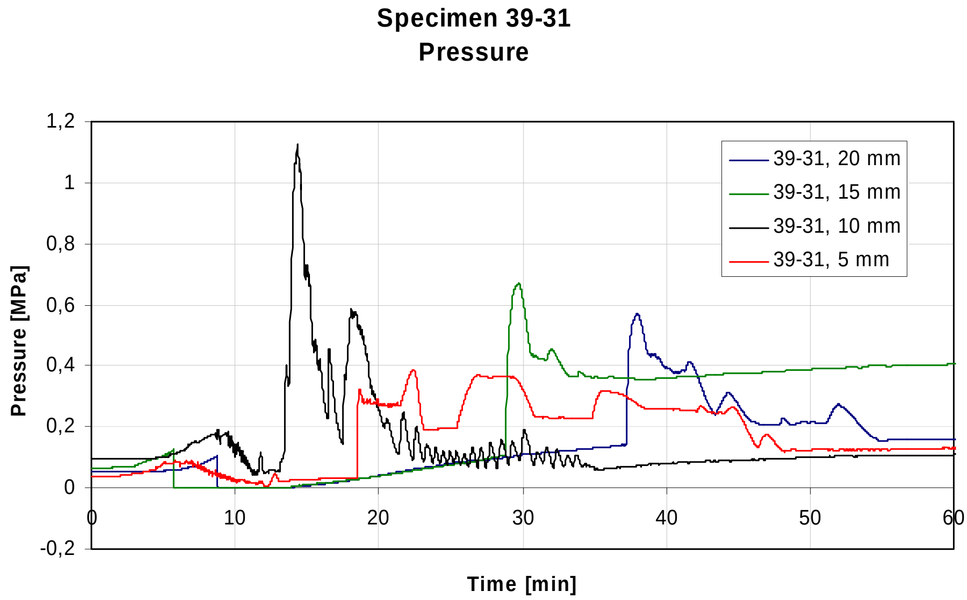


Figure A.411 Measured vapour pressure in specimen 39-31.

Table A.225 Spalling measurements on specimen 39-31.

Position	0	100	200	300	400	500
0	0	0	0	3	0	0
100	0	23	24	28	7	0
200	0	50	52	38	25	0
300	7	56	56	42	22	0
400	9	46	50	34	23	0
500	0	3	34	33	23	0
600	0	2	2	7	0	0

Mean all	17
Mean inner	33
Max in diagram	56
Max measured	66

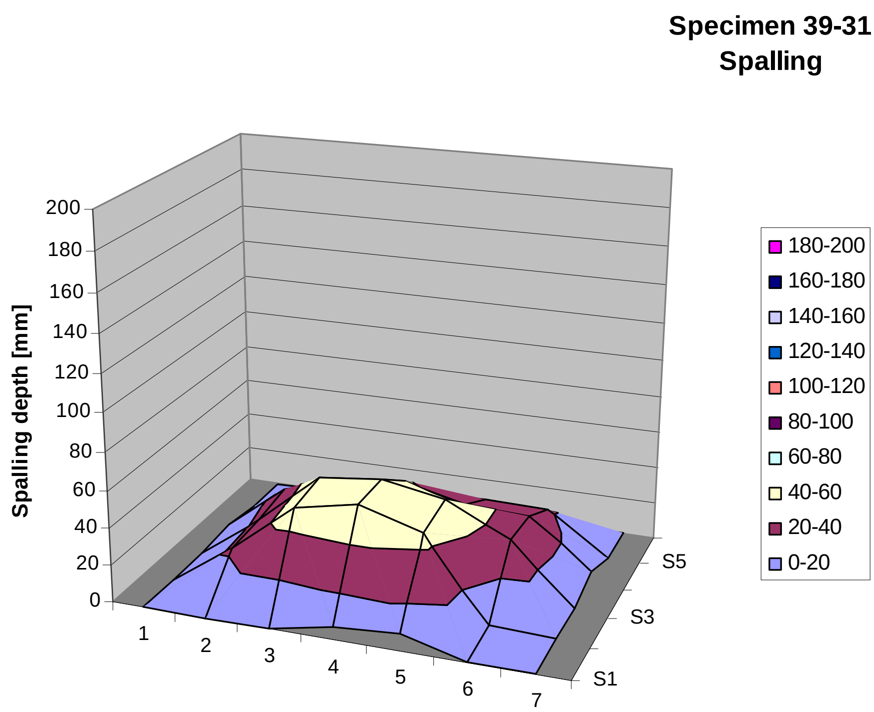


Figure A.412 Spalling measurements on specimen 39-31.

Table A.226 Observations made on specimen 39-31.

Time	Observation
0,00	Start of test
3,00	One small explosion
3,33	Continuous spalling
17,50	Spalling stopped
20,00	Cracks and water on sides
60,00	Test terminated

Test date:	2007-05-22	
Specimen:	39-31	
Load level:	154	kN/bar
Weight loss:	16,9	kg

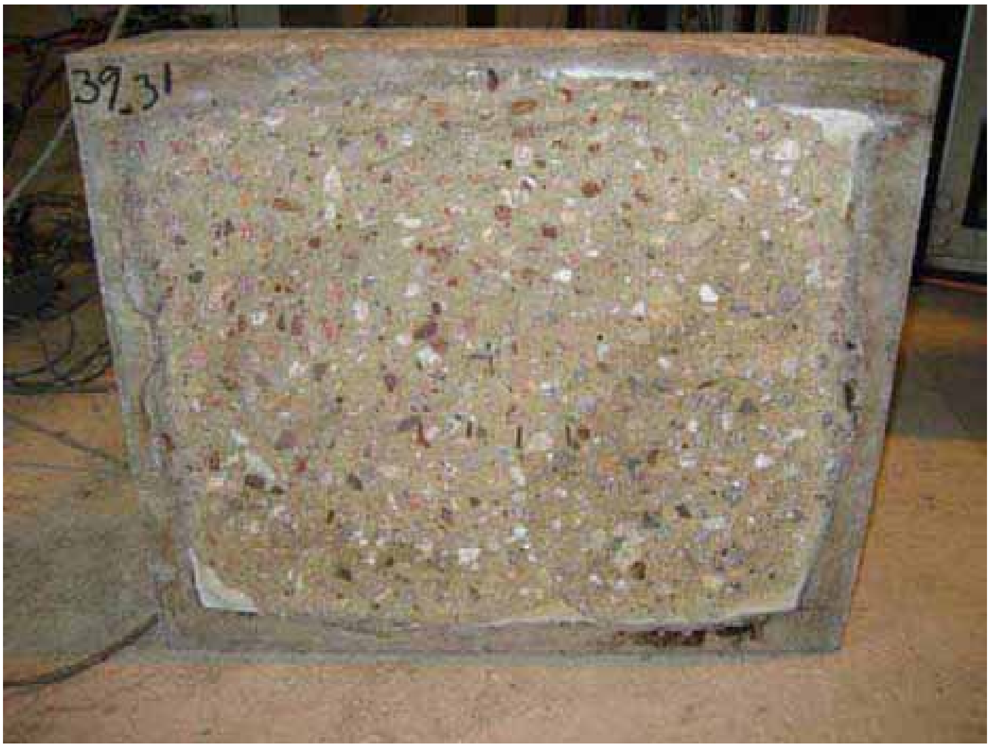


Figure A.413 Specimen 39-31 after test.

Specimen 39-33

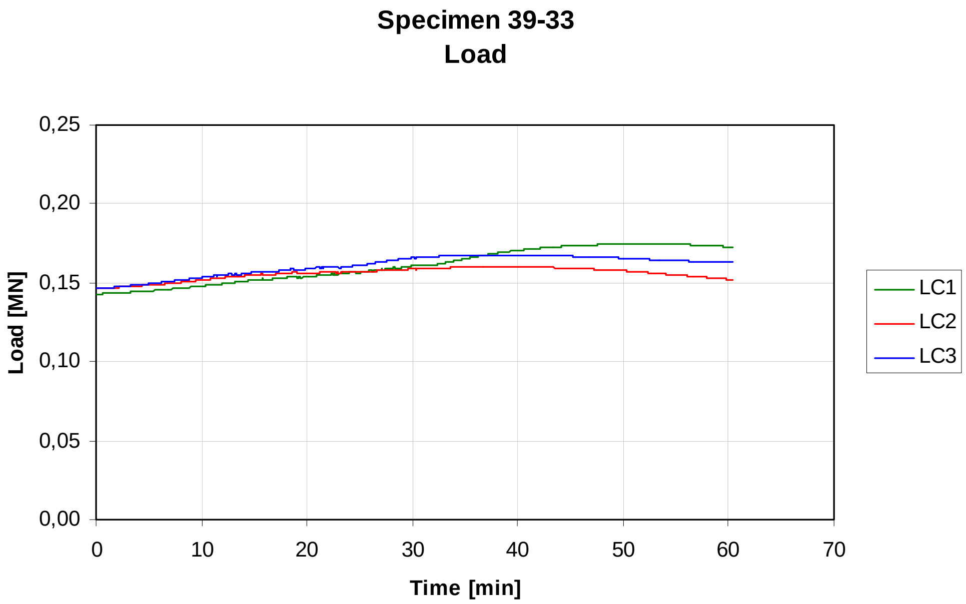


Figure A.414 Load measurements on specimen 39-33.

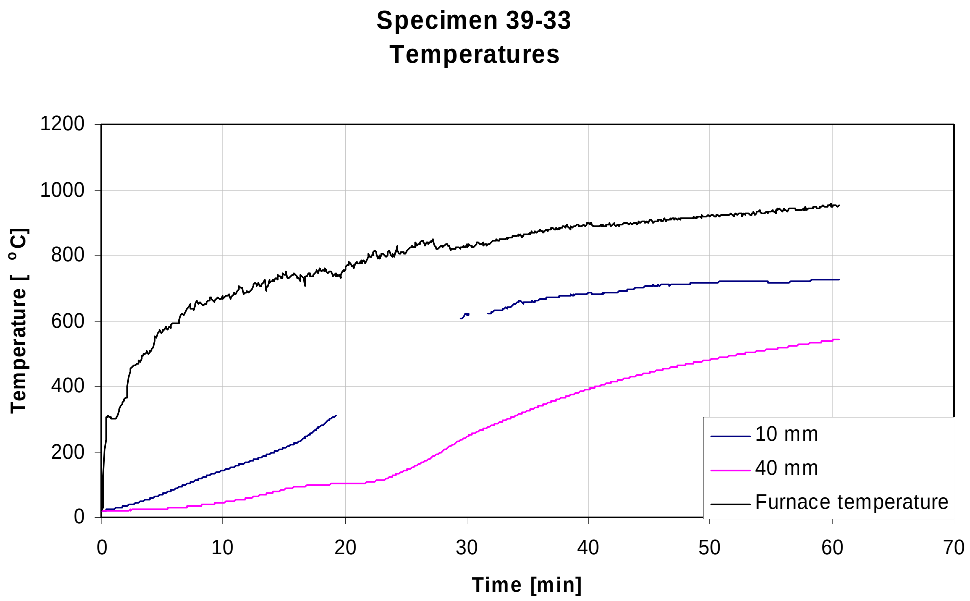


Figure A.415 Measured temperatures in furnace and in specimen 39-33.

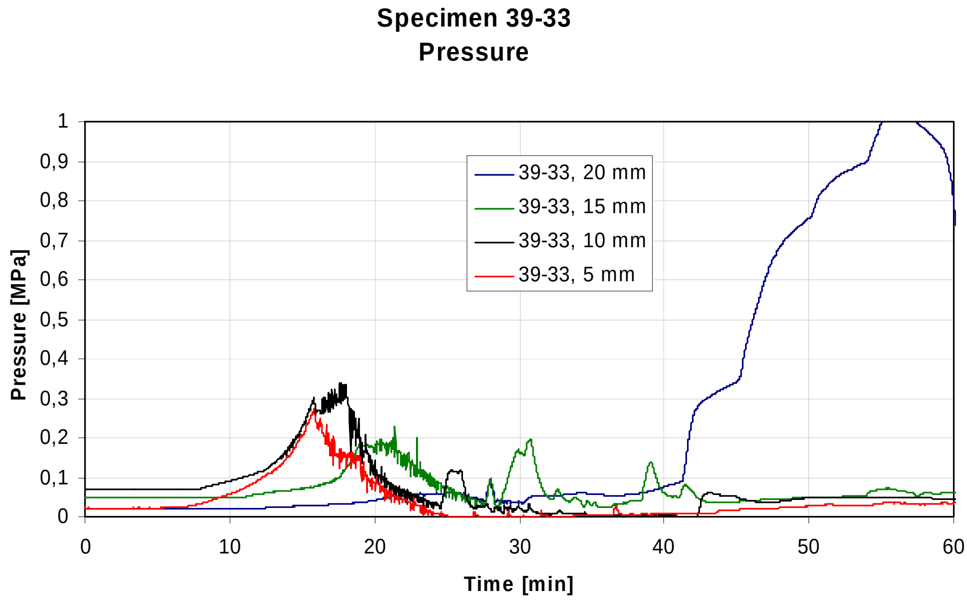


Figure A.416 Measured vapour pressure in specimen 39-33.

Table A.227 Spalling measurements on specimen 39-33.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	18	18	15	16	0
200	3	42	34	28	26	19
300	15	49	30	34	34	16
400	23	47	41	27	35	11
500	18	28	23	7	17	2
600	0	0	0	0	0	0

Mean all	16
Mean inner	28
Max in diagram	49
Max measured	59

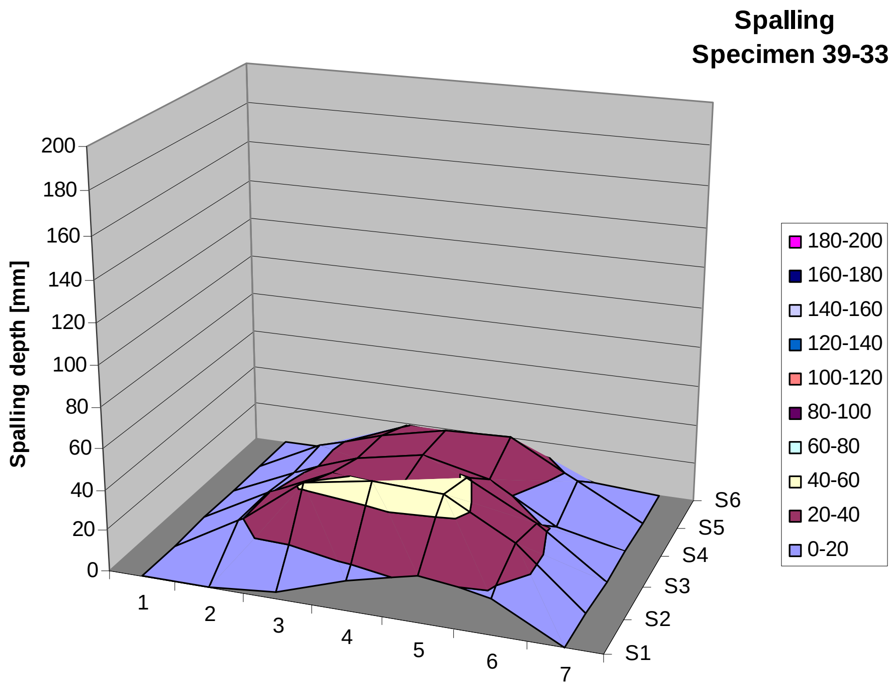


Figure A.417 Spalling measurements on specimen 39-33.

Table A.228 Observations made on specimen 39-33.

Time	Observation
0,00	Start of test
13,00	One explosion
13,50	Two explosions
14,83	Two small explosions
15,25	One small explosion
15,67	One small explosion
29,50	Spalling stops
50,00	Cracks and water on front and back sides
60,00	Test terminates

Test date:	2007-08-30	
Specimen:	39-33	
Load level:	145	kN/bar
Weight loss:	13,8	kg

Figure A.418 Specimen 39-33 after test.

Specimen 39-34

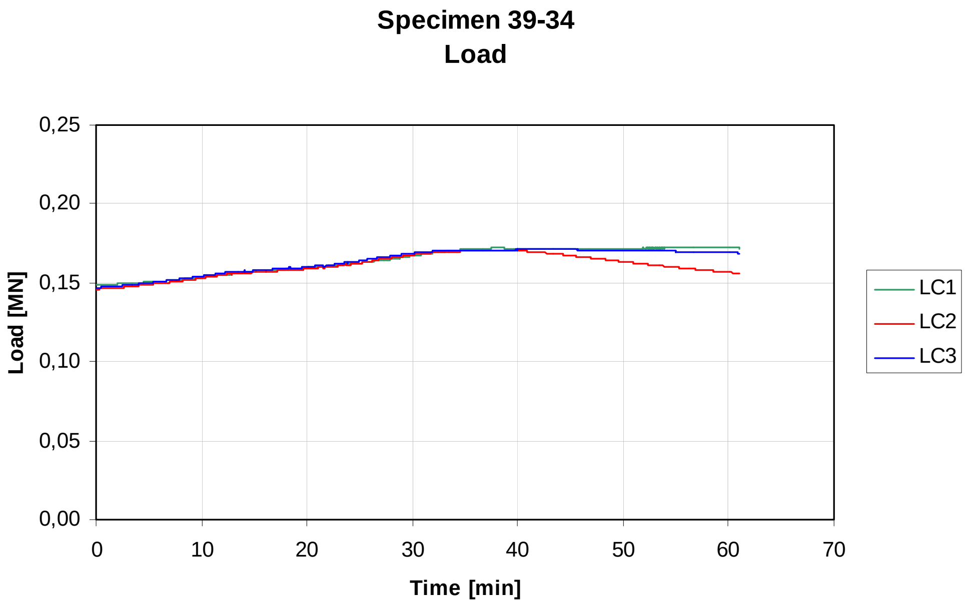


Figure A.419 Load measurements on specimen 39-34.

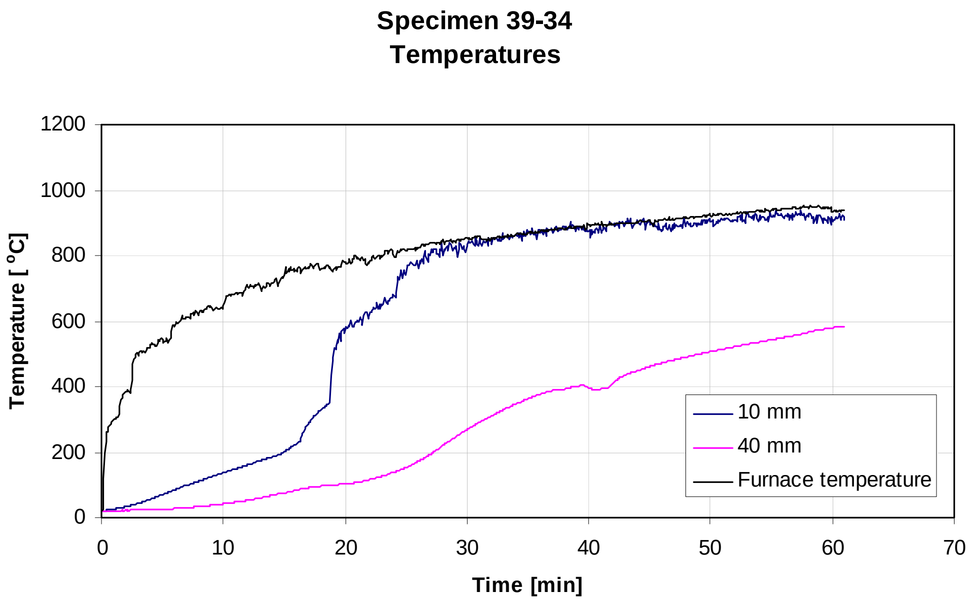


Figure A.420 Measured temperatures in furnace and in specimen 39-34.

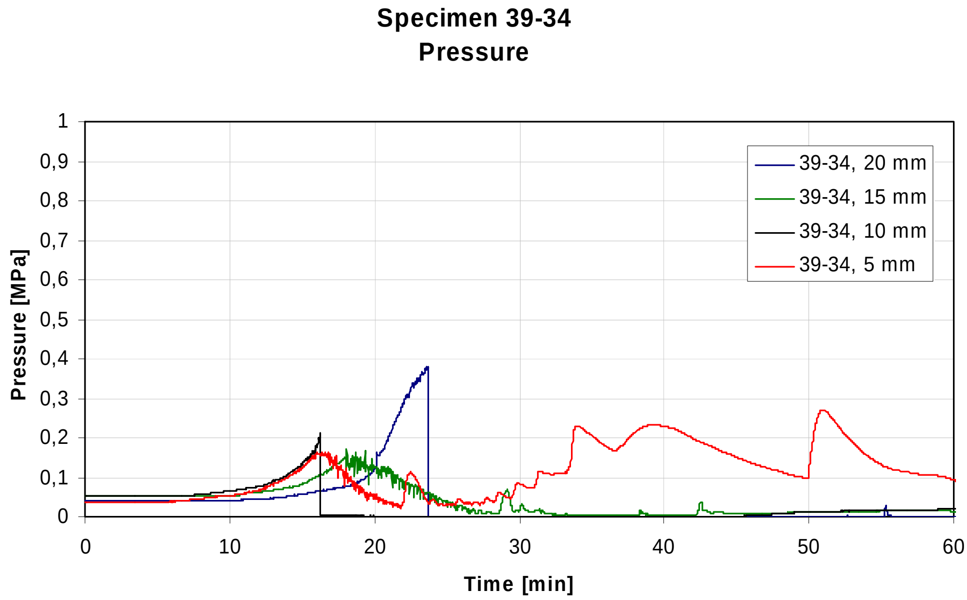


Figure A.421 Measured vapour pressure in specimen 39-34.

Table A.229 Spalling measurements on specimen 39-34.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	4	15	20	15	13
200	0	13	19	23	24	11
300	0	33	37	29	30	9
400	0	35	18	27	25	8
500	0	21	26	23	22	5
600	0	0	0	4	7	0

Mean all	12
Mean inner	23
Max in diagram	37
Max measured	41

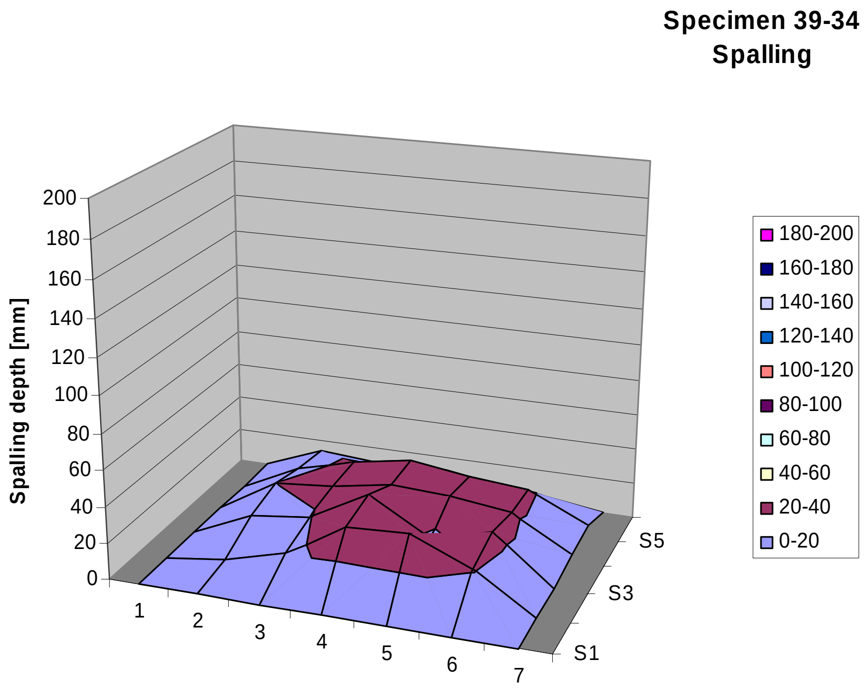


Figure A.422 Spalling measurements on specimen 39-34.

Table A.230 Observations made on specimen 39-34.

Time	Observation
0,00	Start of test
13,00	One explosion
13,83	Two explosions
14,33	Three explosions
30,00	Spalling stops
35,00	Cracks and water on front and back sides
61,00	Test terminates

Test date:	2007-08-31	
Specimen:	39-34	
Load level:	147	kN/bar
Weight loss:	12,5	kg

Figure A.423 Specimen 39-34 after test.

Specimen 39-35

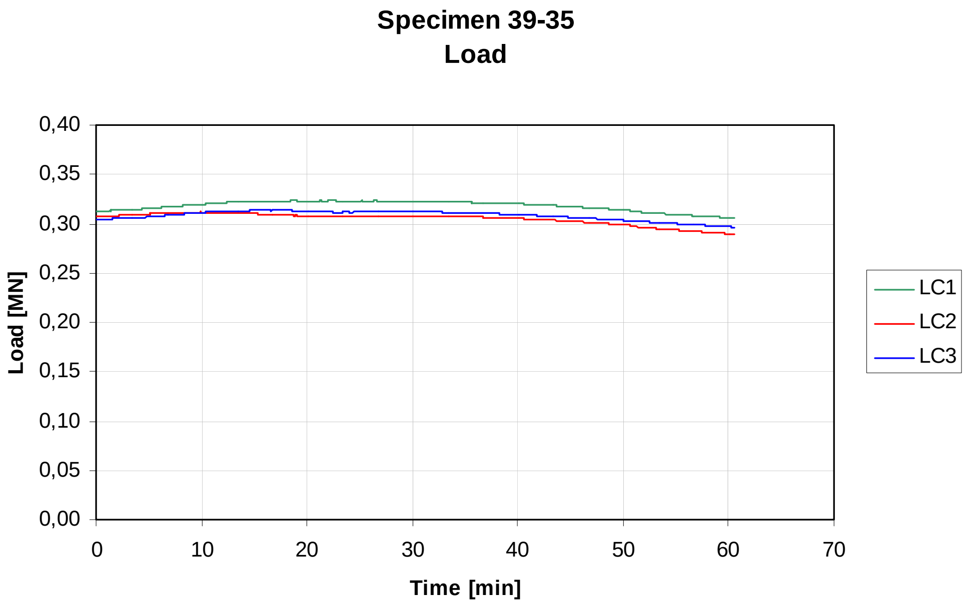


Figure A.424 Load measurements on specimen 39-35.

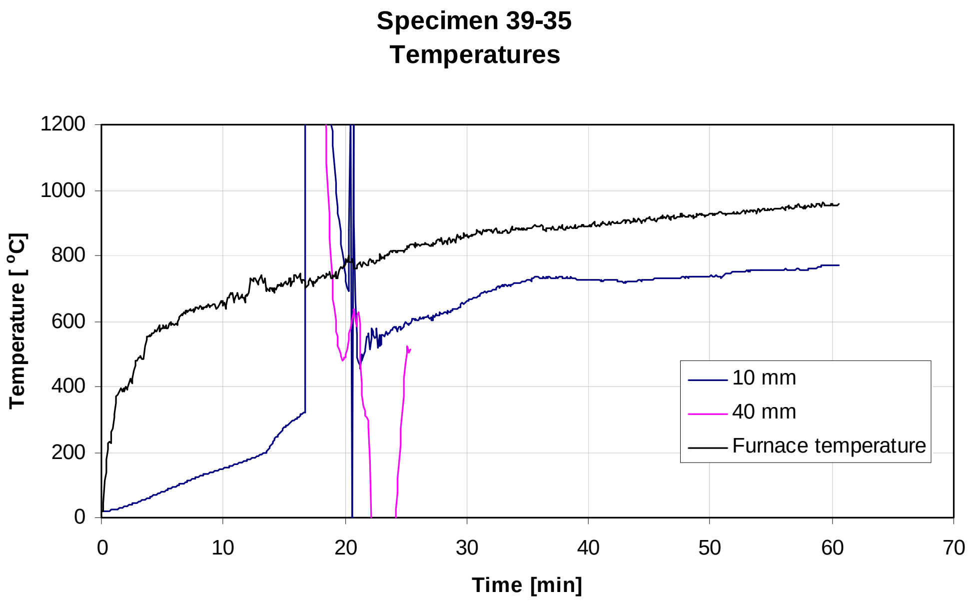


Figure A.425 Measured temperatures in furnace and in specimen 39-35.

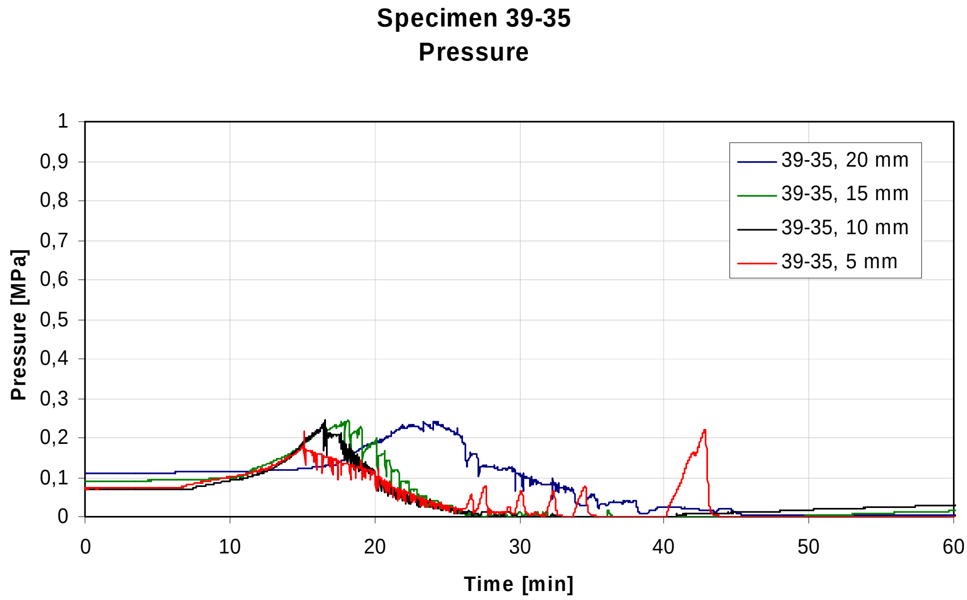


Figure A.426 Measured vapour pressure in specimen 39-35.

Table A.231 Spalling measurements on specimen 39-35.

Position	0	100	200	300	400	500
0	0	3	2	0	0	0
100	2	18	16	0	0	0
200	10	26	15	8	7	8
300	9	31	18	24	32	10
400	14	35	20	37	38	4
500	12	20	23	34	36	7
600	5	0	0	0	0	0

Mean all	12
Mean inner	22
Max in diagram	38
Max measured	55

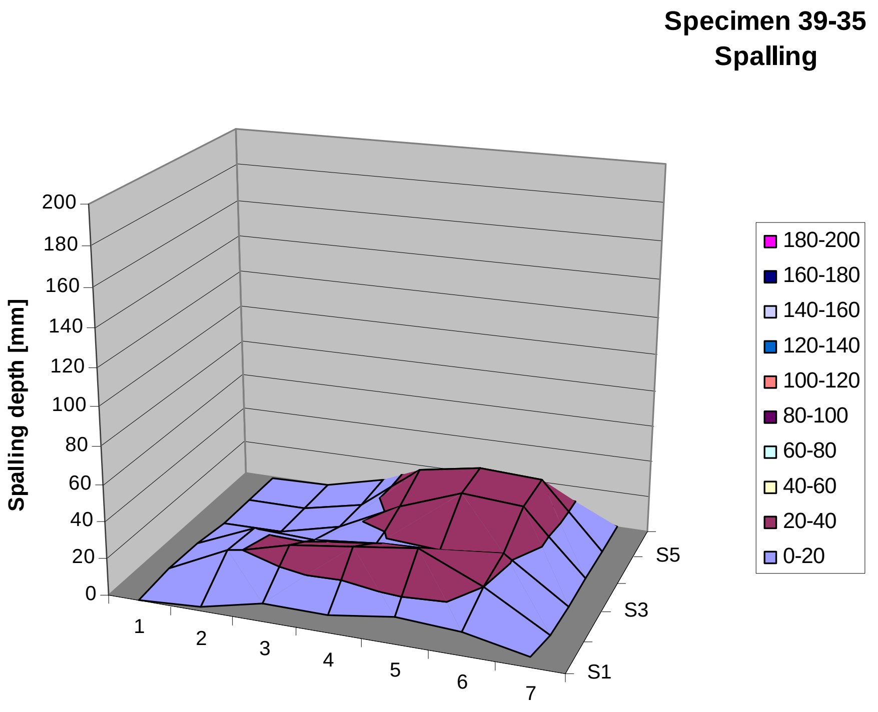


Figure A.427 Spalling measurements on specimen 39-35.

Table A.232 Observations made on specimen 39-35.

Time	Observation
0,00	Start of test
10,00	Small explosion
10,70	Continuous spalling
25,00	Cracks and water on sides
30,00	Spalling stopped
60,50	Test terminated

Test date:	2007-05-25	
Specimen:	39-35	
Load level:	308	kN/bar
Weight loss:	12,5	kg

Figure A.428 Specimen 39-35 after test.

Specimen 39-36

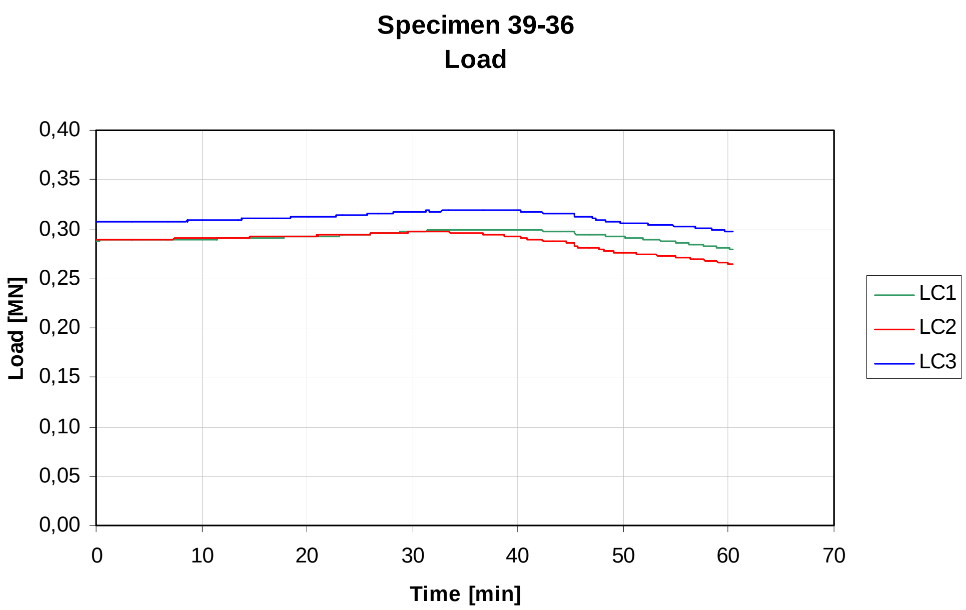


Figure A.429 Load measurements on specimen 39-36.

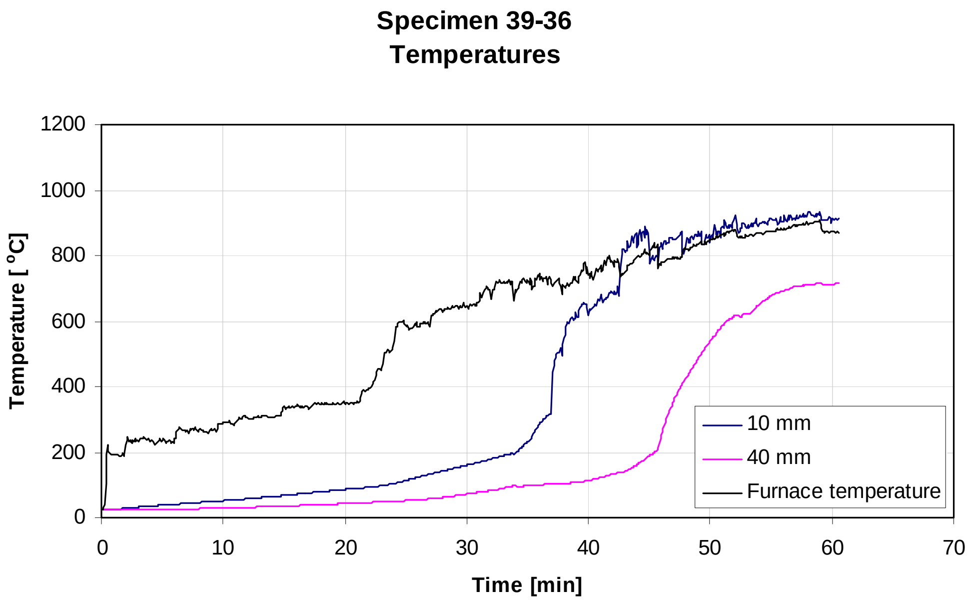


Figure A.430 Measured temperatures in furnace and in specimen 39-36.

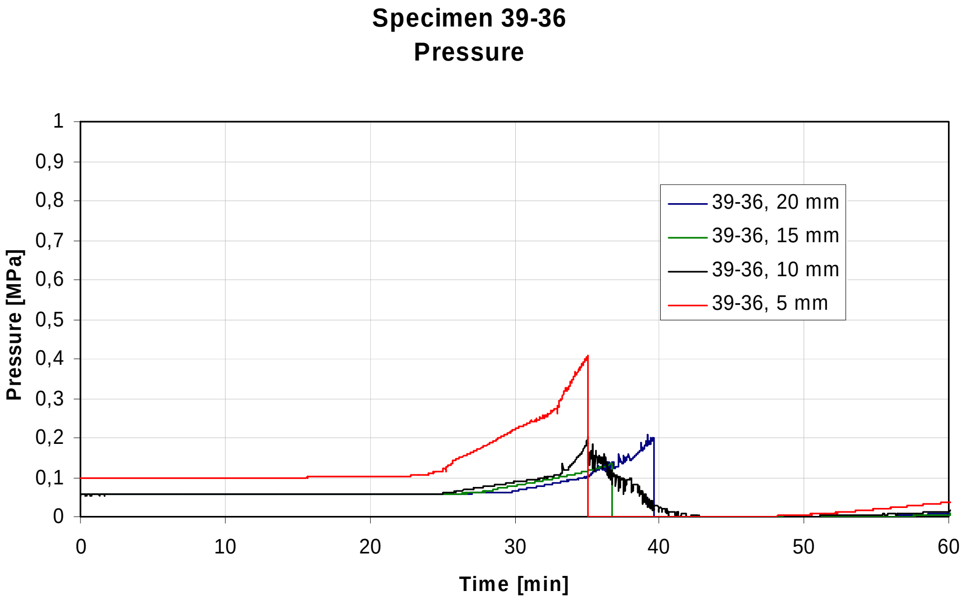


Figure A.431 Measured vapour pressure in specimen 39-36.

Table A.233 Spalling measurements on specimen 39-36.

Position	0	100	200	300	400	500
0	0	0	1	0	0	0
100	0	3	34	19	10	0
200	0	15	41	26	16	1
300	3	22	38	53	35	11
400	14	40	48	54	46	6
500	20	44	52	44	52	10
600	0	7	21	6	15	1

Mean all	19
Mean inner	35
Max in diagram	54
Max measured	64

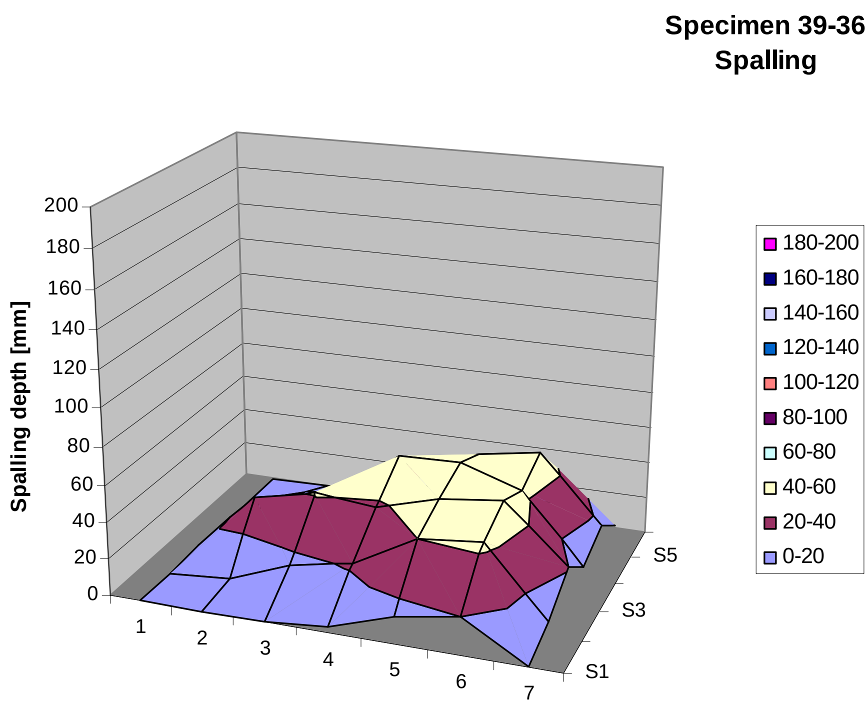


Figure A.432 Spalling measurements on specimen 39-36.

Table A.234 Observations made on specimen 39-36.

Time	Observation
0,00	Start of test
31,92	One explosion
32,33	Continuous spalling
45,00	Cracks and water on sides
50,00	Spalling stopped
60,50	Test terminated

Test date:	2007-06-07	
Specimen:	39-35	
Load level:	295	kN/bar
Weight loss:	18,3	kg

Figure A.433 Specimen 39-36 after test.

Specimen 39-37

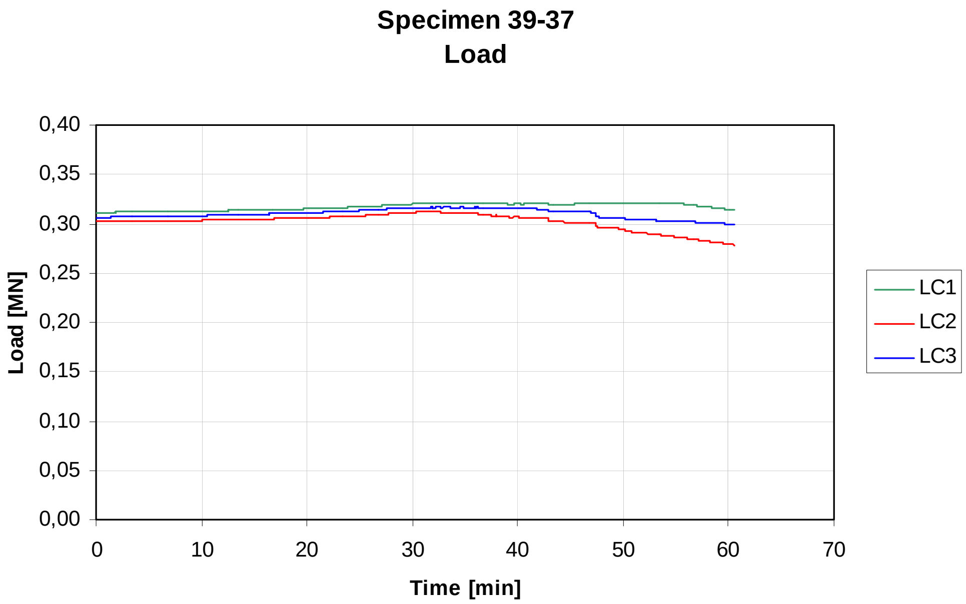


Figure A.434 Load measurements on specimen 39-37.

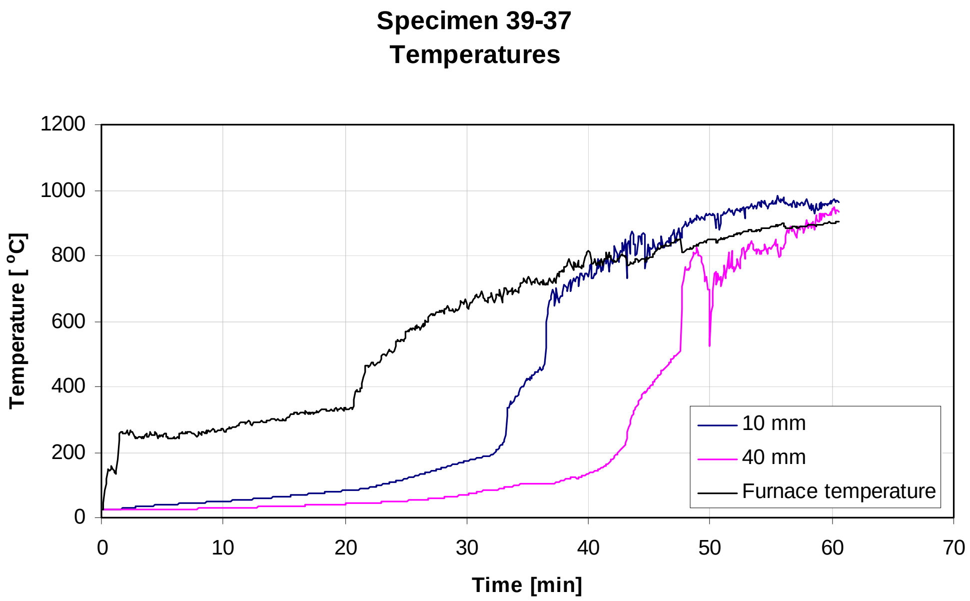


Figure A.435 Measured temperatures in furnace and in specimen 39-37.

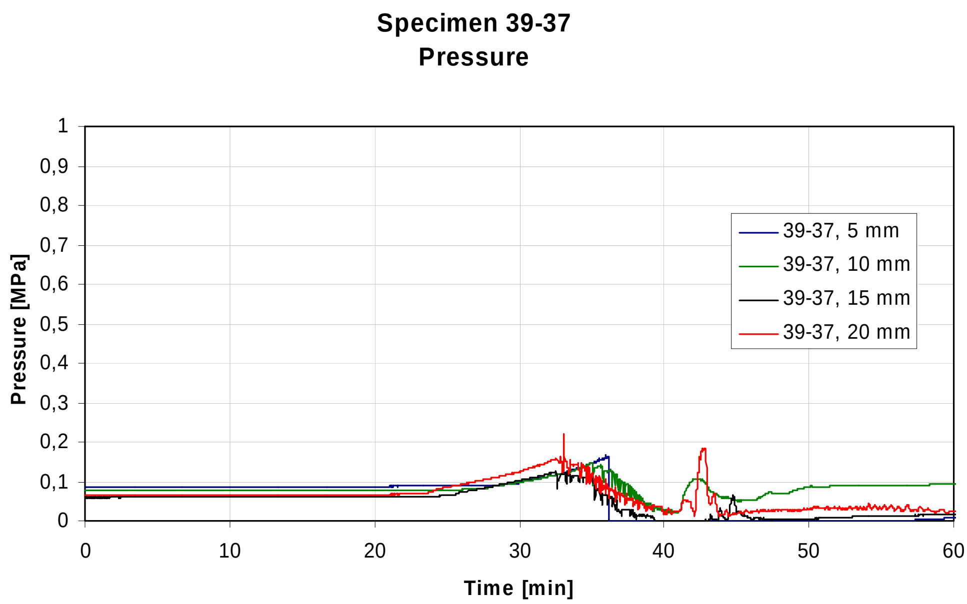


Figure A.436 Measured vapour pressure in specimen 39-37.

Table A.235 Spalling measurements on specimen 39-37.

Position	0	100	200	300	400	500
0	0	2	2	1	3	0
100	3	31	32	34	35	3
200	10	39	61	43	36	2
300	14	44	33	37	38	9
400	6	41	51	44	24	1
500	0	40	53	38	15	0
600	0	1	2	20	0	0

Mean all	20
Mean inner	38
Max in diagram	61
Max measured	71

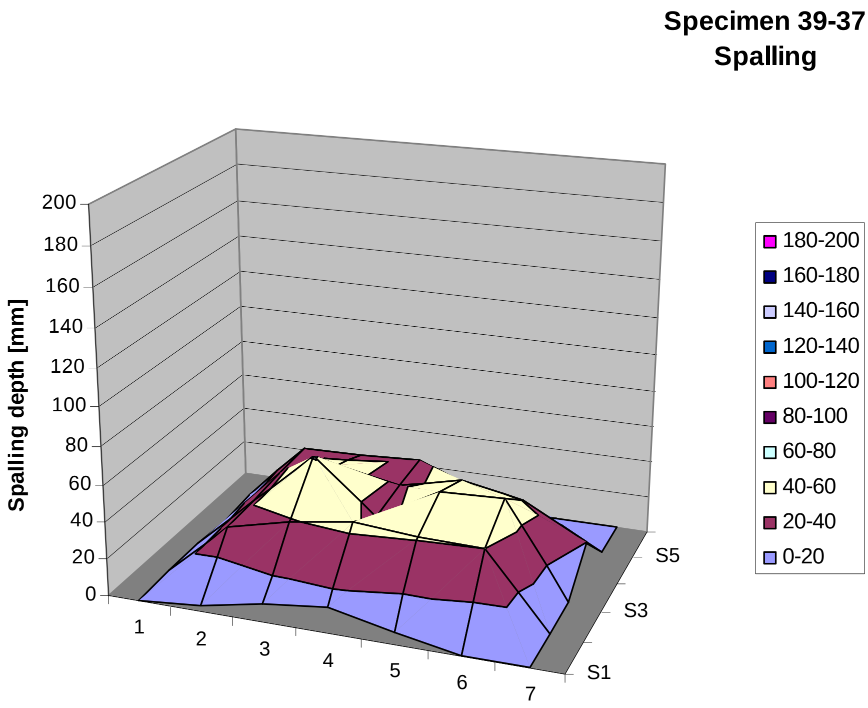


Figure A.437 Spalling measurements on specimen 39-37.

Table A.236 Observations made on specimen 39-37.

Time	Observation
0,00	Start of test
30,00	One small explosion
30,17	Continuous spalling
40,00	Cracks and water on sides
51,00	Spalliong stopped
60,50	Test terminated

Test date:	2007-05-29	
Specimen:	39-37	
Load level:	307	kN/bar
Weight loss:	17,3	kg

Figure A.438 Specimen 39-37 after test.

Specimen 39-38

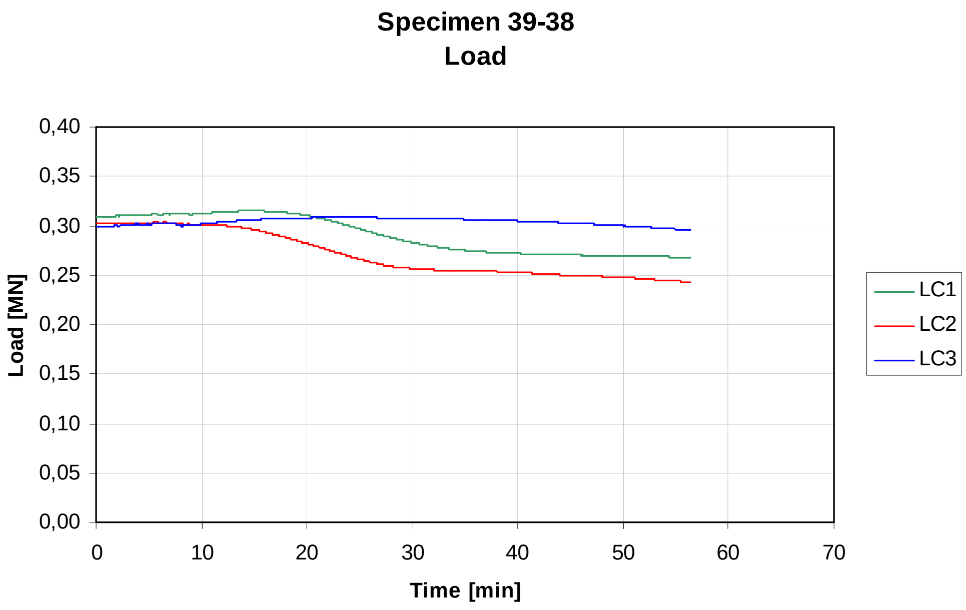


Figure A.439 Load measurements on specimen 39-38.

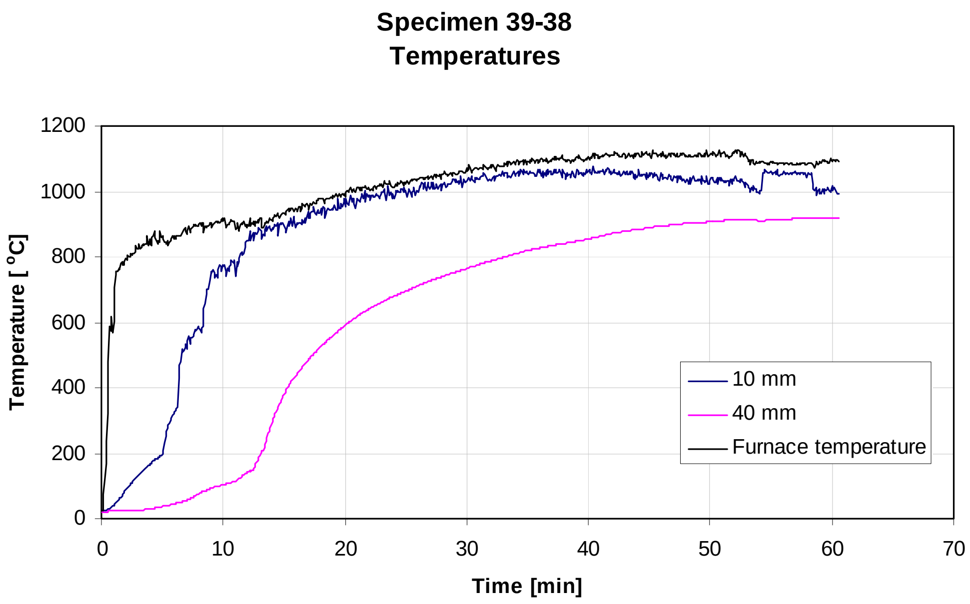


Figure A.440 Measured temperatures in furnace and in specimen 39-38.

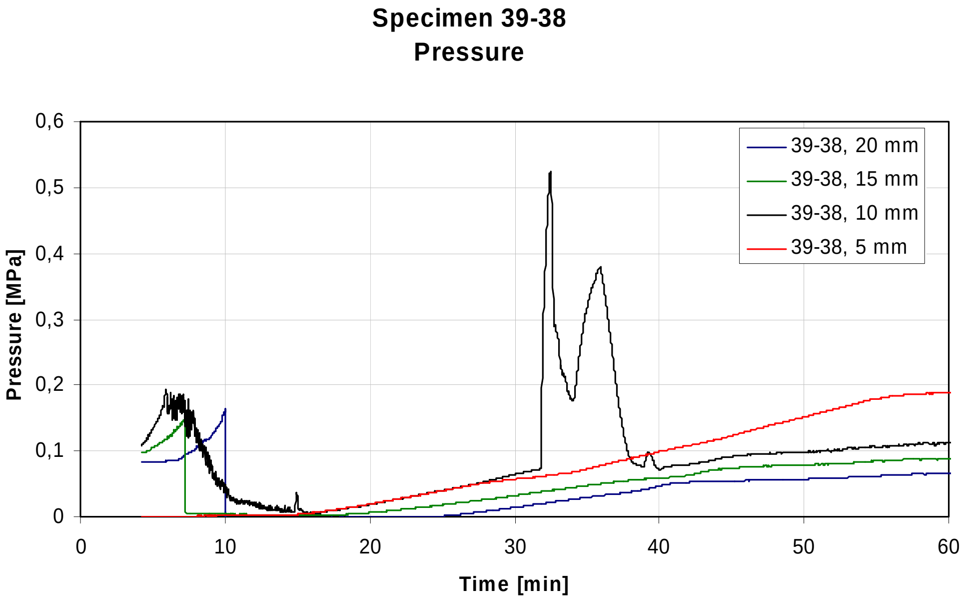


Figure A.441 Measured vapour pressure in specimen 39-38.

Table A.237 Spalling measurements on specimen 39-38.

Position	0	100	200	300	400	500
0	0	0	0	1	2	0
100	0	23	26	16	8	3
200	2	24	33	26	5	10
300	1	34	41	34	19	4
400	1	22	28	25	19	7
500	3	15	16	21	11	5
600	0	0	0	0	0	0

Mean all	12
Mean inner	22
Max in diagram	41
Max measured	47

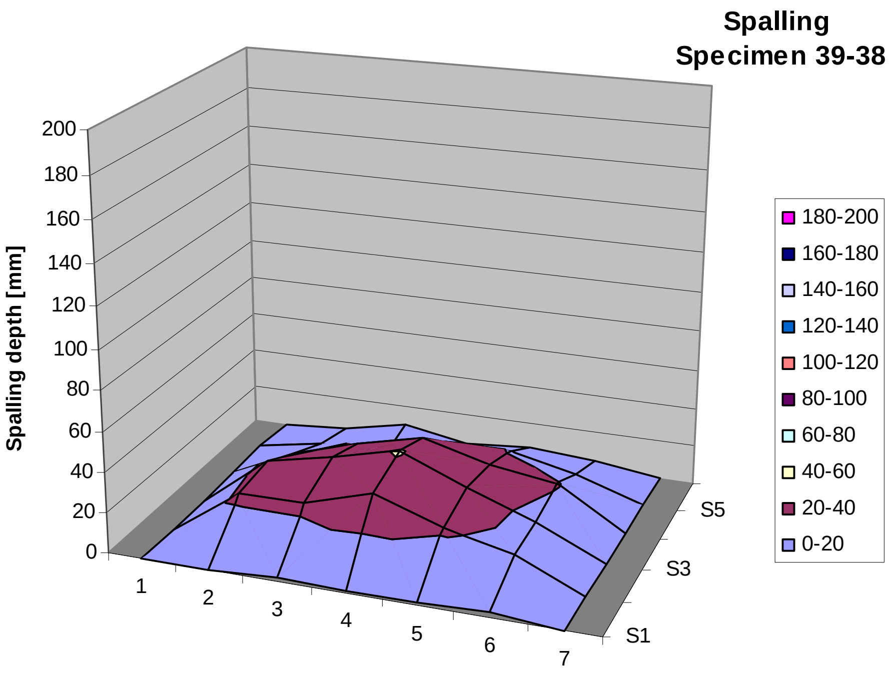


Figure A.442 Spalling measurements on specimen 39-38.

Table A.238 Observations made on specimen 39-38

Time	Observation			
0,00	Start of test	Test date:	2007-08-31	
2,50	Repeated small explosions	Specimen:	39-38	
4,25	Load measurements start	Load level:	303	kN/bar
4,92	Loud explosion	Weight loss:	13,7	kg
15,00	Spalling stops			
15,00	Horisontal cracks and water on front and back sides			
60,00	Test terminates			

Figure A.443 Specimen 39-38 after test.

Specimen 39-39

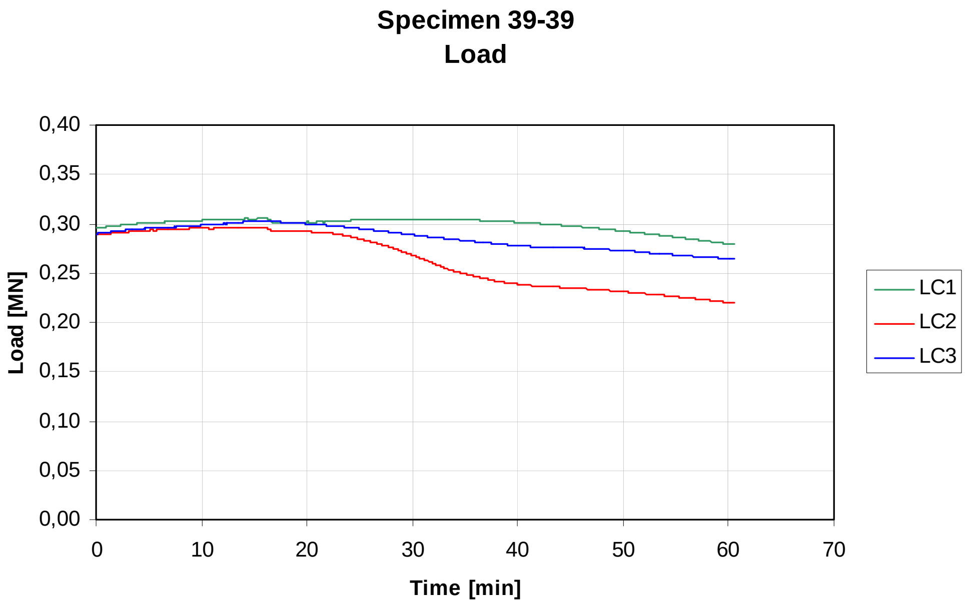


Figure A.444 Load measurements on specimen 39-39.

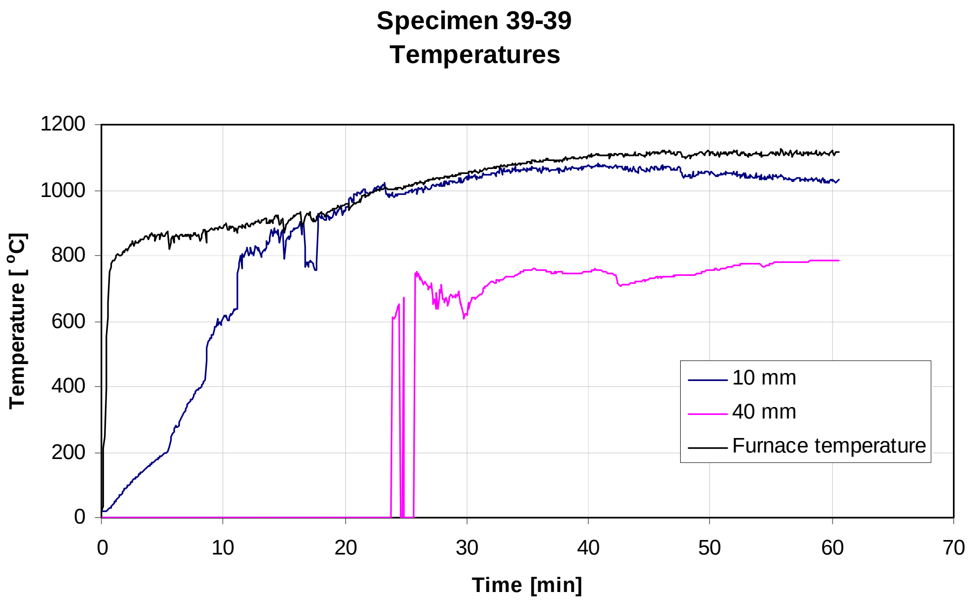


Figure A.445 Measured temperatures in furnace and in specimen 39-39.

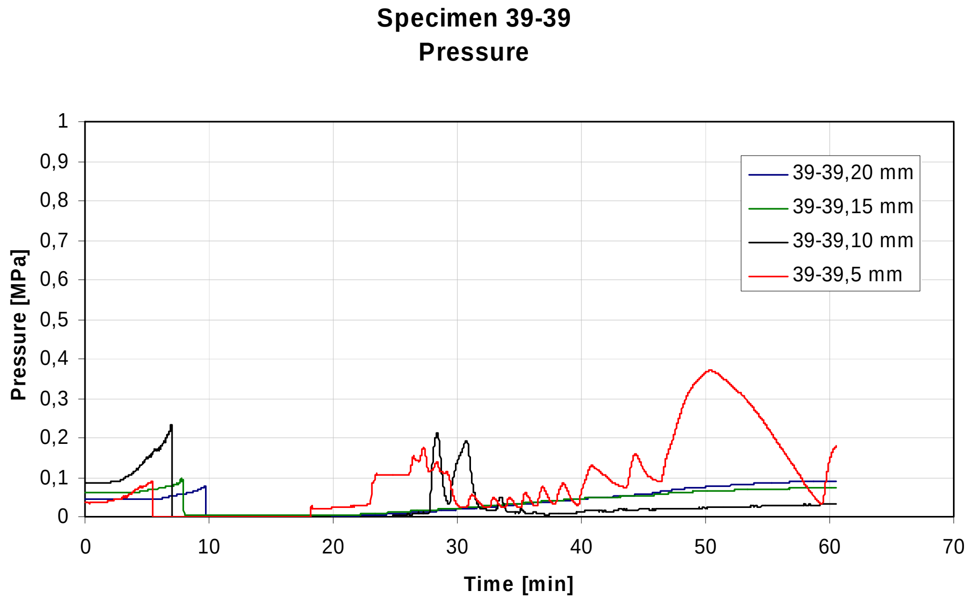


Figure A.446 Measured vapour pressure in specimen 39-39.

Table A.239 Spalling measurements on specimen 39-39.

Position	0	100	200	300	400	500
0	1	0	0	2	6	2
100	20	36	37	43	25	10
200	31	46	49	41	38	11
300	9	37	41	43	24	9
400	2	23	39	39	24	4
500	0	14	26	30	30	11
600	0	0	2	4	15	0

Mean all	20
Mean inner	34
Max in diagram	49
Max measured	64

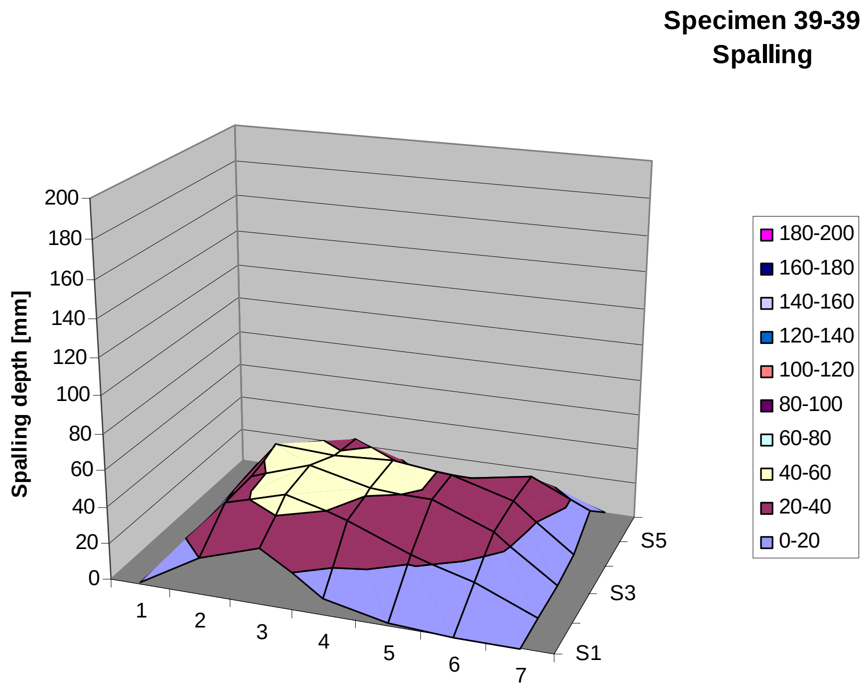


Figure A.447 Spalling measurements on specimen 39-39.

Table A.240 Observations made on specimen 39-39.

Time	Observation
0,00	Start of test
2,67	One small explosion
2,83	Two small explosions
3,42	Repeated explosions
15,00	Cracks and water on front and back sides
22,00	Spalling stops
61,00	Test terminates

Test date:	2007-09-03	
Specimen:	39-39	
Load level:	291	kN/bar
Weight loss:	19,4	kg

Figure A.448 Specimen 39-39 after test.

Specimen 39-40

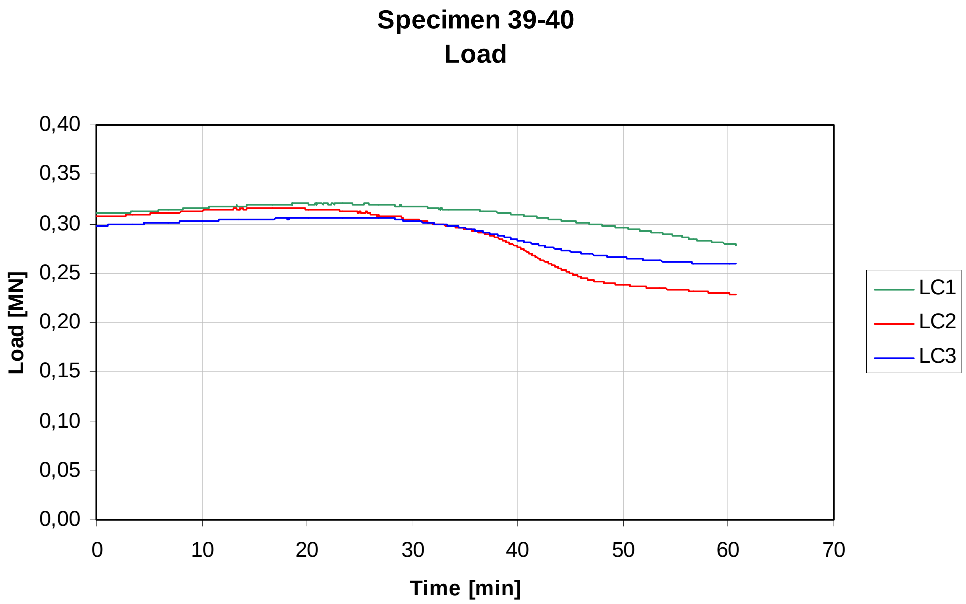


Figure A.449 Load measurements on specimen 39-40.

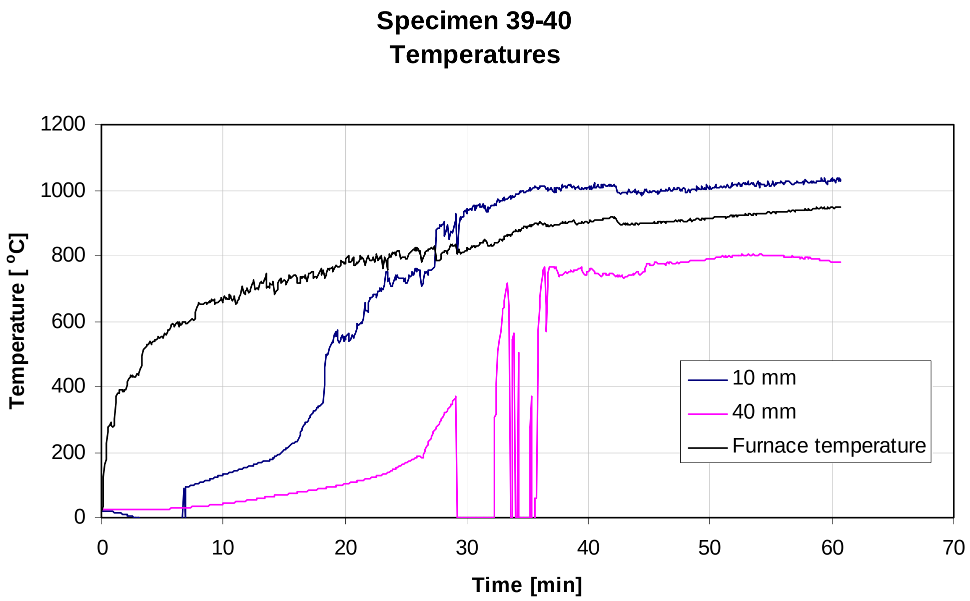


Figure A.450 Measured temperatures in furnace and in specimen 39-40.

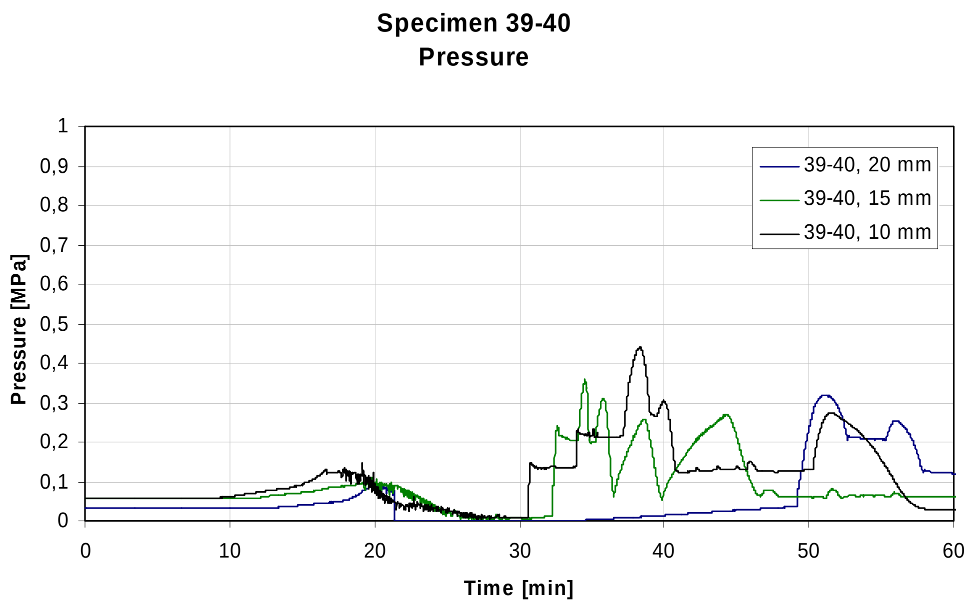


Figure A.451 Measured vapour pressure in specimen 39-40.

Table A.241 Spalling measurements on specimen 39-40.

Position	0	100	200	300	400	500
0	0	0	3	0	0	0
100	16	38	33	37	15	0
200	16	45	48	44	29	0
300	21	56	56	52	27	0
400	15	57	57	56	32	0
500	3	39	39	32	21	0
600	0	0	1	1	3	0

Mean all	21
Mean inner	41
Max in diagram	57
Max measured	67

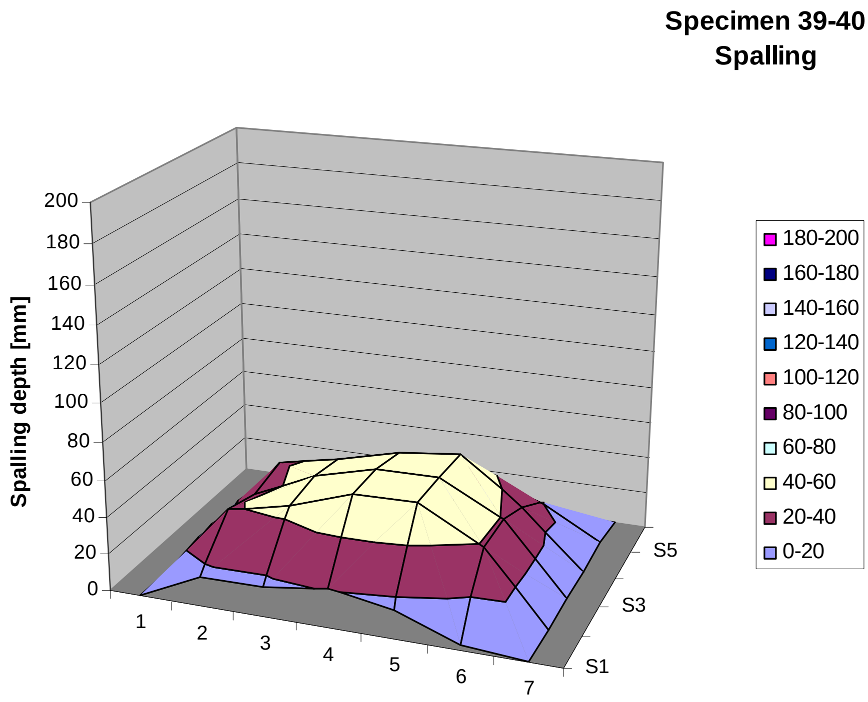


Figure A.452 Spalling measurements on specimen 39-40.

Table A.242 Observations made on specimen 39-40.

Time	Observation
0,00	Start of test
11,00	One explosion
12,00	Continuous spalling
30,00	Cracks and water on sides
33,00	Spalling stopped
60,75	Test terminated

Test date:	2007-05-28	
Specimen:	39-40	
Load level:	305	kN/bar
Weight loss:	19,7	kg

Figure A.453 Specimen 39-40 after test.

Concrete 40

Table A.243 Concrete admixture recipe 40.

Recipe	**40**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	252
Water-powder ratio, w/p	0,25
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	12,0
Sikament 20HE 50 (% of cement weight)	2,86
Fiber, Sika Crackstop, ϕ=18 µm, l=6 mm (kg/m^3)	1,5
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	630
T50 (s)	6
Air (%)	3.2
Compressive strength, 28 days (MPa)	69.6

Specimen 40-3

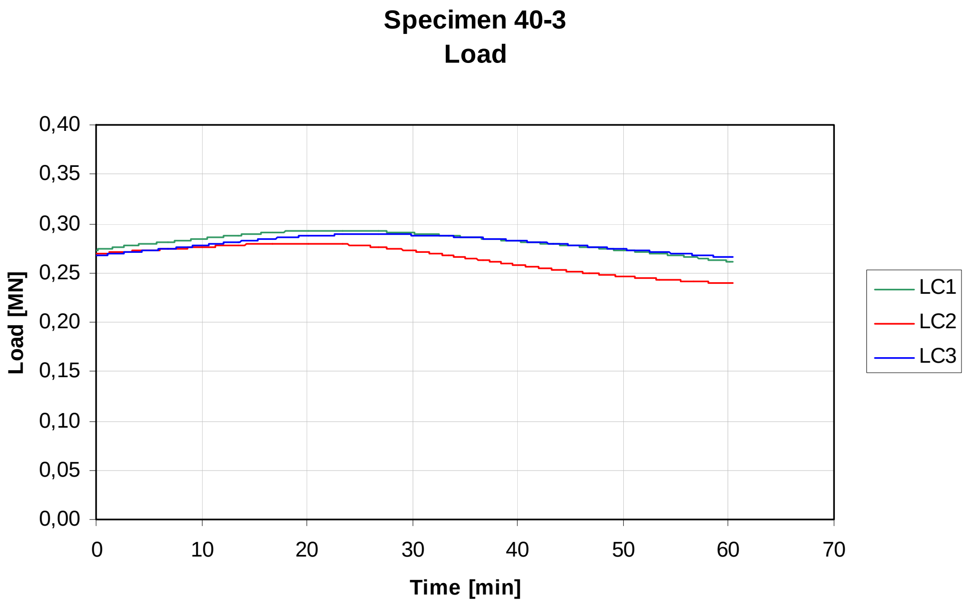


Figure A.454 Load measurements on specimen 40-3.

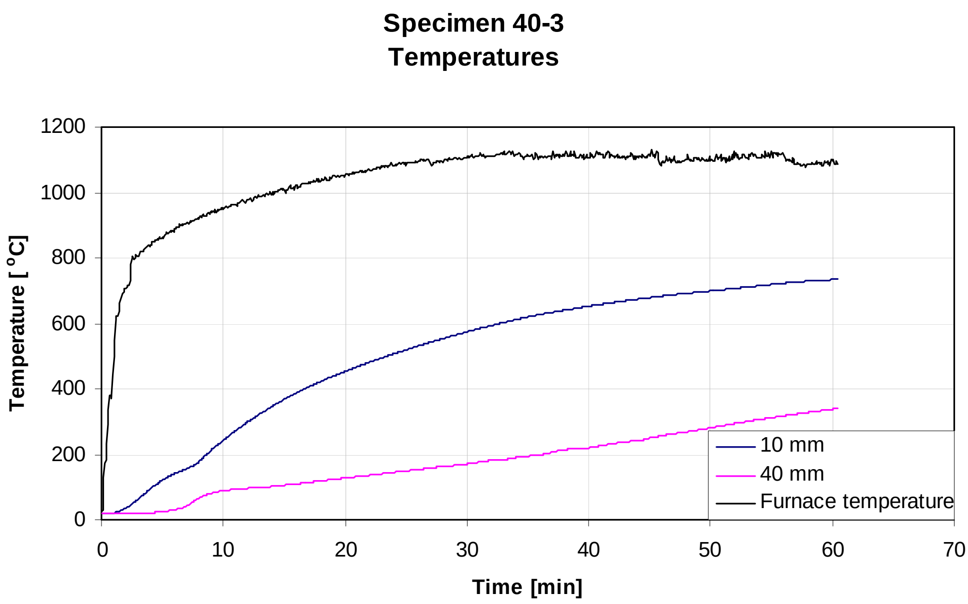


Figure A.455 Measured temperatures in furnace and in specimen 40-3.

Table A.244 Spalling measurements on specimen 40-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

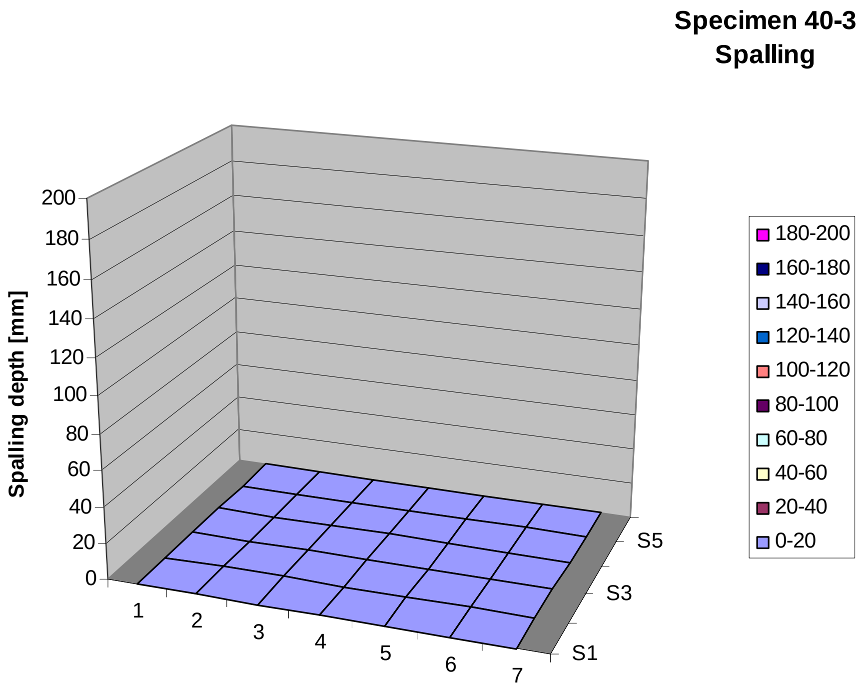


Figure A.456 Spalling measurements on specimen 40-3.

Table A.245 Observations made on specimen 40-3.

Time	Observation			
0,00	Start of test	Test date:	2007-05-08	
9,00	Moisture at lower edge	Specimen:	40-3	
20,00	Water on top surface	Load level:	270	kN/bar
60,50	Test terminated	Weight loss:	1,7	kg

Figure A.457 Specimen 40-3 after test.

Specimen 40-4

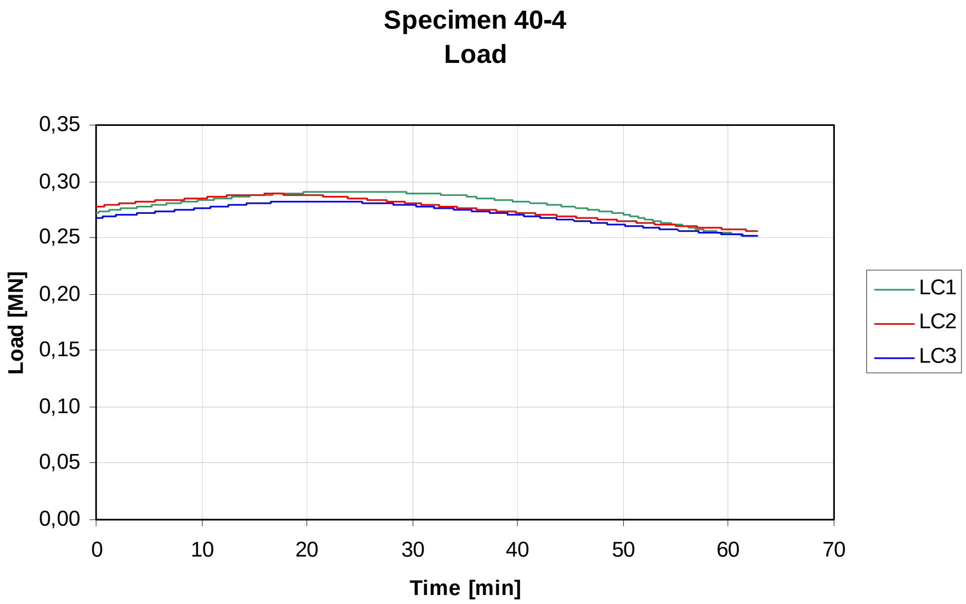


Figure A.458 Load measurements on specimen 40-4.

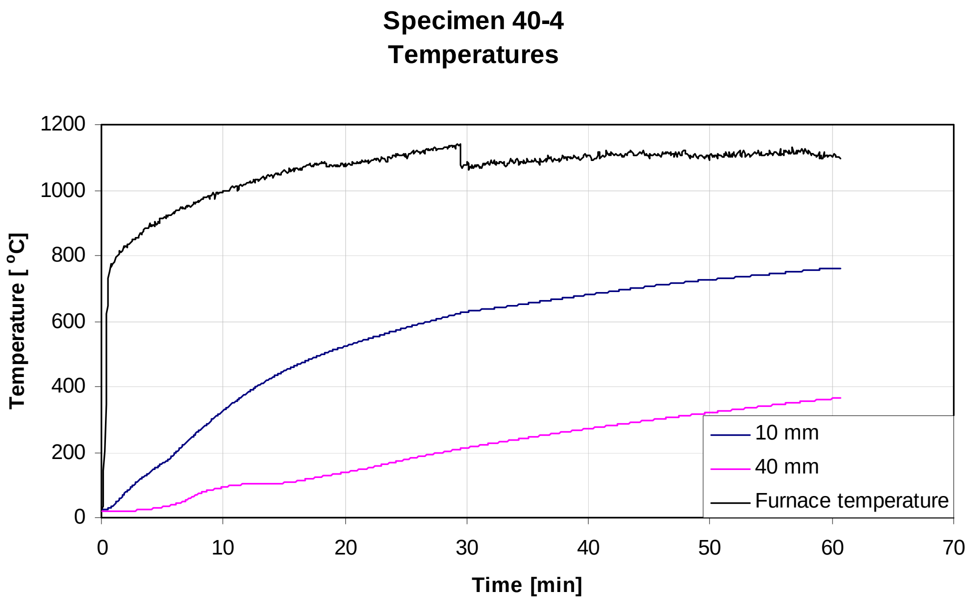


Figure A.459 Measured temperatures in furnace and in specimen 40-4.

Table A.246 Spalling measurements on specimen 40-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

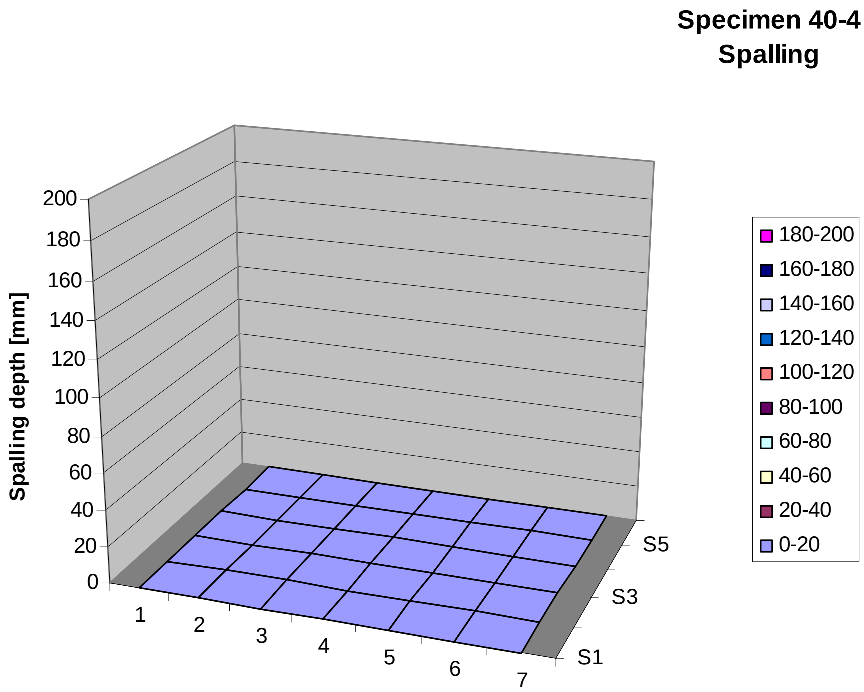


Figure A.460 Spalling measurements on specimen 40-4.

Table A.247 Observations made on specimen 40-4.

Time	Observation
0,00	Start of test
10,00	Moisture at lower edge
19,00	Water on top surface
60,50	Test terminated

Test date:	2007-05-08	
Specimen:	40-4	
Load level:	272	kN/bar
Weight loss:	4,8	kg

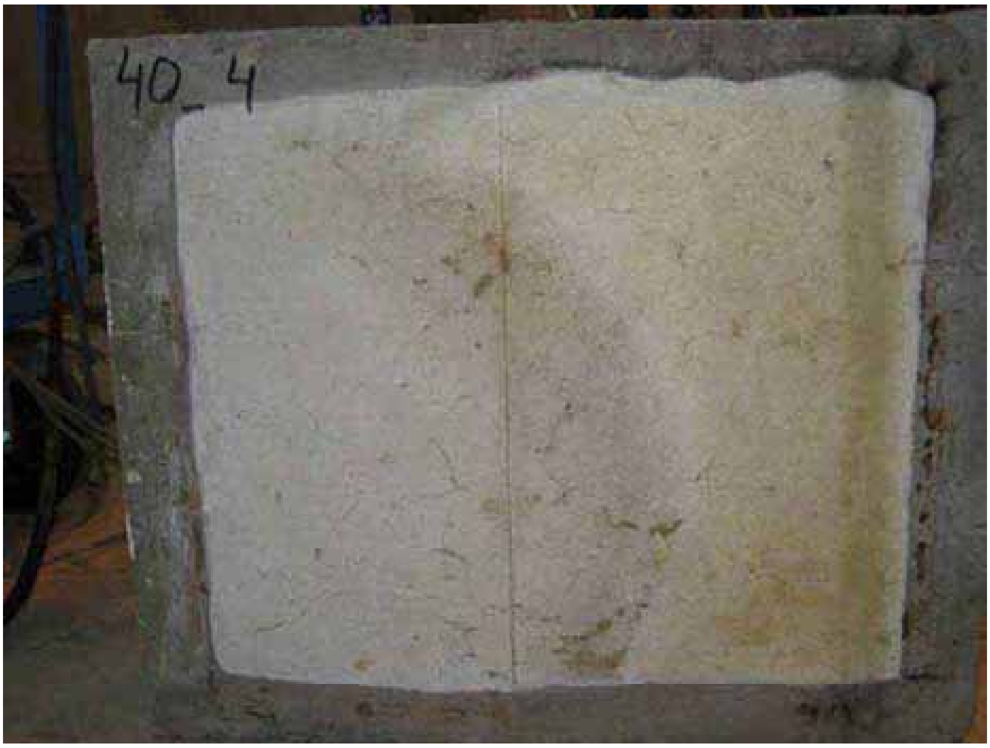


Figure A.461 Specimen 40-4 after test.

Concrete 41

Table A.248 Concrete admixture recipe 41.

Recipe	**41**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	252
Water-powder ratio, w/p	0,25
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	10,0
Sikament 20HE 50 (% of cement weight)	2,38
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	660
T50 (s)	7
Air (%)	1.8
Compressive strength, 28 days (MPa)	77.3

Specimen 41-1

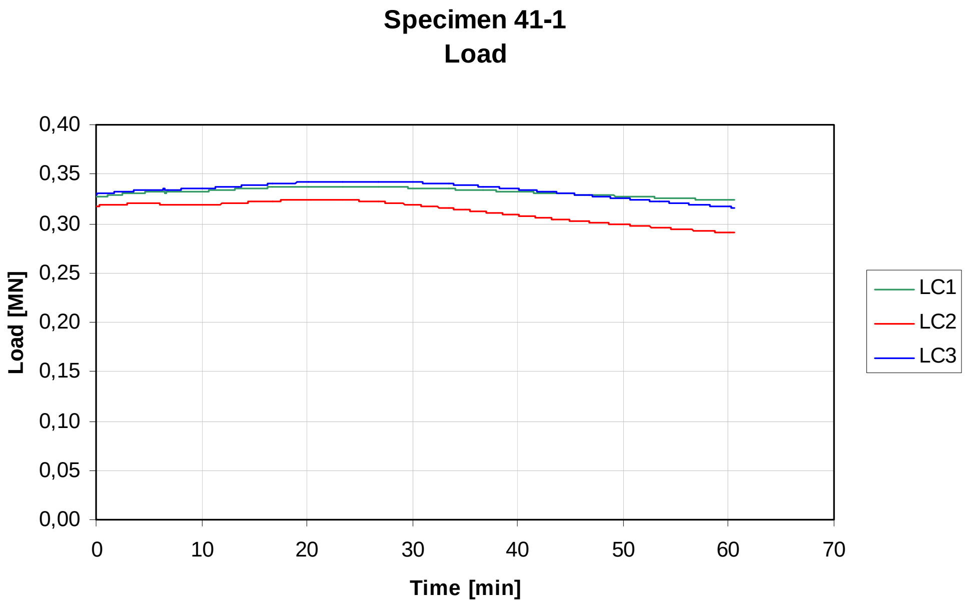


Figure A.462 Load measurements on specimen 41-1.

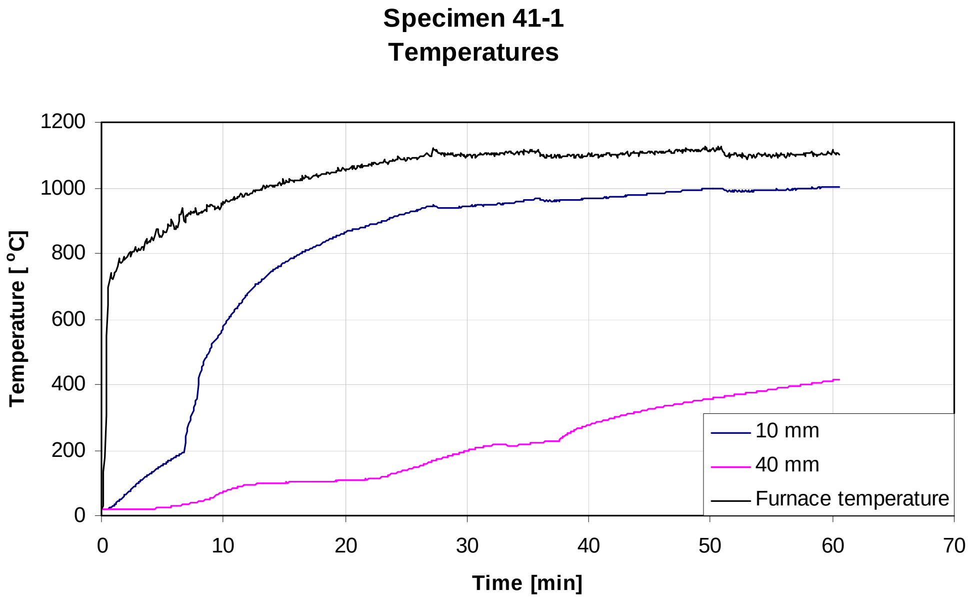


Figure A.463 Measured temperatures in furnace and in specimen 41-1.

Table A.249 Spalling measurements on specimen 41-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	6	0	0
200	0	0	12	21	11	0
300	3	11	11	20	7	0
400	3	10	13	12	5	0
500	0	5	9	12	10	0
600	0	0	0	0	0	0

Mean all	4
Mean inner	9
Max in diagram	21
Max measured	27

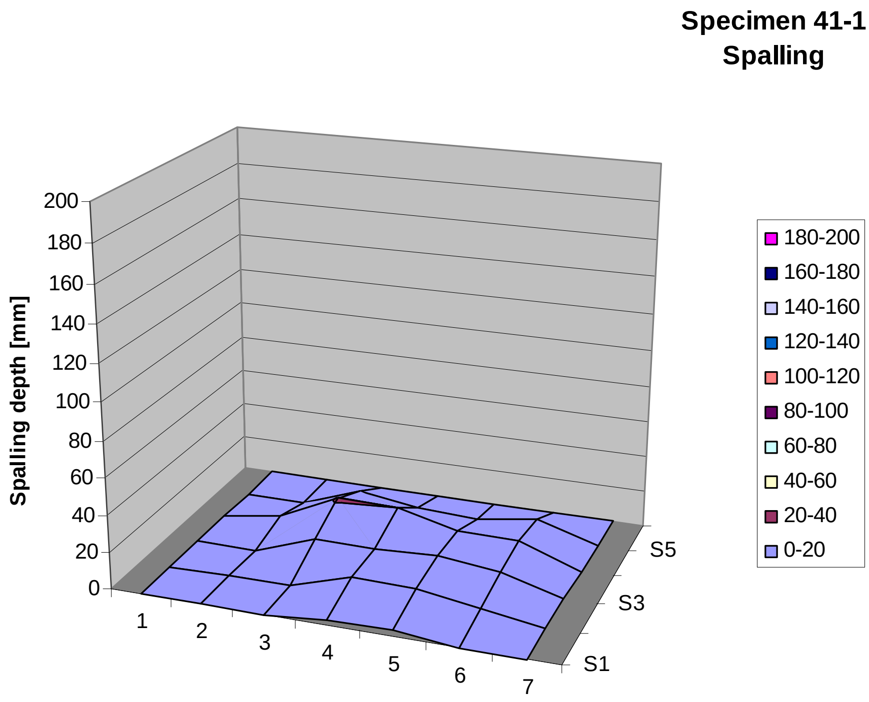


Figure A.464 Spalling measurements on specimen 41-1.

Table A.250 Observations made on specimen 41-1.

Time	Observation
0,00	Start of test
6,25	One explosion
6,75	Three explosions
9,25	One explosion - spalling stops
13,00	Water and cracks on sides
60,50	Test terminated

Test date:	2007-05-09	
Specimen:	41-1	
Load level:	325	kN/bar
Weight loss:	11,2	kg

Figure A.465 Specimen 41-1 after test.

Specimen 41-2

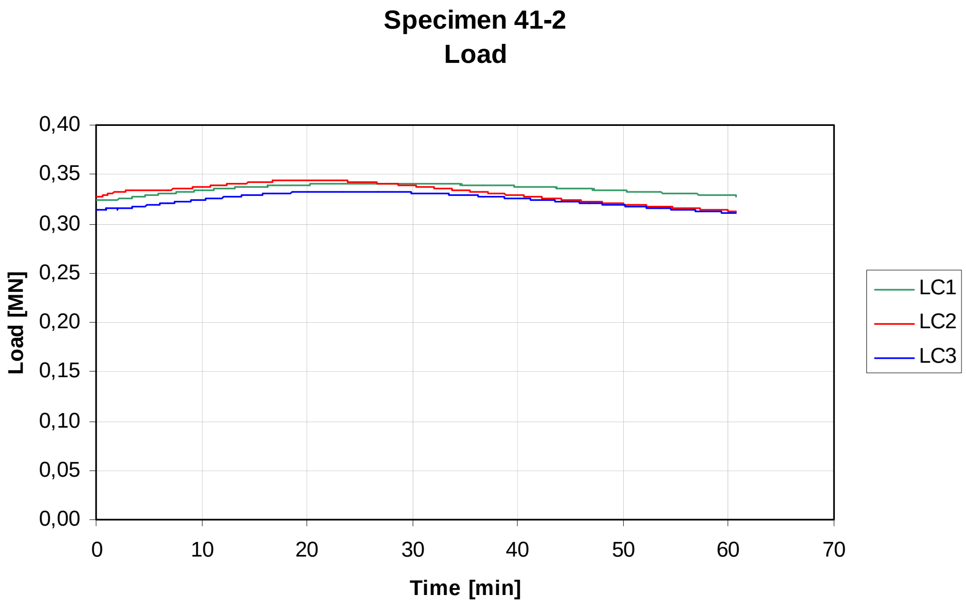


Figure A.466 Load measurements on specimen 41-2.

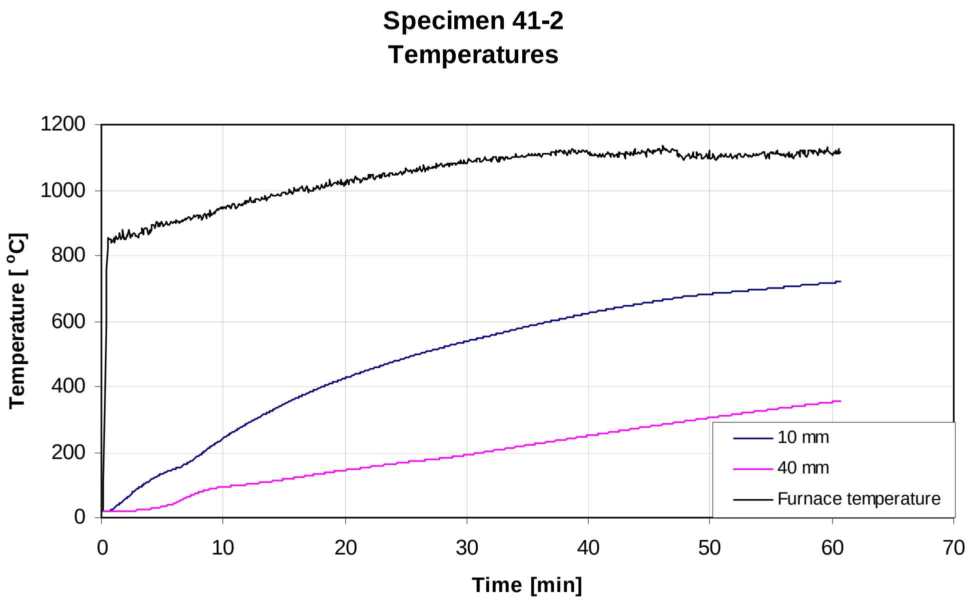


Figure A.467 Measured temperatures in furnace and in specimen 41-2.

Table A.251 Spalling measurements on specimen 41-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

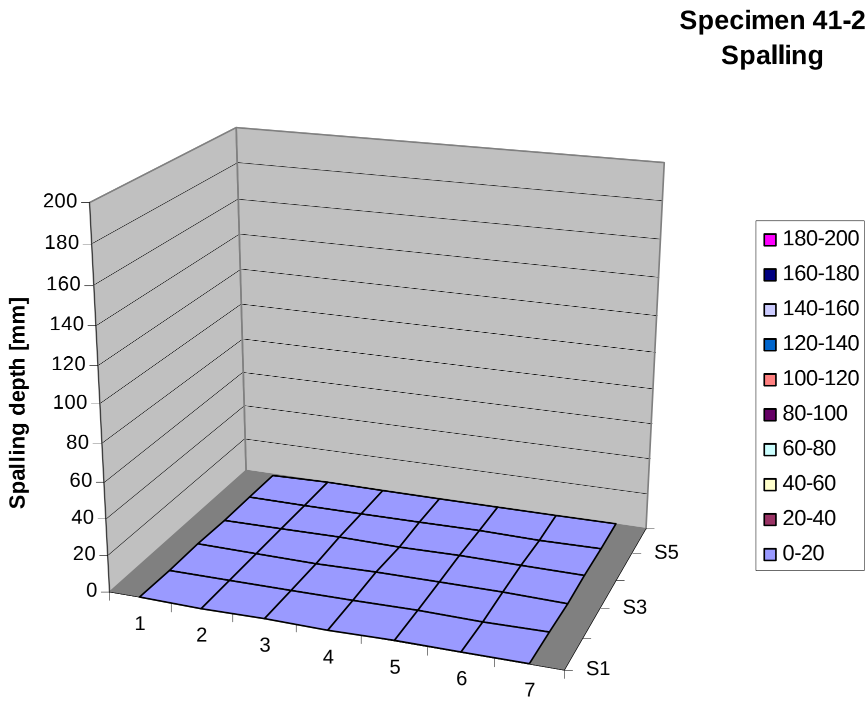


Figure A.468 Spalling measurements on specimen 41-2.

Table A.252 Observations made on specimen 41-2.

Time	Observation
0,00	Start of test
15,00	Water and cracks on sides
60,50	Test terminated

Test date:	2007-05-10	
Specimen:	41-2	
Load level:	321	kN/bar
Weight loss:	3,0	kg

Figure A.469 Specimen 41-2 after test.

Concrete 42

Table A.253 Concrete admixture recipe 42.

Recipe	**42**
Water (kg/m^3)	172
CEM I 42,5N BV/LA/SR (kg/m^3)	435
Limestone filler, Limus 25 (kg/m^3)	145
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	8,0
Sikament 20HE 50 (% of cement weight)	1,84
Sika Aer-S (10%-ig)	2,8
Sika Aer-S (% of cement weight)	-
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	1,5
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	600
T50 (s)	6
Air (%)	3.7
Compressive strength, 28 days (MPa)	67.0

Specimen 42-3

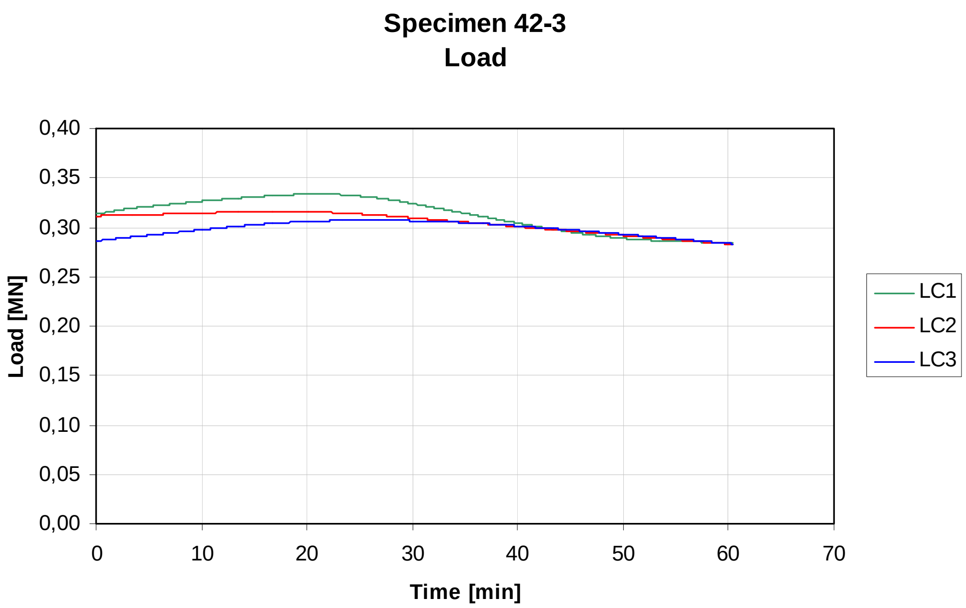


Figure A.470 Load measurements on specimen 42-3.

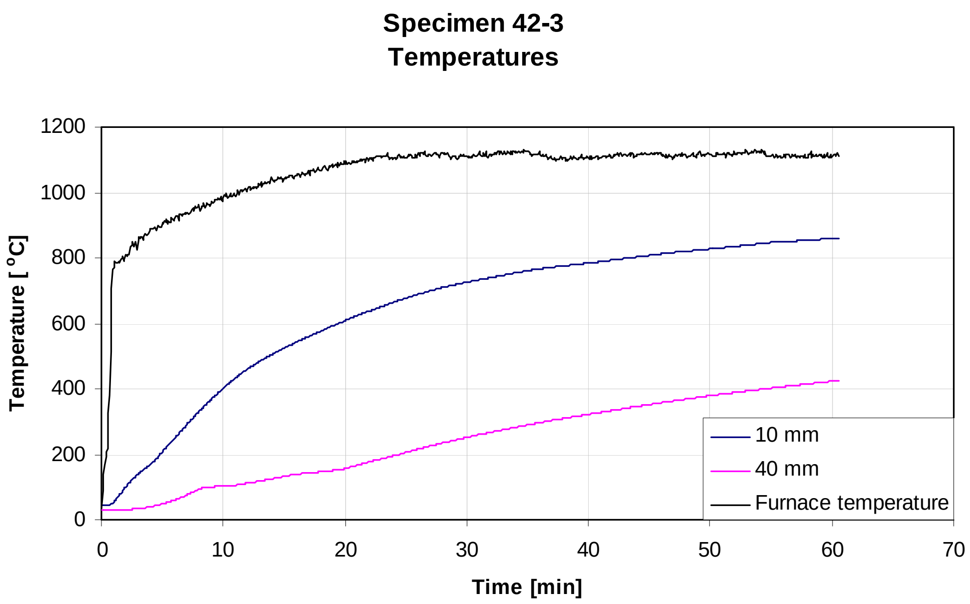


Figure A.471 Measured temperatures in furnace and in specimen 42-3.

Table A.254 Spalling measurements on specimen 42-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

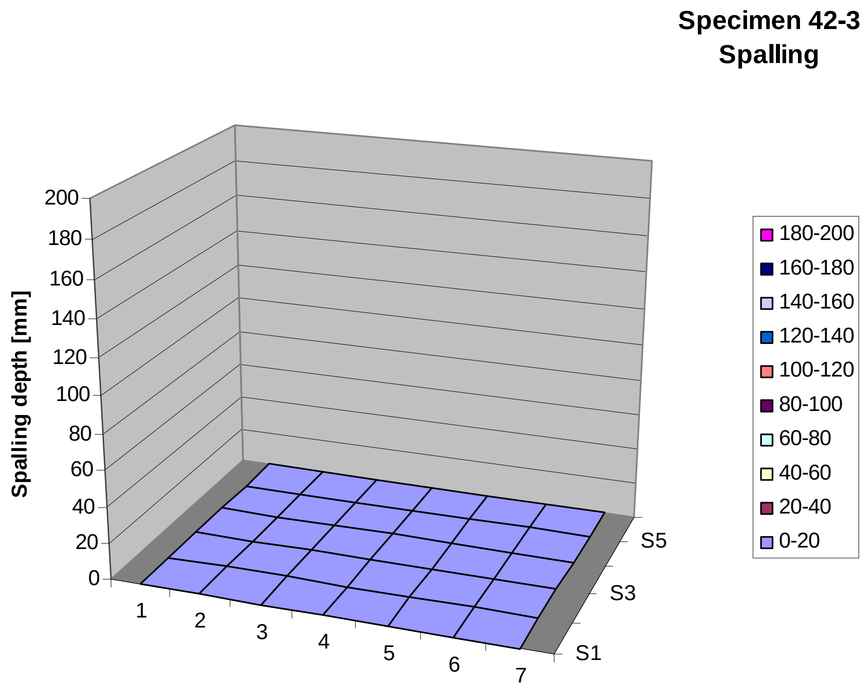


Figure A.472 Spalling measurements on specimen 42-3.

Table A.255 Observations made on specimen 42-3.

Time	Observation			
0,00	Start of test	Test date:	2007-06-11	
10,00	Water on top surface	Specimen:	42-3	
20,00	Water and cracks on sides	Load level:	394	kN/bar
60,50	Test terminated	Weight loss:	3,0	kg

Figure A.473 Specimen 42-3 after test.

Specimen 42-4

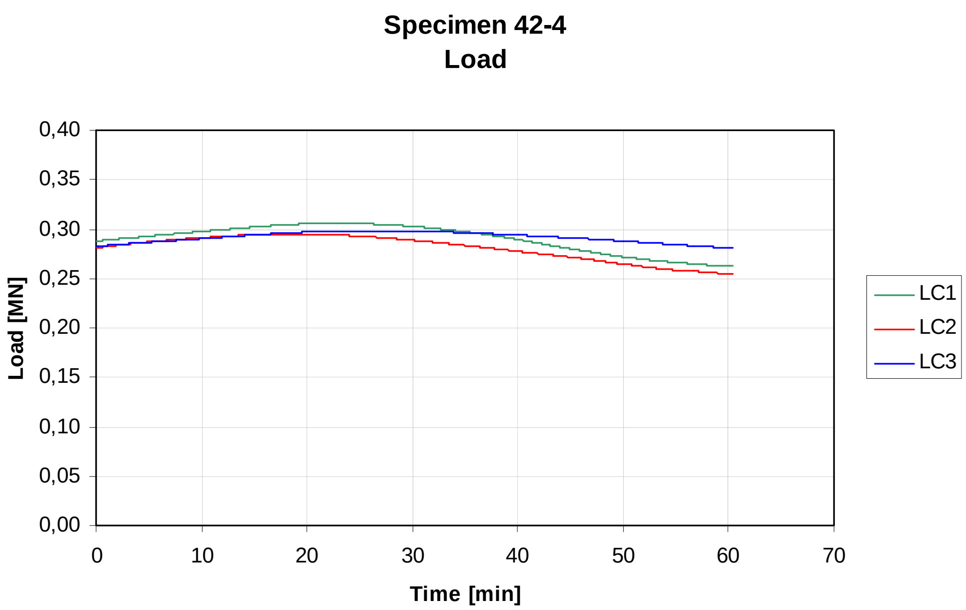


Figure A.474 Load measurements on specimen 42-4.

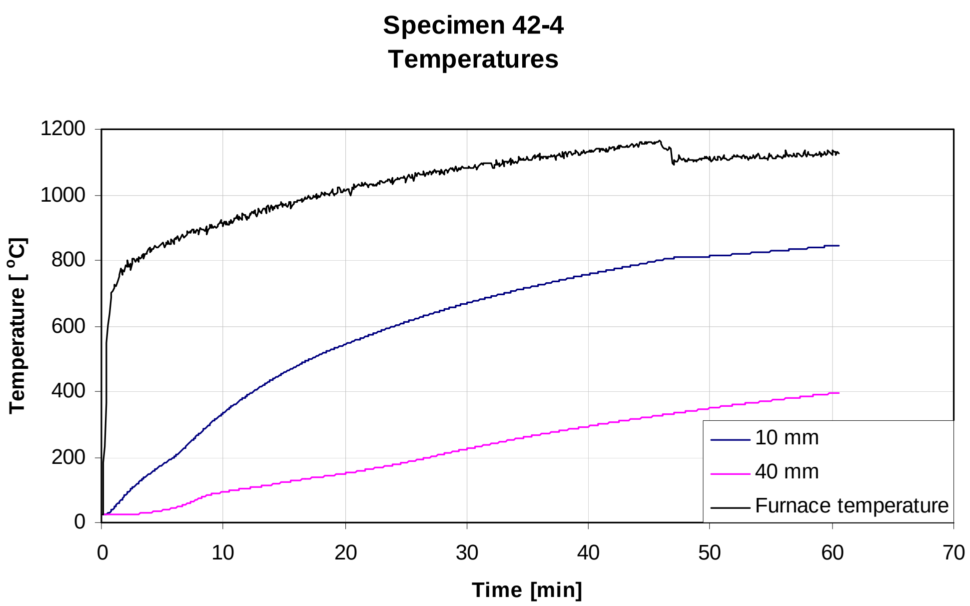


Figure A.475 Measured temperatures in furnace and in specimen 42-4.

Table A.256 Spalling measurements on specimen 42-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

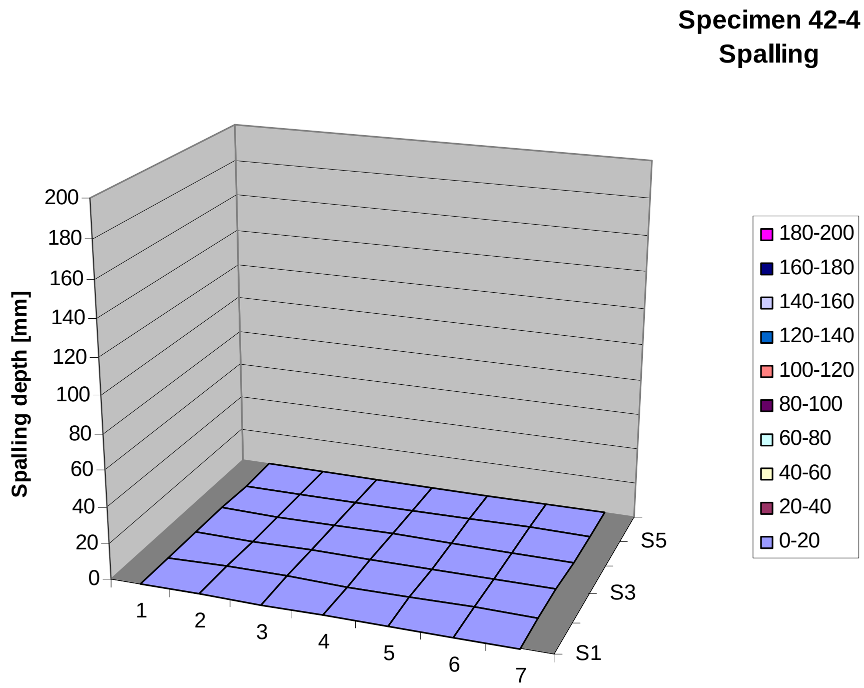


Figure A.476 Spalling measurements on specimen 42-4.

Table A.257 Observations made on specimen 42-4.

Time	Observation			
0,00	Start of test	Test date:	2007-06-11	
10,00	Water on top surface	Specimen:	42-4	
20,00	Water and cracks on sides	Load level:	394	kN/bar
60,50	Test terminated	Weight loss:	0,9	kg

Figure A.477 Specimen 42-4 after test.

Concrete 43

Table A.258 Concrete admixture recipe 43.

Recipe	**43**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	140
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	8,00
Sikament 20HE 50 (% of cement weight)	1,90
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	1,5
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	620
T50 (s)	6
Air (%)	2.8
Compressive strength, 28 days (MPa)	71.8

Specimen 43-7

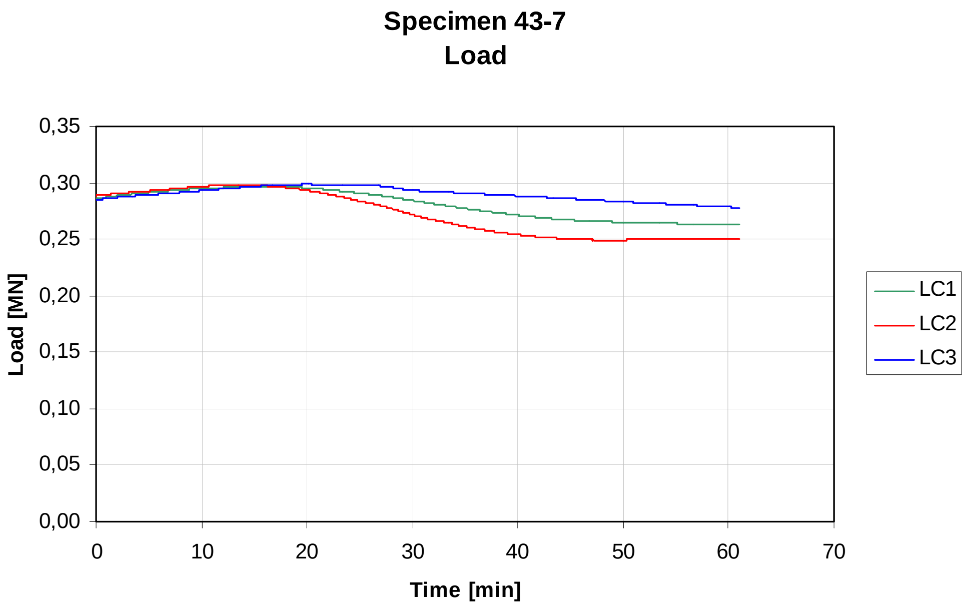


Figure A.478 Load measurements on specimen 43-7

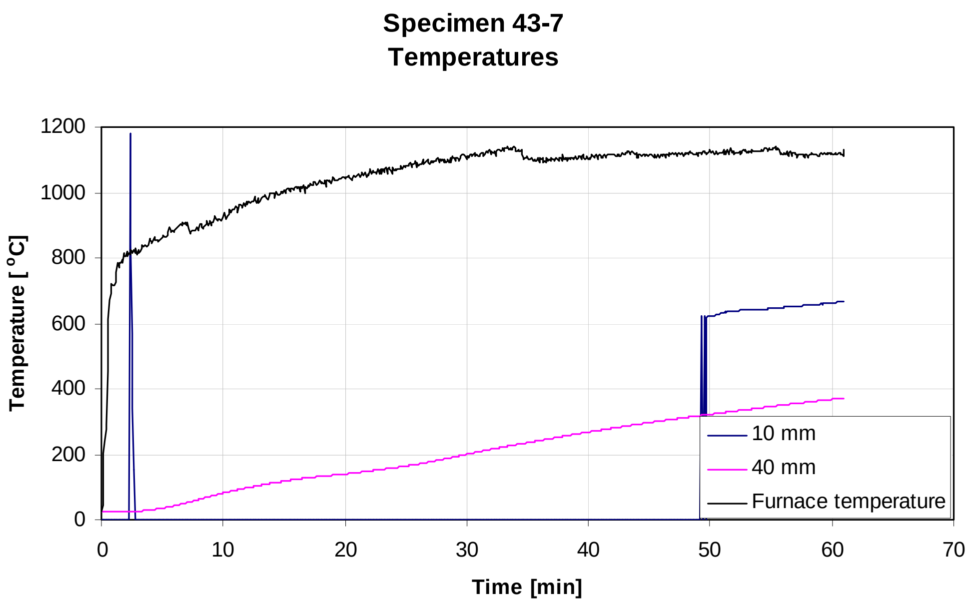


Figure A.479 Measured temperatures in furnace and in specimen 43-7.

Table A.259 Spalling measurements on specimen 43-7.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

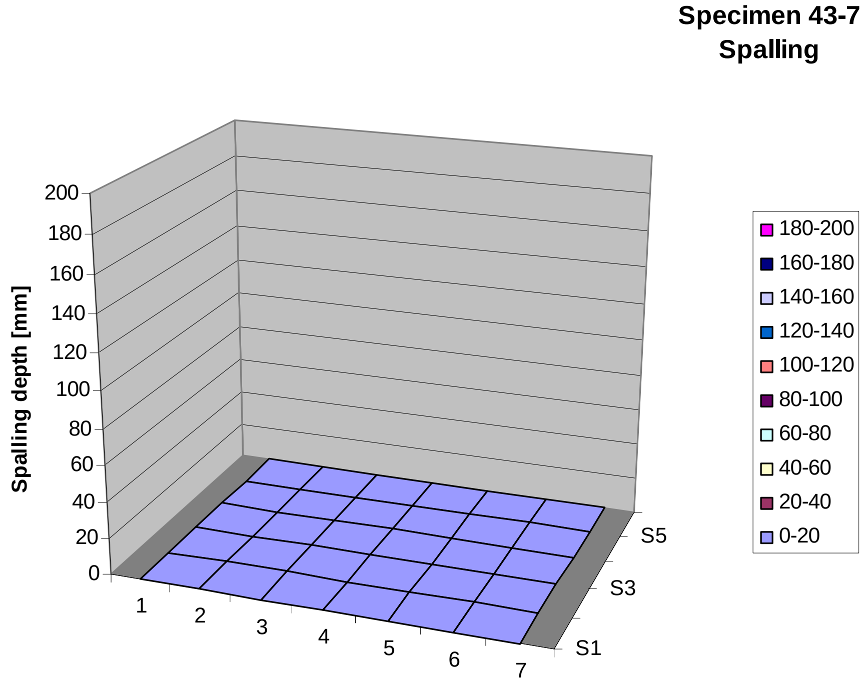


Figure A.480 Spalling measurements on specimen 43-7.

Table A.260 Observations made on specimen 43-7.

Observation	Test date:	2007-06-12	
Start of test	Specimen:	43-7	
Moisture on sides	Load level:	287	kN/bar
Water and cracks on sides	Weight loss:	3,2	kg
Test terminated			

Figure A.481 Specimen 43-7 after test.

Specimen 43-8

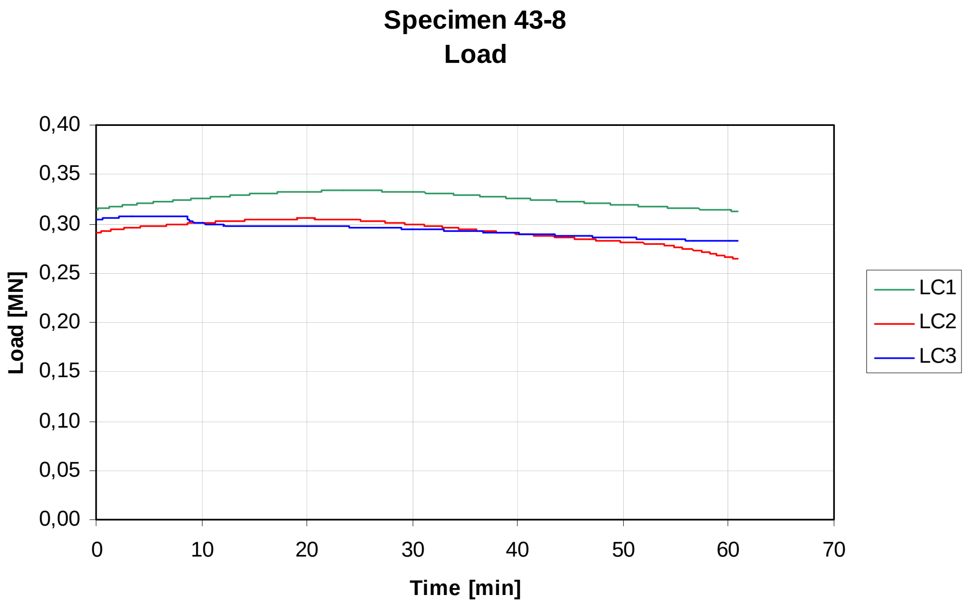


Figure A.482 Load measurements on specimen 43-8.

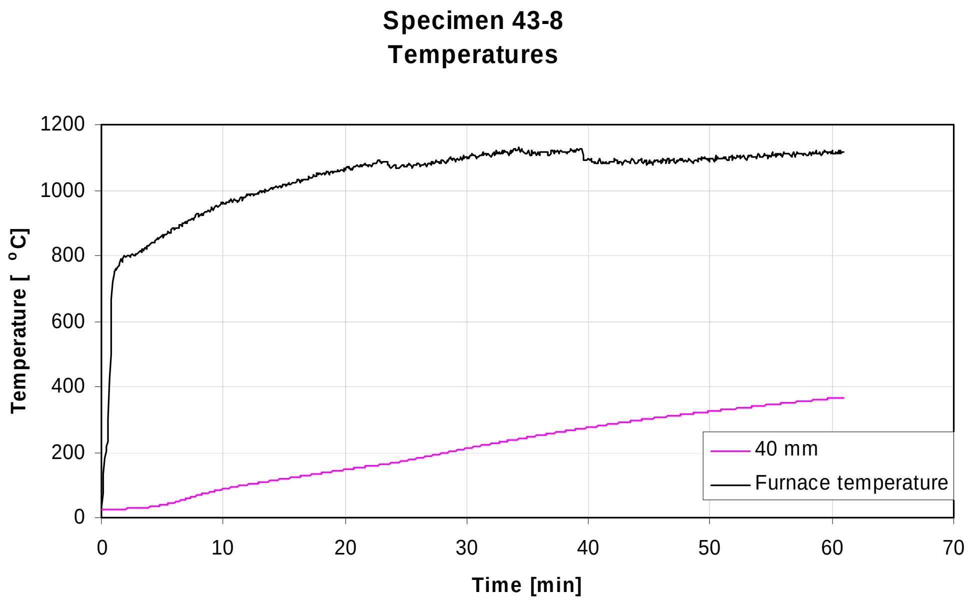


Figure A.483 Measured temperatures in furnace and in specimen 43-8.

Table A.261 Spalling measurements on specimen 43-8.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

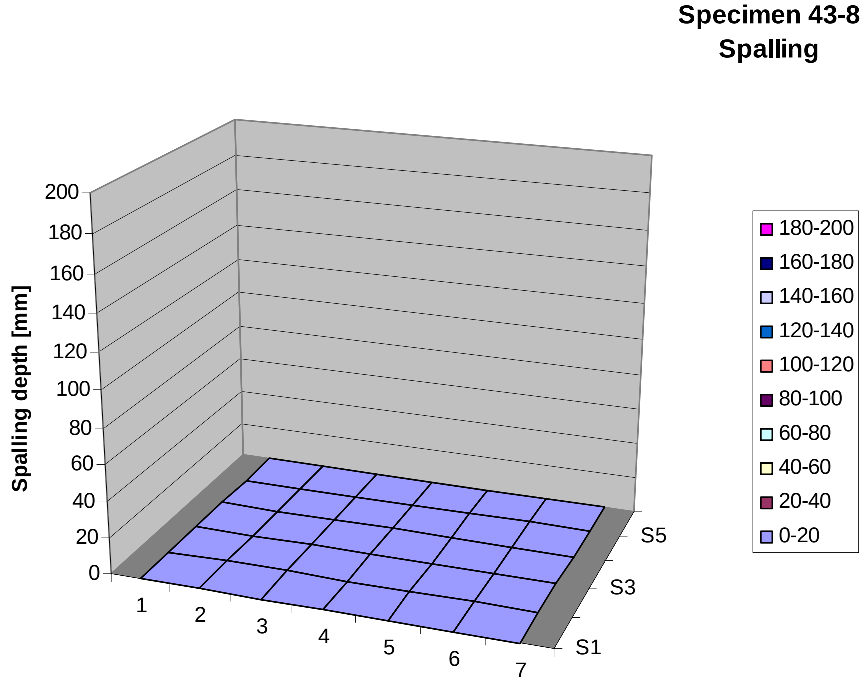


Figure A.484 Spalling measurements on specimen 43-8.

Table A.262 Observations made on specimen 43-8.

Observation			
Start of test	Test date:	2007-06-12	
Water and cracks on sides	Specimen:	43-8	
Test terminated	Load level:	304	kN/bar
	Weight loss:	2,8	kg

Figure A.485 Specimen 43-8 after test.

Concrete 44

Table A.263 Concrete admixture recipe 44.

Recipe	**44**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	0
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	6,50
Sikament 20HE 50 (% of cement weight)	1,55
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	0,5
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	600
T50 (s)	5
Air (%)	4.7
Compressive strength, 28 days (MPa)	66.5

Specimen 44-3

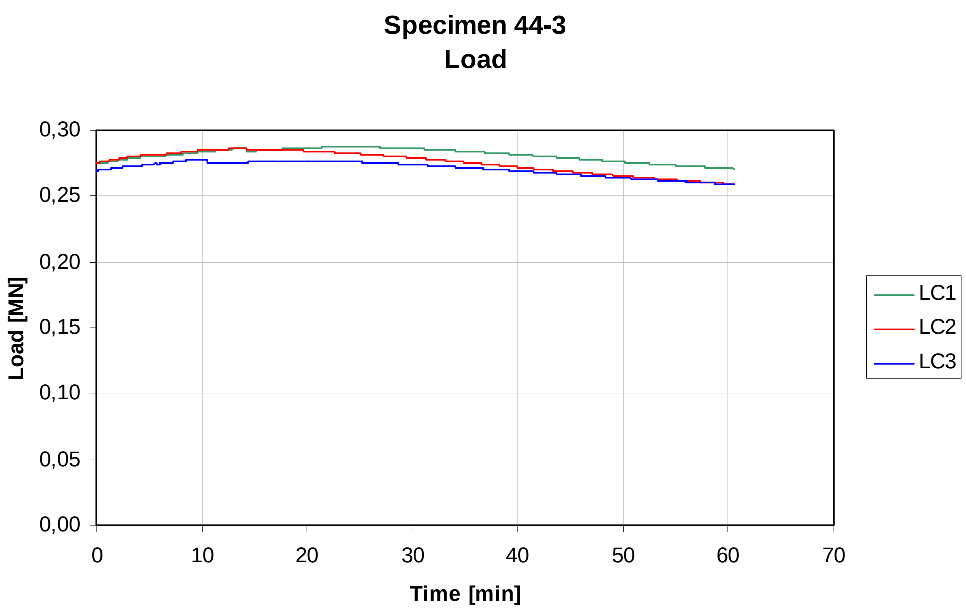


Figure A.486 Load measurements on specimen 44-3.

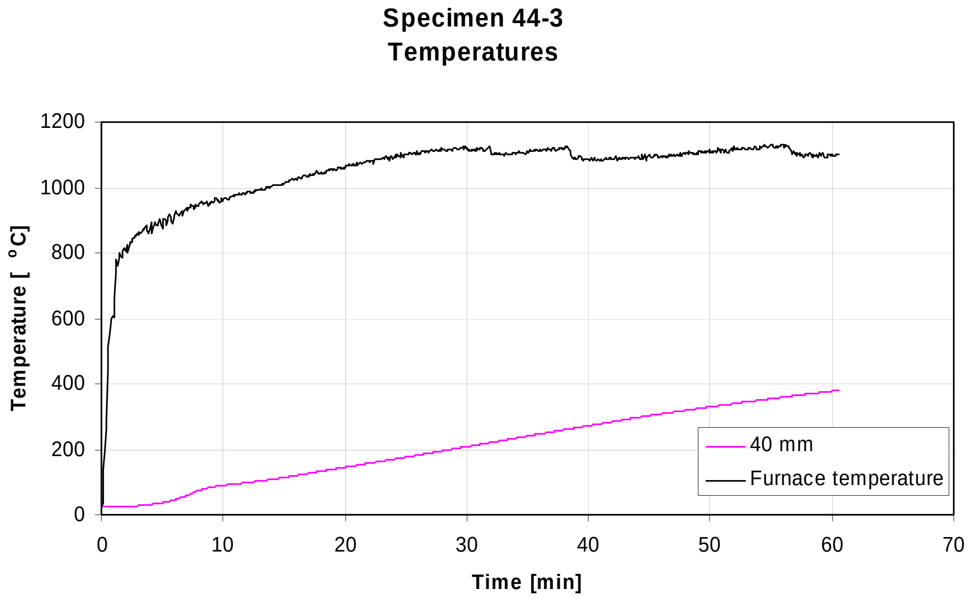


Figure A.487 Measured temperatures in furnace and in specimen 44-3.

Table A.264 Spalling measurements on specimen 44-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	6	7	0
200	0	0	0	11	12	0
300	0	0	0	10	8	0
400	0	0	0	8	5	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	2
Mean inner	3
Max in diagram	12
Max measured	16

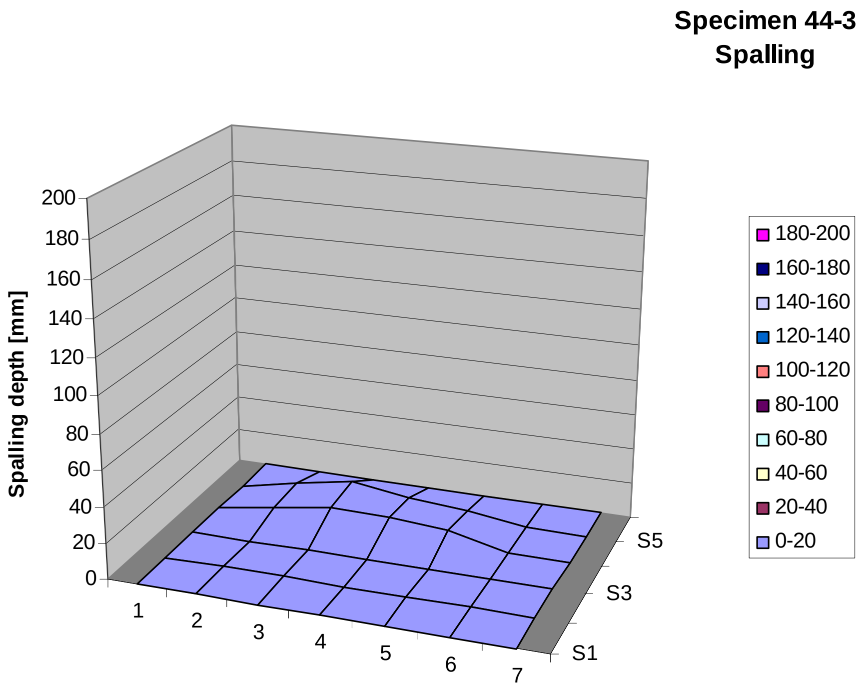


Figure A.488 Spalling measurements on specimen 44-3.

Table A.265 Observations made on specimen 44-3.

Time	Observation
0,00	Start of test
3,75	One small explosion
6,00	One small explosion
20,00	Cracks and water on sides
60,00	Test terminated

Test date:	2007-06-13	
Specimen:	44-3	
Load level:	273	kN/bar
Weight loss:	2,7	kg

Figure A.489 Specimen 44-3 after test.

Specimen 44-4

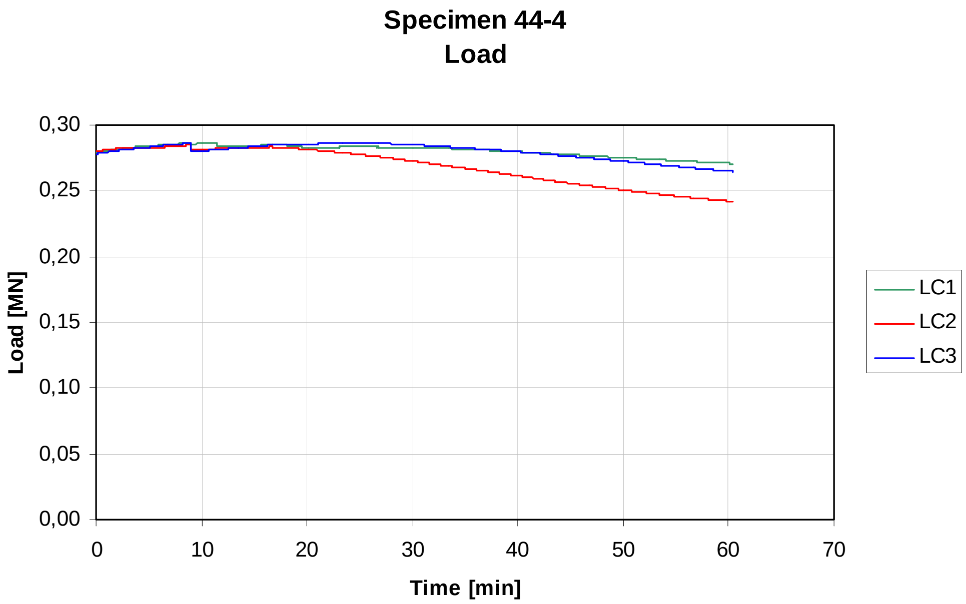


Figure A.490 Load measurements on specimen 44-4.

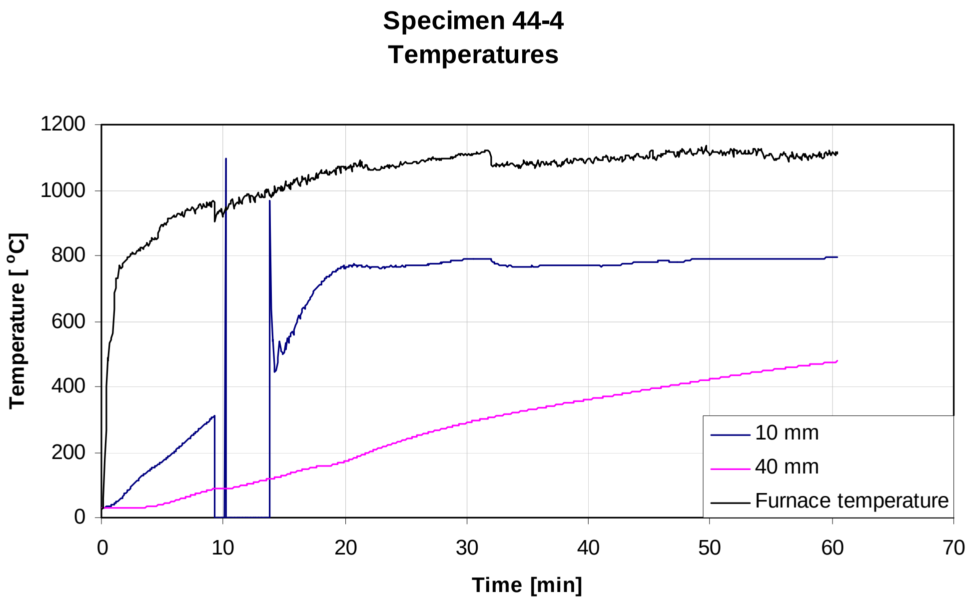


Figure A.491 Measured temperatures in specimen 44-4.

Table A.266 Spalling measurements on specimen 44-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	18	18	10	0
300	0	0	10	15	21	0
400	0	0	1	17	3	0
500	0	0	0	4	12	0
600	0	0	0	0	0	0

Mean all	3
Mean inner	6
Max in diagram	21
Max measured	26

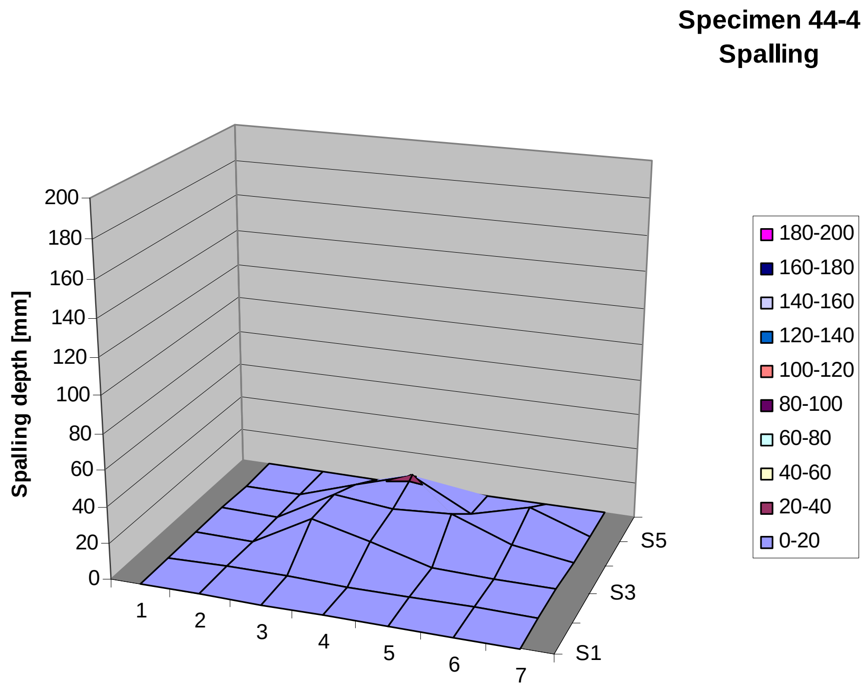


Figure A.492 Spalling measurements on specimen 44-4.

Table A.267 Observations made on specimen 44-4.

Time	Observation
0,00	Start of test
9,33	Two small explosions
13,00	Cracks on sides
20,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-06-13	
Specimen:	44-4	
Load level:	279	kN/bar
Weight loss:	4,0	kg

Figure A.493 Specimen 44-4 after test.

Concrete 45

Table A.268 Concrete admixture recipe 45.

Recipe	45
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	0,0
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,40
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	610
T50 (s)	7
Air (%)	2.8
Compressive strength, 28 days (MPa)	64.2

Specimen 45-1

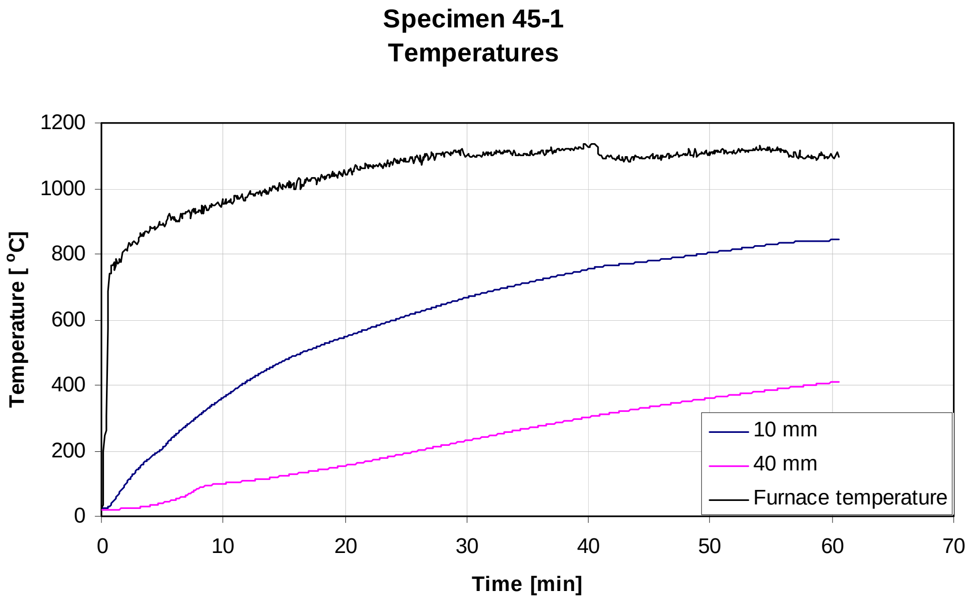


Figure A.494 Measured temperatures in furnace and in specimen 45-1.

Table A.269 Spalling measurements on specimen 45-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	1	3	5	0
200	0	2	1	2	2	0
300	0	4	3	3	2	0
400	0	5	1	1	1	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	1
Mean inner	2
Max in diagram	5
Max measured	11

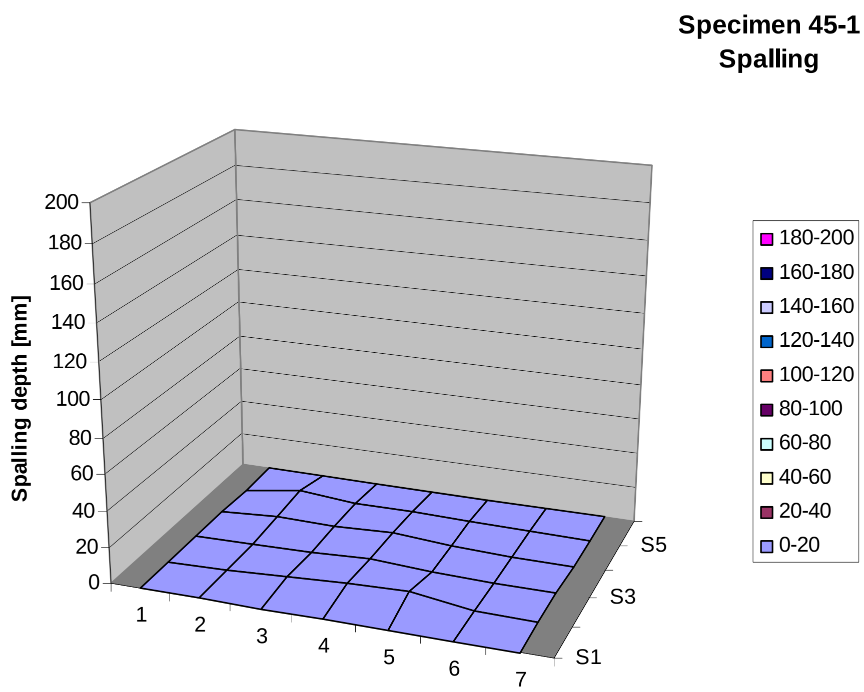


Figure A.495 Spalling measurements on specimen 45-1

Table A.270 Observations made on specimen 45-1.

Time	Observation
0,00	Start of test
3,92	One small explosion
5,33	One small explosion
10,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-06-14	
Specimen:	45-1	
Load level:	0	kN/bar
Weight loss:	2,7	kg

Figure A.496 Specimen 45-1 after test.

Specimen 45-2

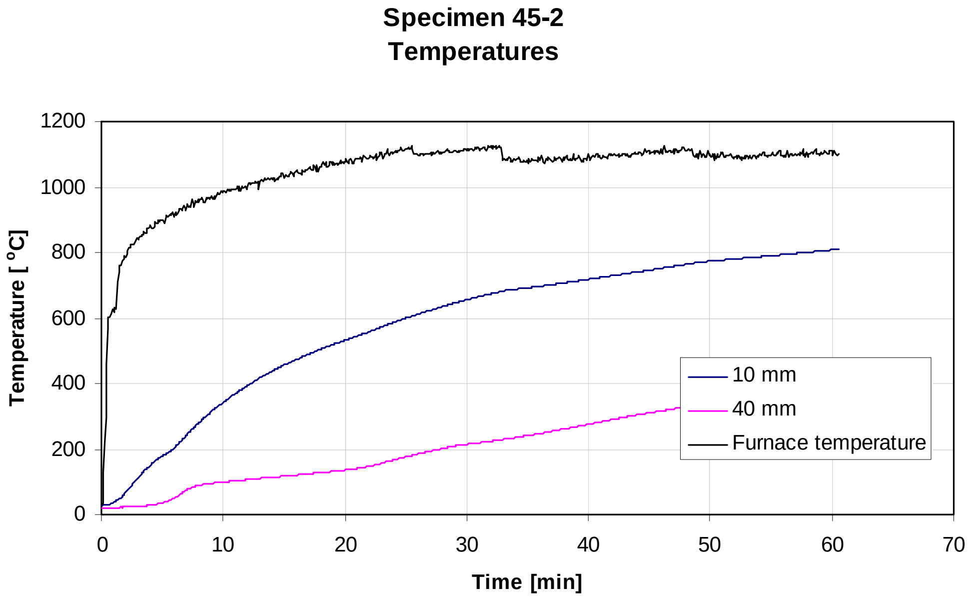


Figure A.497 Measured temperatures in furnace and in specimen 45-2.

Table A.271 Spalling measurements on specimen 45-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	2	10	0	0
400	0	0	2	7	0	0
500	0	0	4	6	0	0
600	0	0	0	0	0	0

Mean all	1
Mean inner	2
Max in diagram	10
Max measured	13

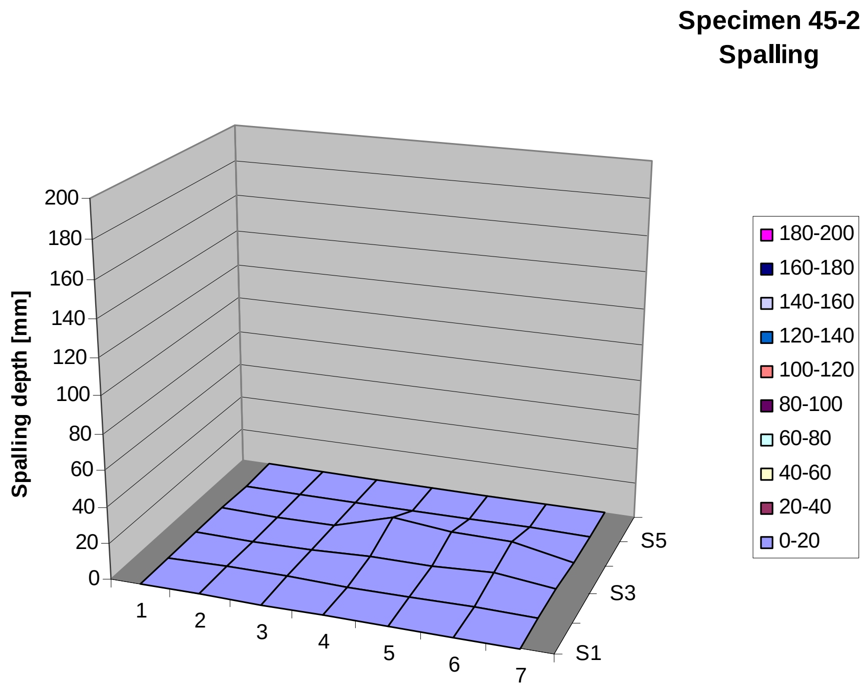


Figure A.498 Spalling measurements on specimen 45-2.

Table A.272 Observations made on specimen 45-2.

Time	Observation
0,00	Start of test
3,33	One small explosion
3,83	One small explosion
4,08	One small explosion
5,08	One small explosion
8,00	Cracks on sides
20,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-06-14	
Specimen:	45-2	
Load level:	0	kN/bar
Weight loss:	2,1	kg

Figure A.499 Specimen 45-2 after test.

Specimen 45-4

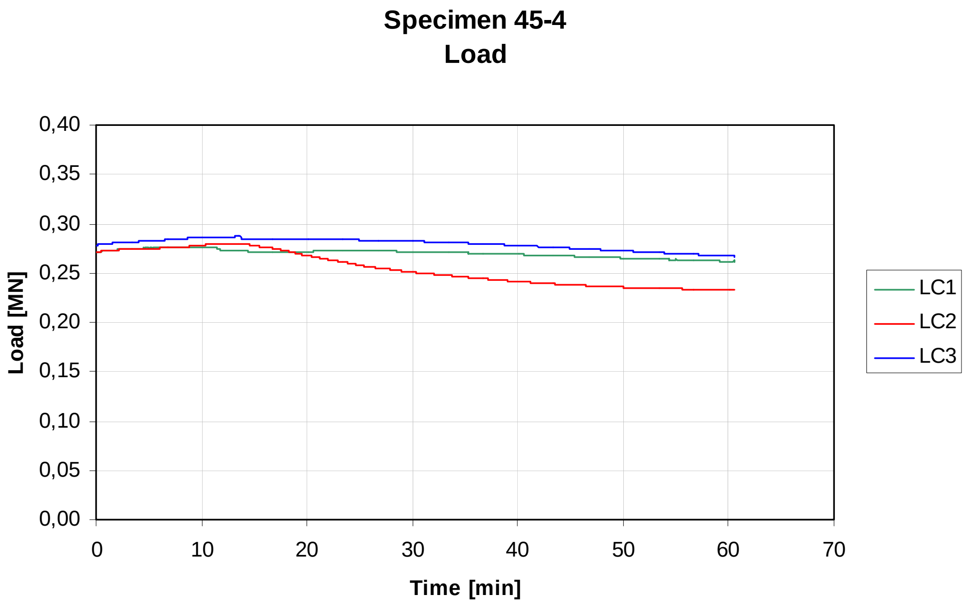


Figure A.500 Load measurements on specimen 45-4.

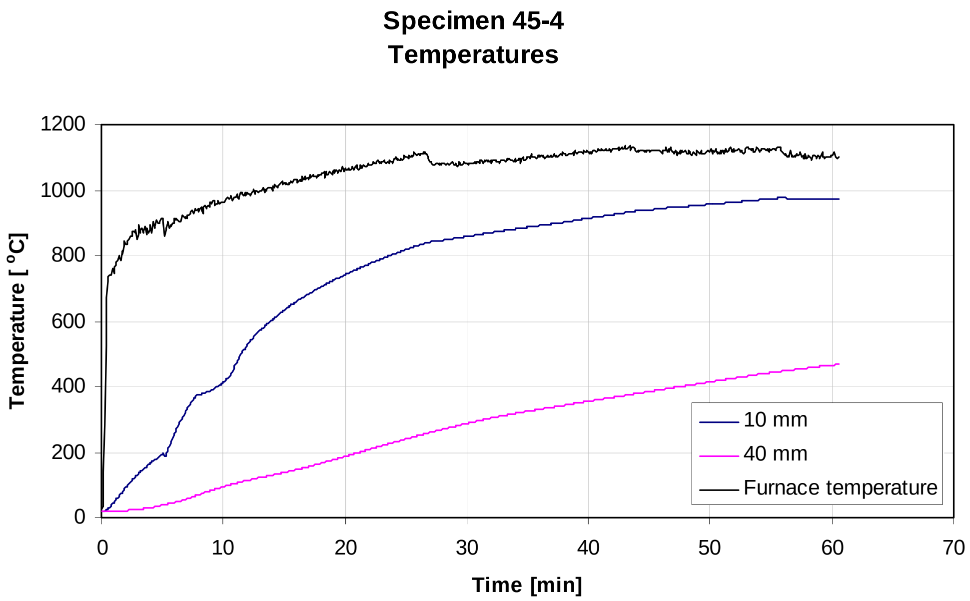


Figure A.501 Measured temperatures in furnace and in specimen 45-4.

Table A.273 Spalling measurements on specimen 45-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	2	9	9	2	0
200	0	4	6	3	5	0
300	0	5	9	8	1	0
400	0	0	8	4	0	0
500	0	3	2	0	1	0
600	0	0	0	0	0	0

Mean all	2
Mean inner	4
Max in diagram	9
Max measured	16

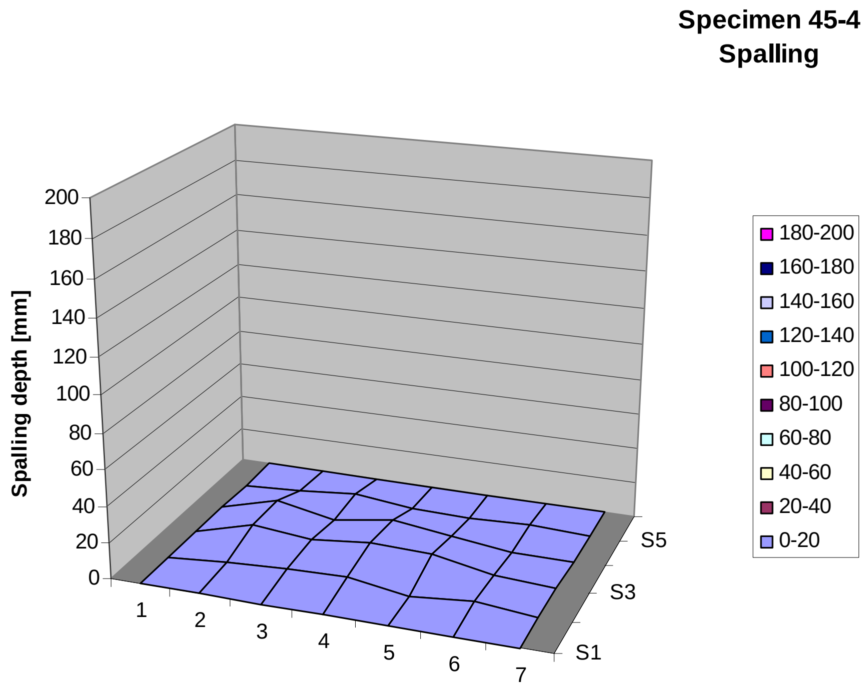


Figure A.502 Spalling measurements on specimen 45-4.

Table A.274 Observations made on specimen 45-4.

Time	Observation
0,00	Start of test
3,67	One small explosion
4,25	One small explosion
5,17	Two small explosions
10,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-06-15	
Specimen:	45-4	
Load level:	274	kN/bar
Weight loss:	5,4	kg

Figure A.503 Specimen 45-4 after test.

Specimen 45-6

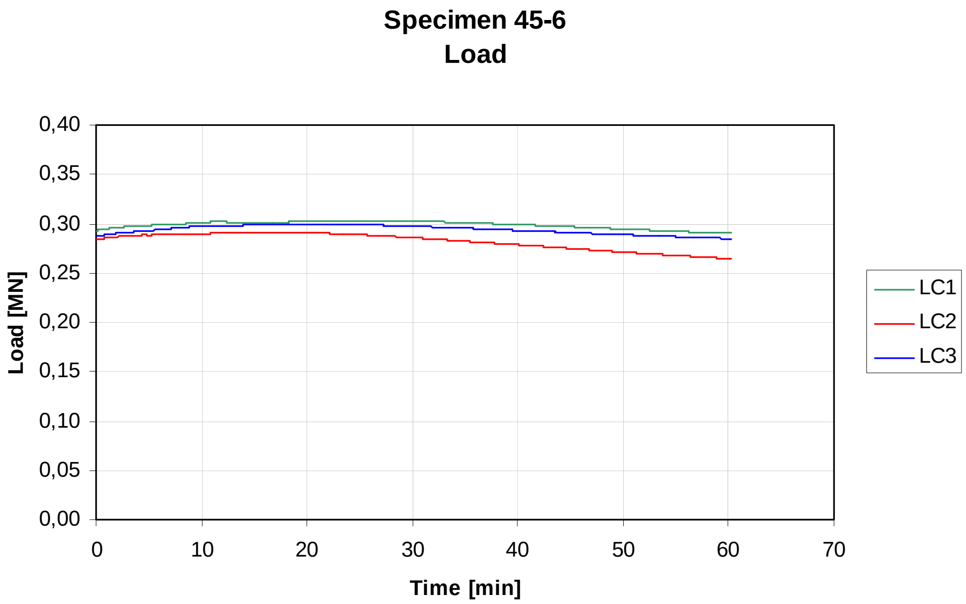


Figure A.504 Load measurements on specimen 45-6.

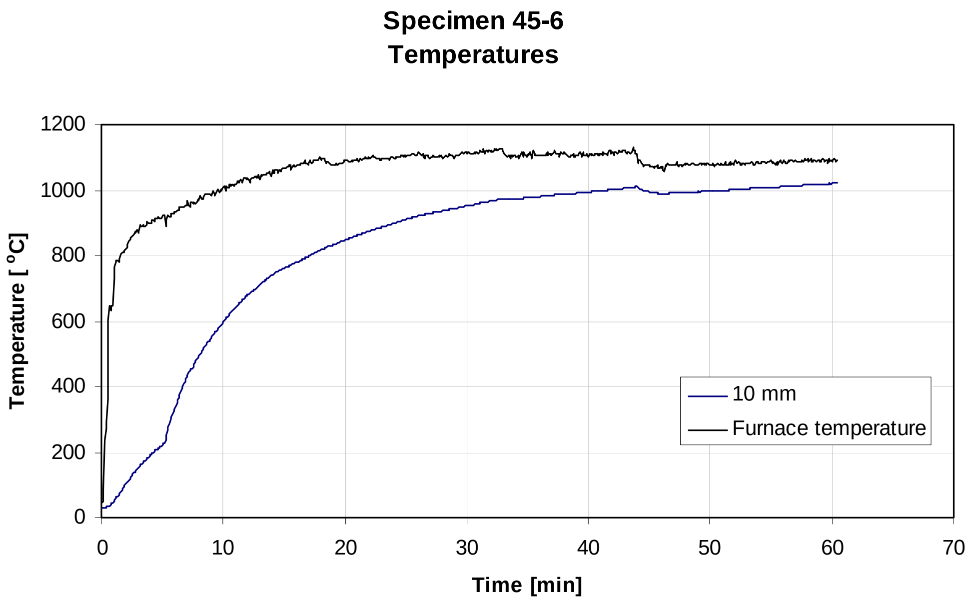


Figure A.505 Measured temperatures in furnace and in specimen 45-6.

Table A.275 Spalling measurements on specimen 45-6.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	1	8	6	2	0
200	0	1	8	2	1	0
300	0	5	14	12	7	0
400	0	8	11	4	7	0
500	0	8	3	1	1	0
600	0	0	0	0	0	0

Mean all	3
Mean inner	6
Max in diagram	14
Max measured	20

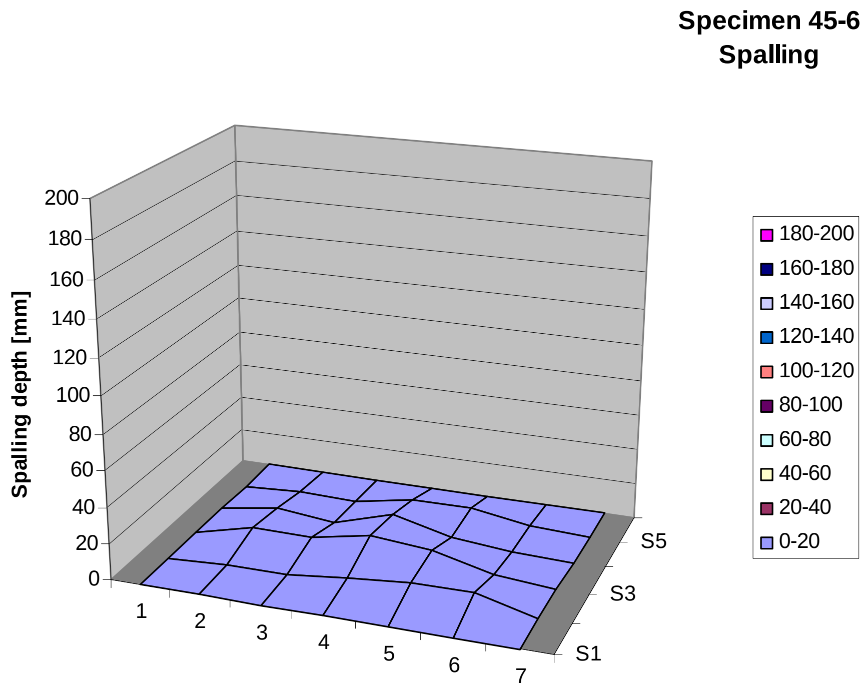


Figure A.506 Spalling measurements on specimen 45-6.

Table A.276 Observations made on specimen 45-6.

Time	Observation
0,00	Start of test
3,00	One small explosion
3,43	One small explosion
3,83	Two small explosions
4,17	One small explosion
4,75	One small explosion
5,17	Two small explosions
10,00	Cracks and water on sides
60,00	Test terminated

Test date:	2007-06-15	
Specimen:	45-6	
Load level:	288	kN/bar
Weight loss:	4,1	kg

Figure A.507 Specimen 45-6 after test.

Specimen 45-7

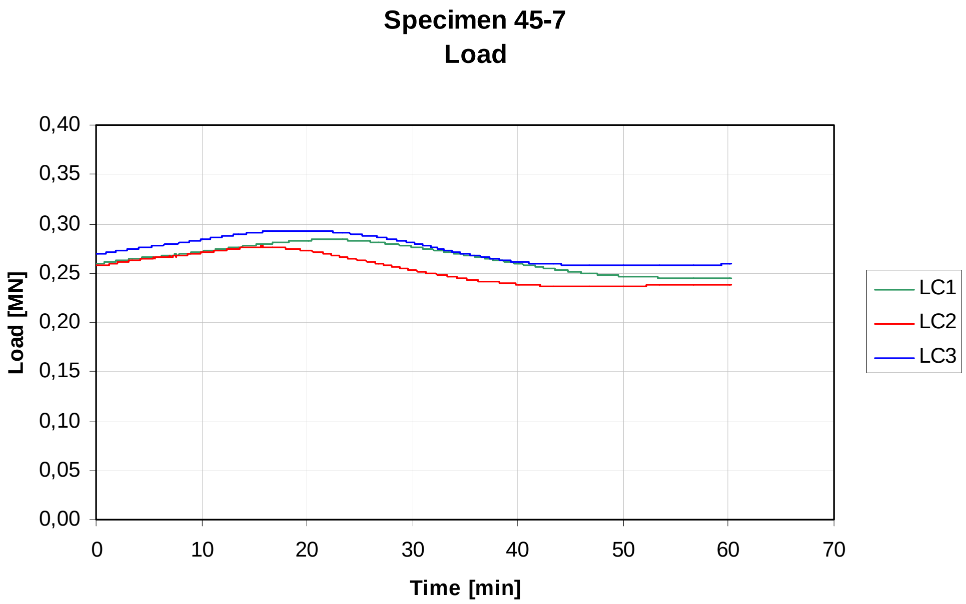


Figure A.508 Load measurements on specimen 45-7.

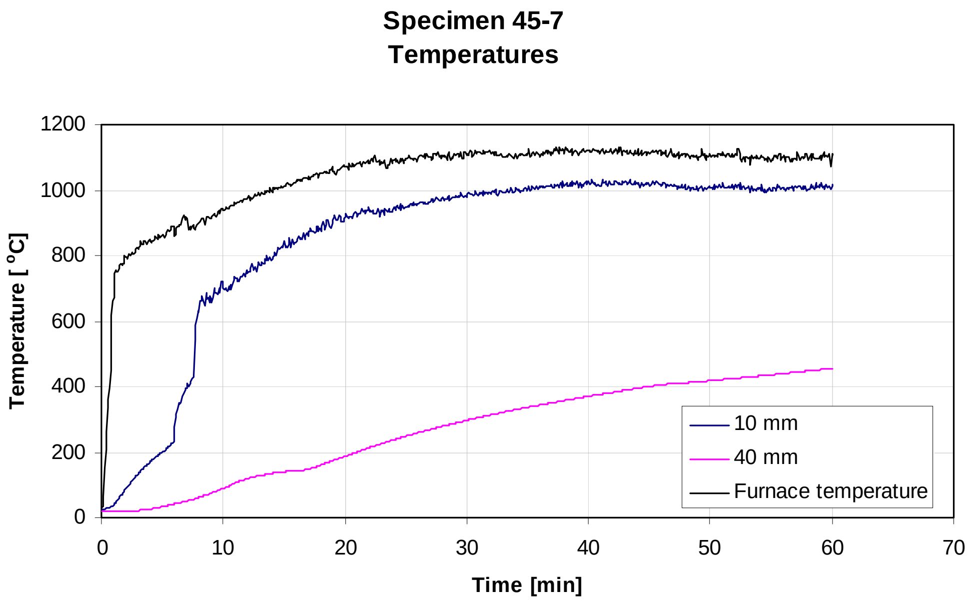


Figure A.509 Measured temperatures in furnace and in specimen 45-7.

Table A.277 Spalling measurements on specimen 45-7.

Position	0	100	200	300	400	500
0	0	3	0	0	2	0
100	0	9	14	3	5	0
200	0	4	16	14	12	0
300	0	4	12	16	14	0
400	0	2	9	9	6	0
500	0	6	0	9	3	0
600	0	0	0	0	0	0

Mean all	4
Mean inner	8
Max in diagram	16
Max measured	22

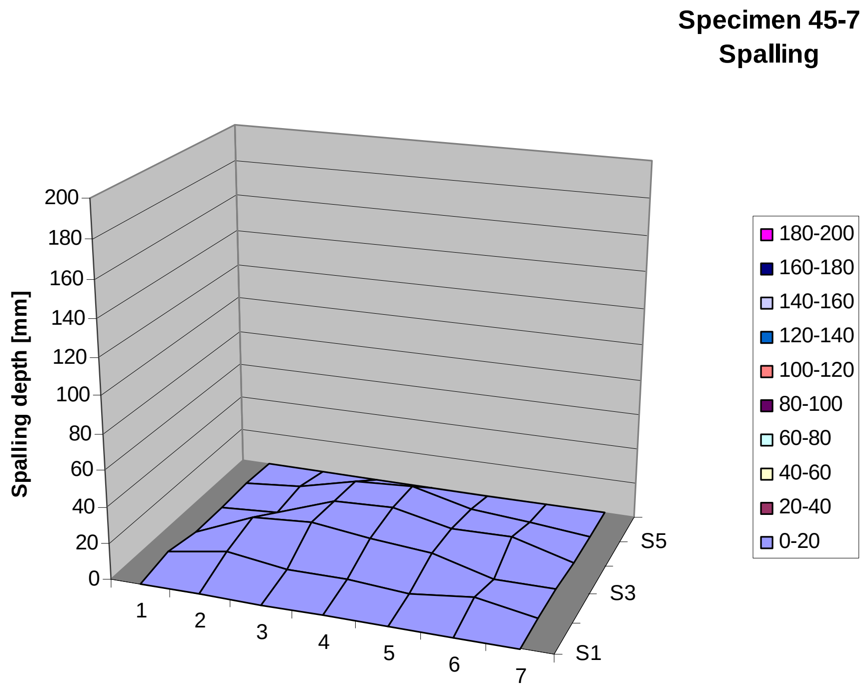


Figure A.510 Spalling measurements on specimen 45-7.

Table A.278 Observations made on specimen 45-7.

Time	Observation
0,00	Start of test
3,67	One small explosion
4,00	One small explosion
4,75	One explosion
5,17	One explosion
5,53	Two small explosions
6,00	One explosion
7,08	One small explosion
7,67	One explosion
12,00	Water on top surface
30,00	Cracks and water on sides
60,08	Test terminated

Test date:	2007-03-16	
Specimen:	45-7	
Load level:	262	kN/bar
Weight loss:	6,8	kg

Figure A.511 Specimen 45-7 after test.

Specimen 45-8

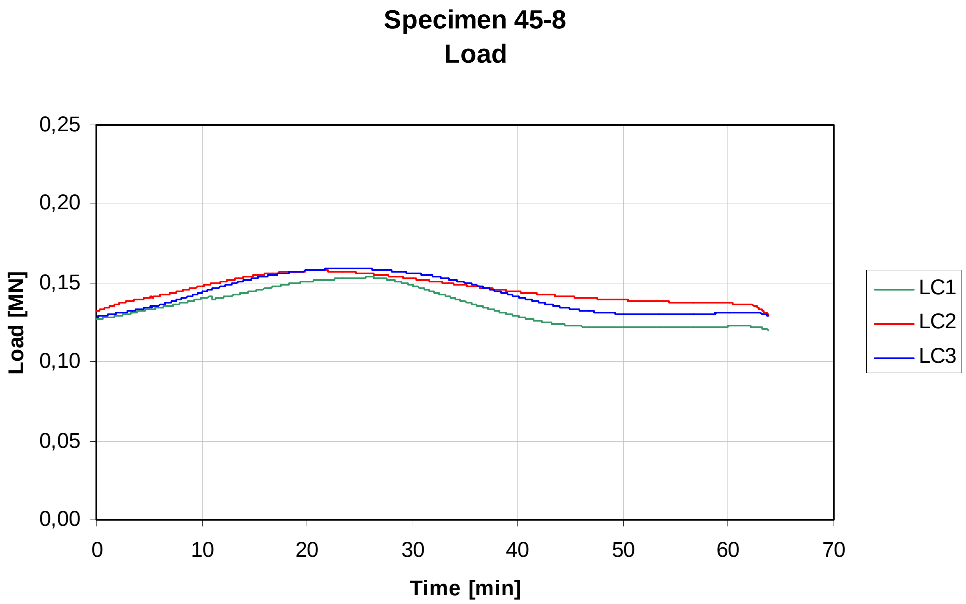


Figure A.512 Load measurements on specimen 45-8.

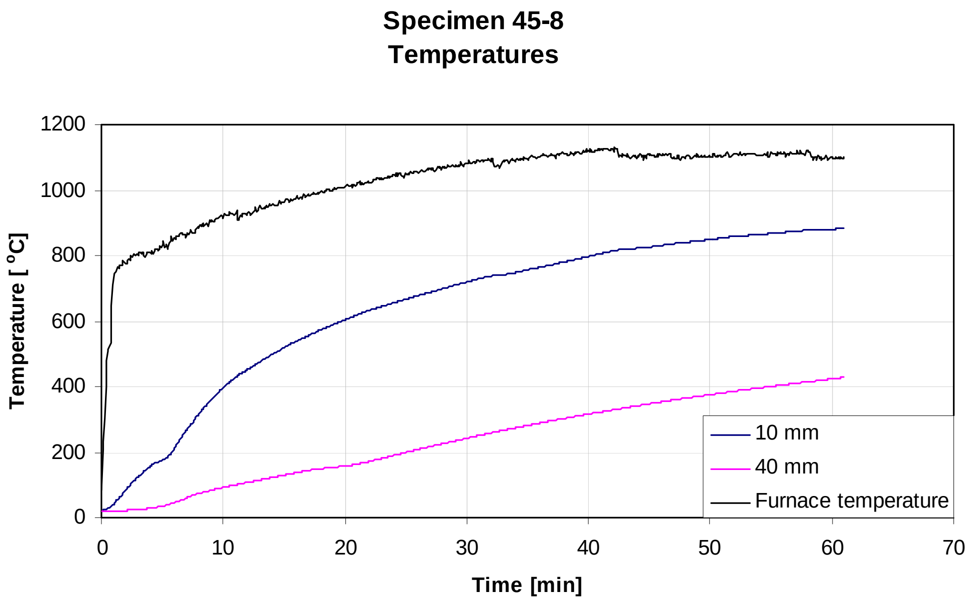


Figure A.513 Measured temperatures in furnace and in specimen 45-8.

Table A.279 Spalling measurements on specimen 45-8.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	5	3	3	0	0
200	9	11	10	11	5	0
300	6	10	9	5	7	0
400	2	6	0	4	1	0
500	3	3	0	0	0	0
600	0	0	0	0	0	0

Mean all	3
Mean inner	5
Max in diagram	11
Max measured	20

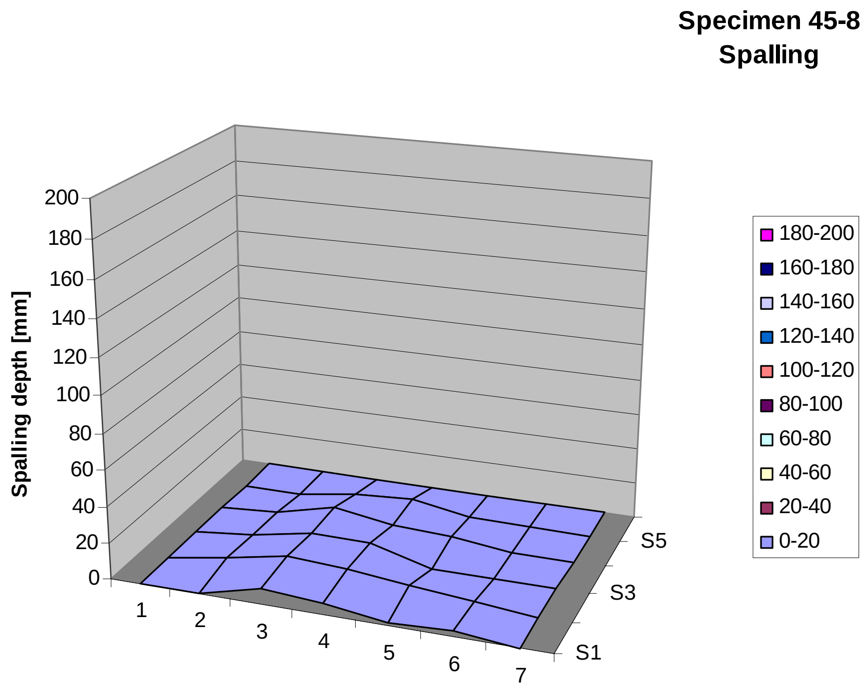


Figure A.514 Spalling measurements on specimen 45-8.

Table A.280 Observations made on specimen 45-8.

Time	Observation
0,00	Start of test
5,33	One explosion
6,92	One explosion
11,17	One small explosion
15,00	Cracks on sides
30,00	Water on sides
50,00	Water on top surface
61,00	Test terminated

Test date:	2007-03-14	
Specimen:	45-8	
Load level:	129	kN/bar
Weight loss:	5,1	kg

Figure A.515 Specimen 45-8 after test.

Specimen 45-11

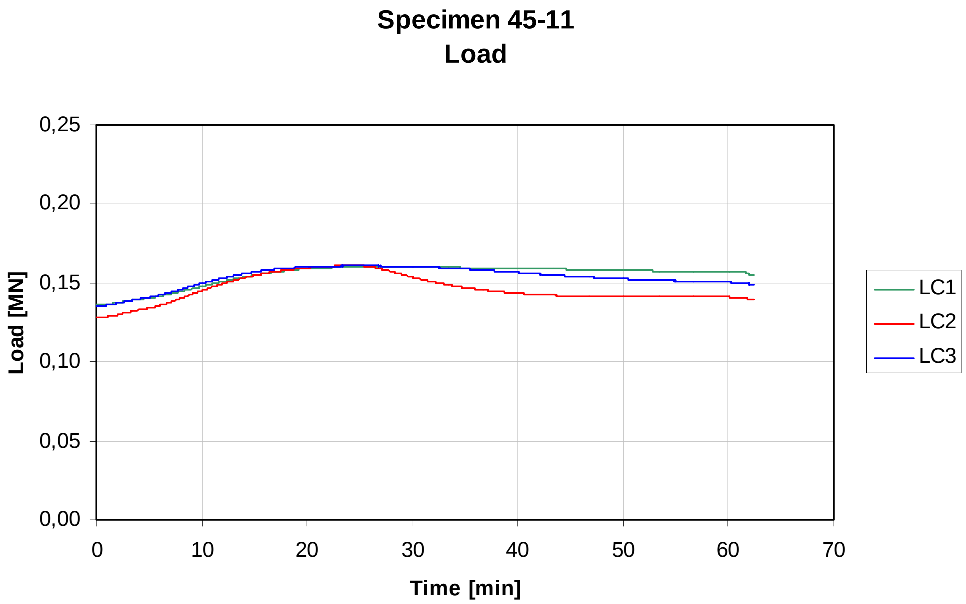


Figure A.516 Load measurements on specimen 45-11.

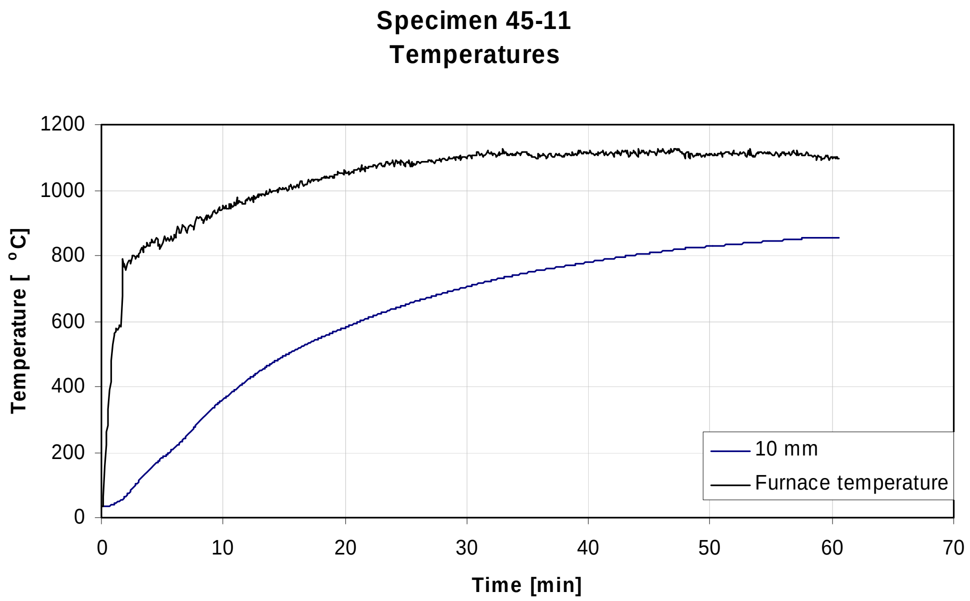


Figure A.517 Measured temperatures in furnace and in specimen 45-11.

Table A.281 Spalling measurements on specimen 45-11.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	1	1	5	0
200	0	0	3	6	10	0
300	0	0	0	2	1	0
400	0	2	1	2	0	0
500	0	3	1	0	0	0
600	0	0	0	0	0	0

Mean all	1
Mean inner	2
Max in diagram	10
Max measured	10

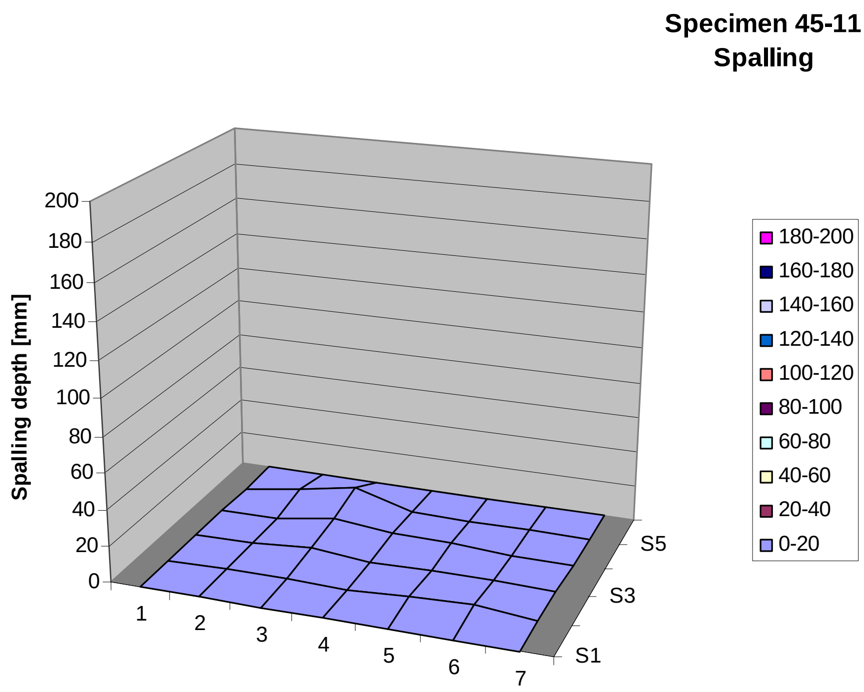


Figure A.518 Spalling measurements on specimen 45-11.

Table A.282 Observations made on specimen 45-11.

Time	Observation
0,00	Start of test
4,25	One small explosion
4,67	One explosion
15,00	Cracks on sides
25,00	Water on sides
60,50	Test terminated

Test date:	2007-03-14	
Specimen:	45-11	
Load level:	133	kN/bar
Weight loss:	2,2	kg

Figure A.519 Specimen 45-11 after test.

Specimen 45-12

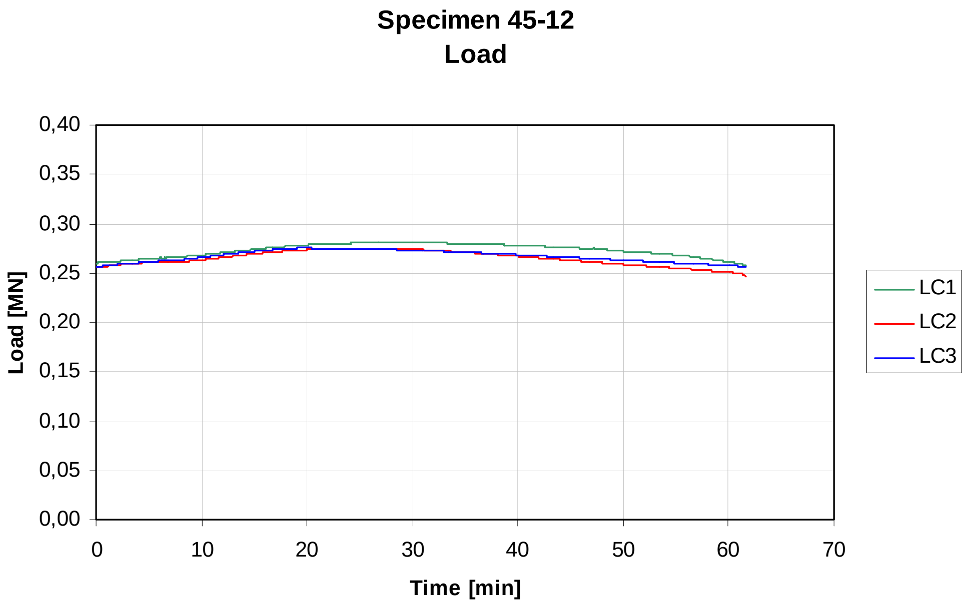


Figure A.520 Load measurements on specimen 45-12.

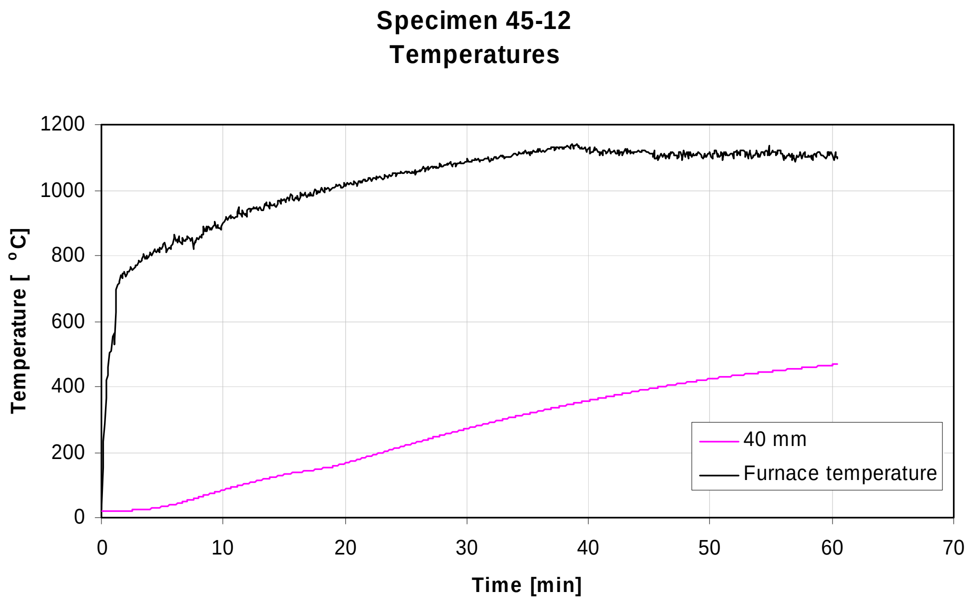


Figure A.521 Measured temperatures in furnace and in specimen 45-12.

Table A.283 Spalling measurements on specimen 45-12.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	1	7	3	0	0	0
200	6	13	14	14	7	0
300	1	5	10	13	15	0
400	0	7	9	15	4	0
500	0	6	9	13	8	0
600	0	0	0	0	0	0

Mean all	4
Mean inner	9
Max in diagram	15
Max measured	20

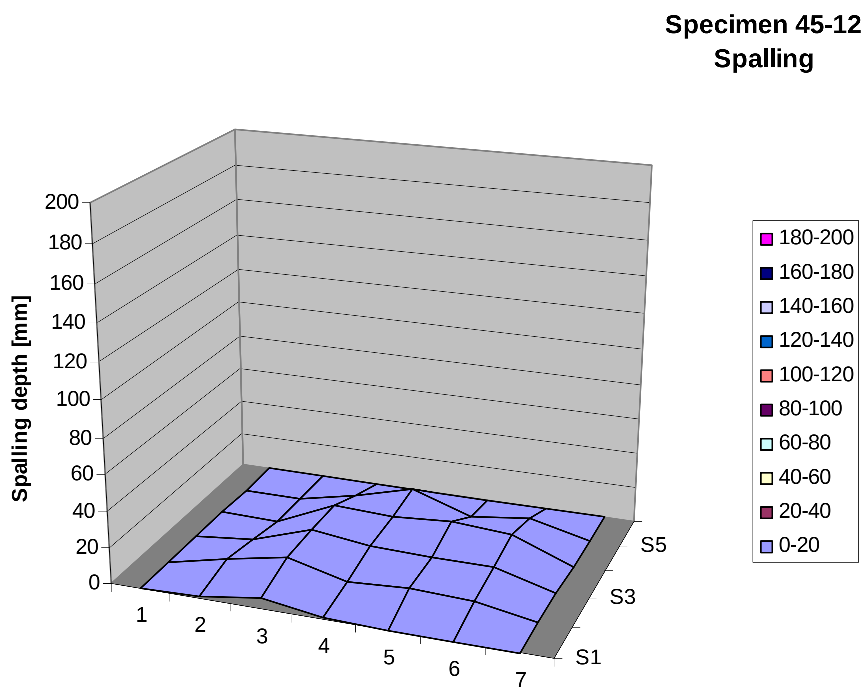


Figure A.522 Spalling measurements on specimen 45-12.

Table A.284 Observations made on specimen 45-12.

Time	Observation
0,00	Start of test
4,17	One small explosion
4,83	One small explosion
5,25	Two explosions
6,33	Two explosions
6,67	One explosion
7,50	One explosion
25,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-03-16	
Specimen:	45-12	
Load level:	258	kN/bar
Weight loss:	5,6	kg

Figure A.523 Specimen 45-12 after test.

Specimen 45-15

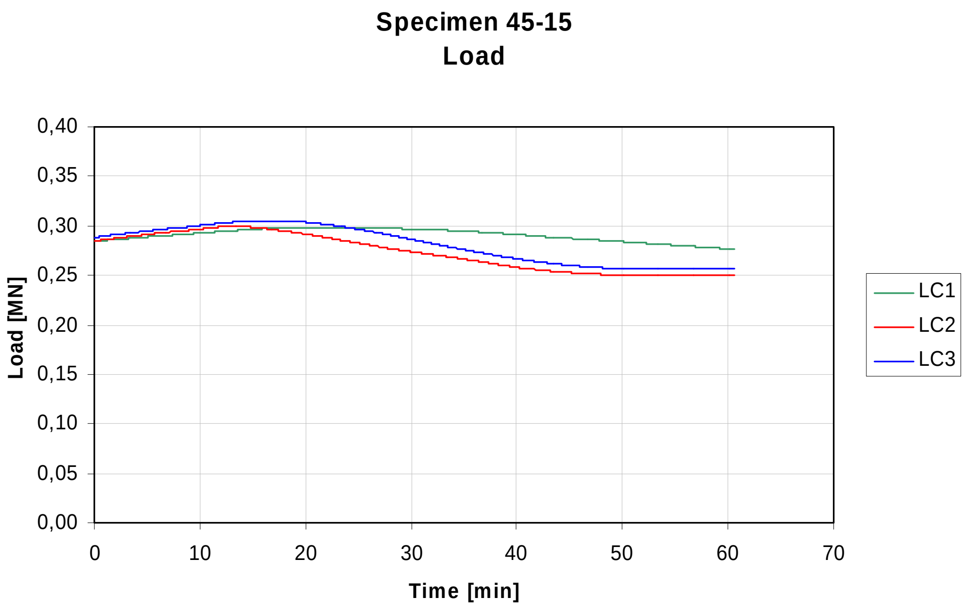


Figure A.524 Load measurements on specimen 45-15.

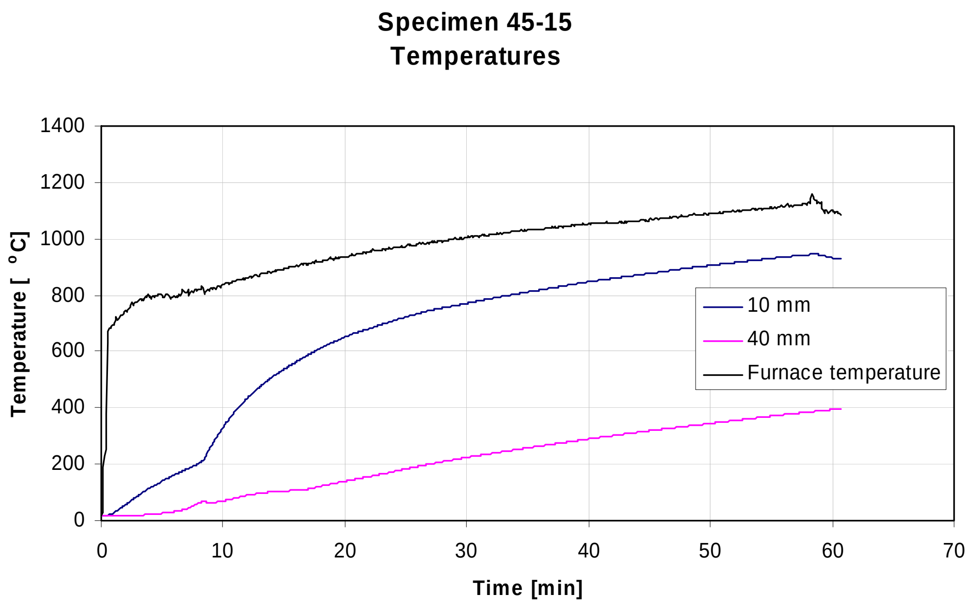


Figure A.525 Measured temperatures in furnace and in specimen 45-15.

Table A.285 Spalling measurements on specimen 45-15.

Position	0	100	200	300	400	500
0	0	0	0	2	1	0
100	0	4	8	10	6	0
200	0	7	10	9	2	0
300	0	2	6	13	2	0
400	0	1	5	1	1	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	2
Mean inner	4
Max in diagram	13
Max measured	18

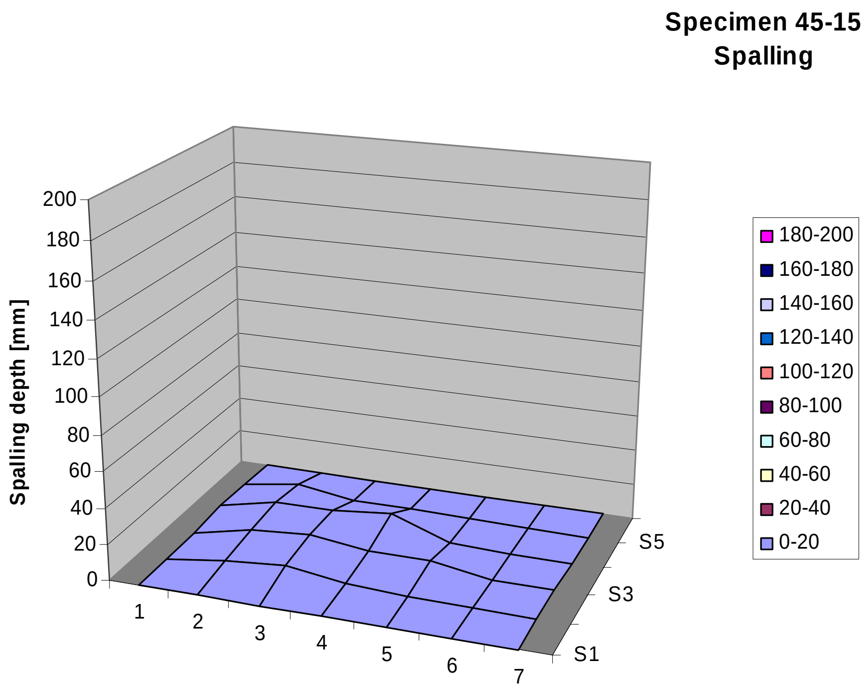


Figure A.526 Spalling measurements on specimen 45-15.

Table A.286 Observations made on specimen 45-15.

Time	Observation
0,00	Start of test
4,60	One small explosion
5,58	One explosion
6,20	One small explosion
7,12	One explosion
7,92	One small explosion
8,33	One small explosion
20,00	Cracks and water on sides
60,67	Test terminated

Test date:	2007-11-30	
Specimen:	45-15	
Load level:	286	kN/bar
Weight loss:	2,2	kg

Figure A.527 Specimen 45-15 after test.

Specimen 45-16

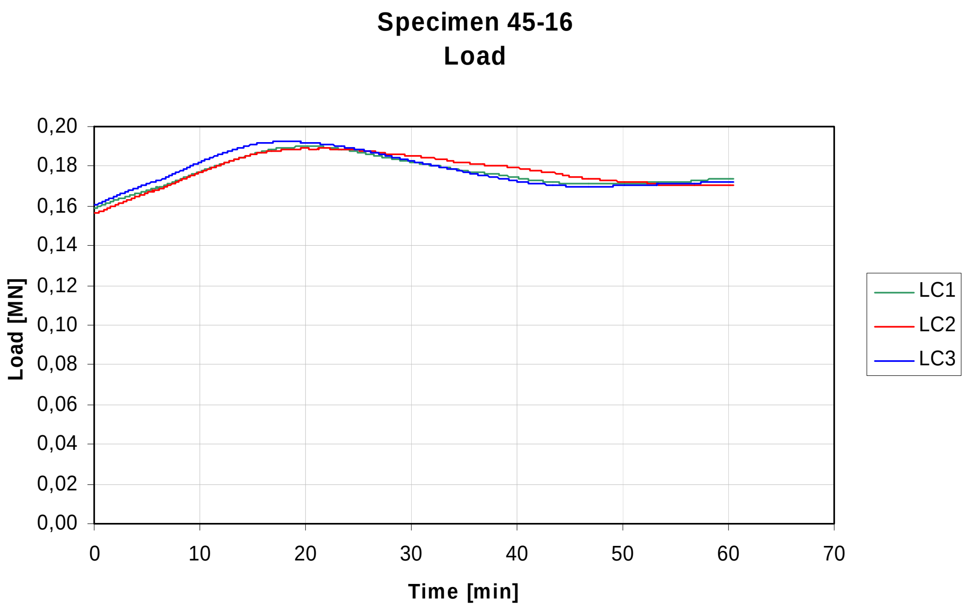


Figure A.528 Load measurements on specimen 45-16.

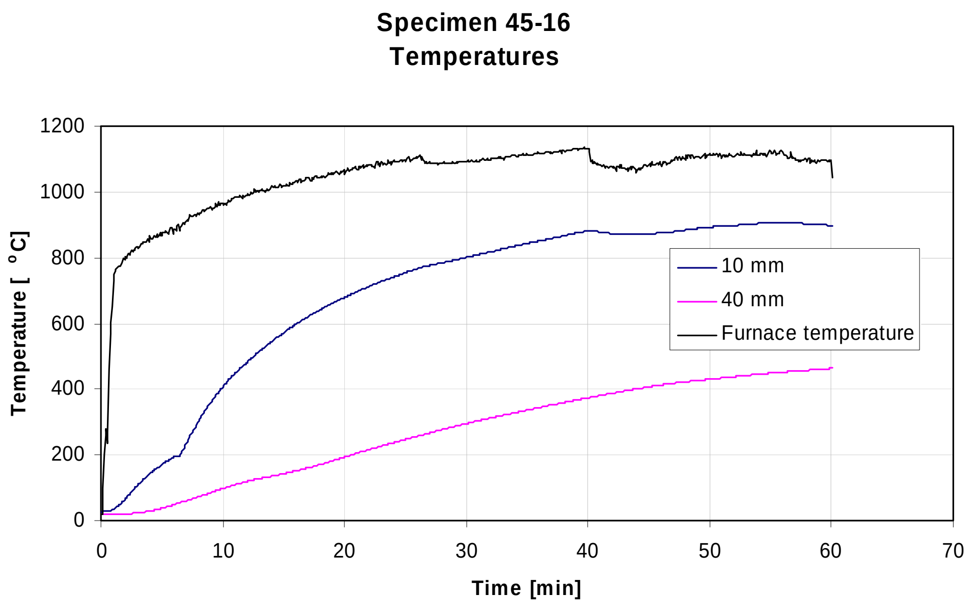


Figure A.529 Measured temperatures in furnace and in specimen 45-16.

Table A.287 Spalling measurements on specimen 45-16.

Position	0	100	200	300	400	500
0	0	0	0	0	0	3
100	0	0	0	3	1	0
200	0	3	1	3	3	0
300	0	6	10	9	10	0
400	0	5	13	10	10	0
500	0	3	7	6	0	0
600	0	0	0	0	0	0

Mean all	2
Mean inner	5
Max in diagram	13
Max measured	14

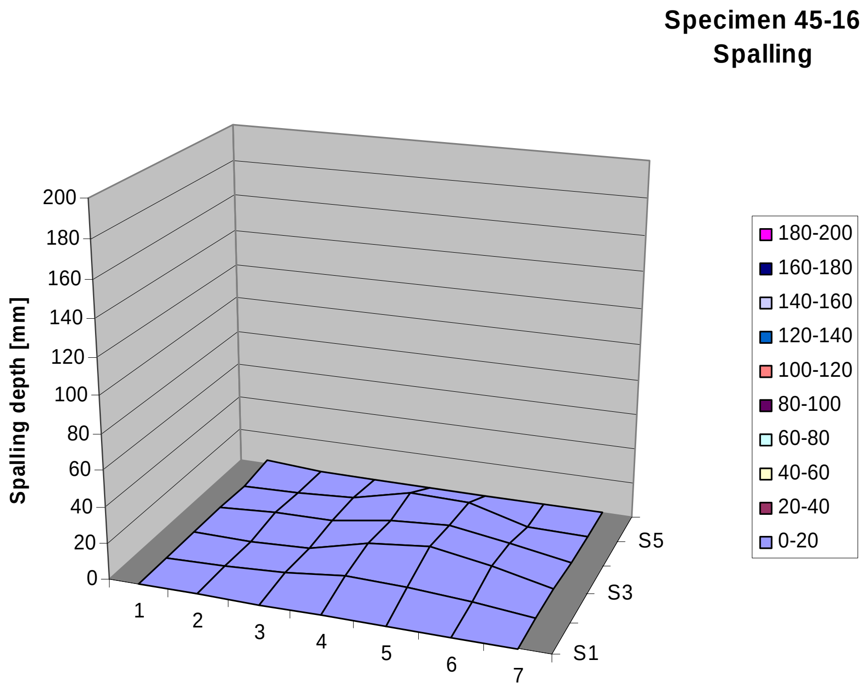


Figure A.530 Spalling measurements on specimen 45-16.

Table A.288 Observations made on specimen 45-16.

Time	Observation
0,00	Start of test
3,00	Several small explosions
4,00	Several small explosions
7,00	Spalling stopped
20,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-11-29	
Specimen:	45-16	
Load level:	159	kN/bar
Weight loss:	7,0	kg

Figure A.531 Specimen 45-16 after test.

Specimen 45-17

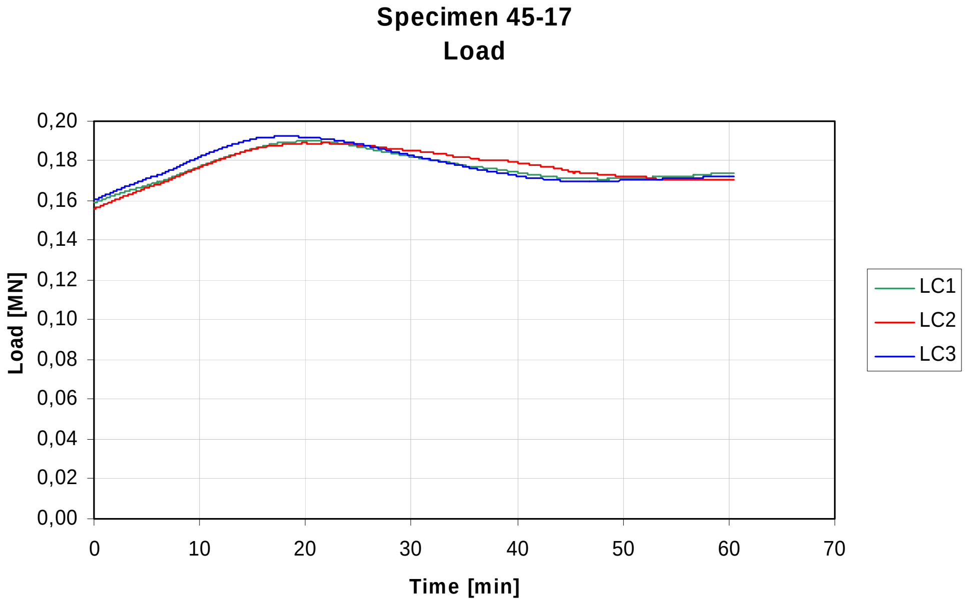


Figure A.532 Load measurements on specimen 45-17.

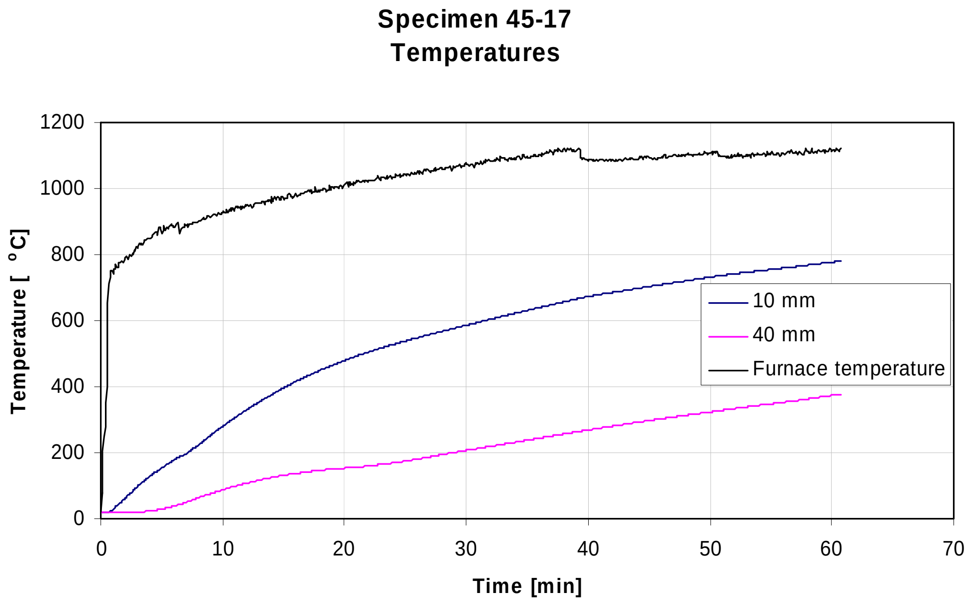


Figure A.533 Measured temperatures in furnace and in specimen 45-17.

Table A.289 Spalling measurements on specimen 45-17.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	3	0	0
200	0	0	0	3	0	0
300	0	0	1	3	1	0
400	0	0	1	9	9	0
500	0	0	0	3	0	0
600	0	0	0	0	0	0

Mean all	1
Mean inner	2
Max in diagram	9
Max measured	11

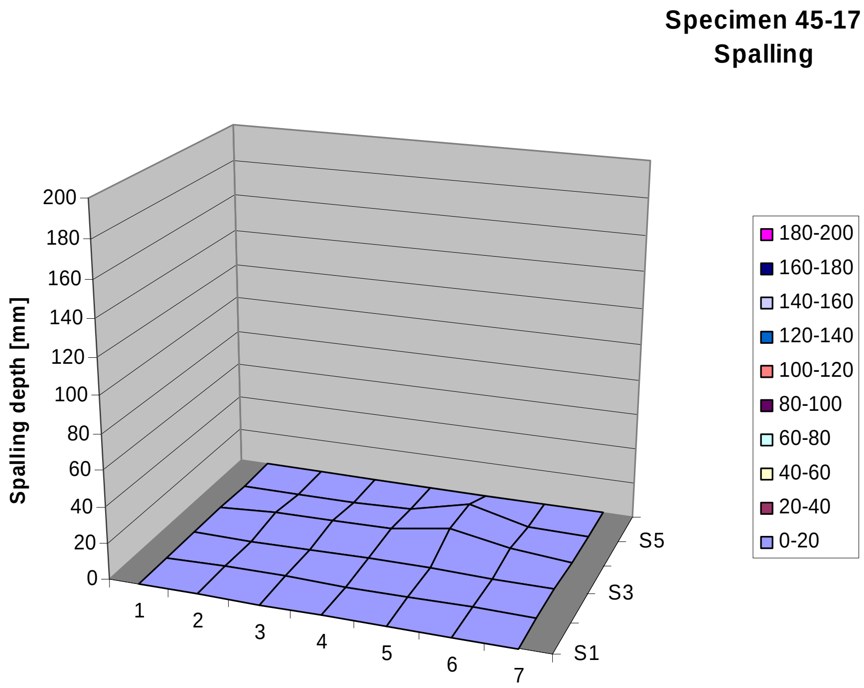


Figure A.534 Spalling measurements on specimen 45-17.

Table A.290 Observations made on specimen 45-17.

Time	Observation
0,00	Start of test
3,37	One small explosion
6,00	One small explosion
6,38	One explosion
20,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-11-29	
Specimen:	45-17	
Load level:	292	kN/bar
Weight loss:	5,5	kg

Figure A.535 Specimen 45-17 after test.

Specimen 45-18

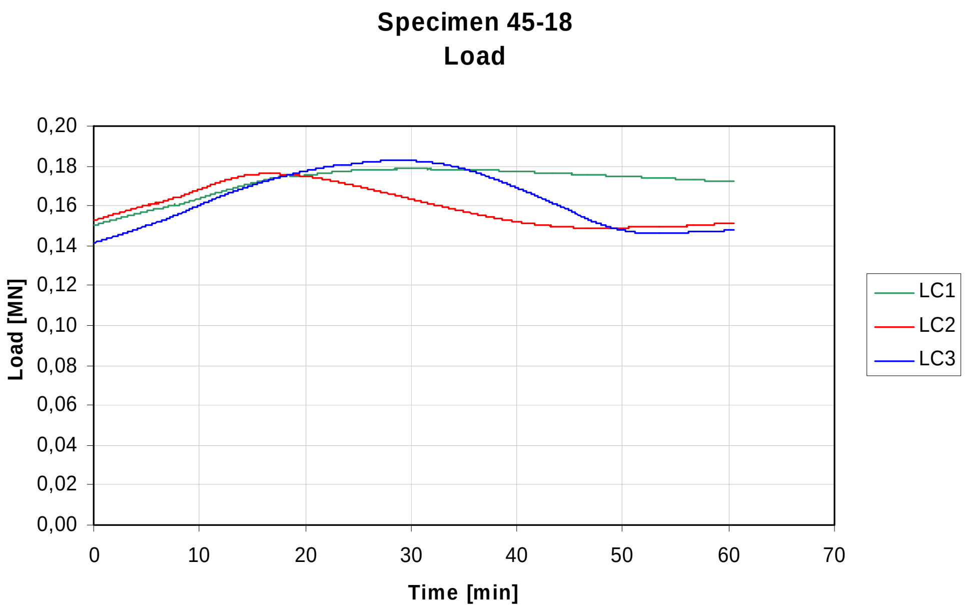


Figure A.536 Load measurements on specimen 45-18.

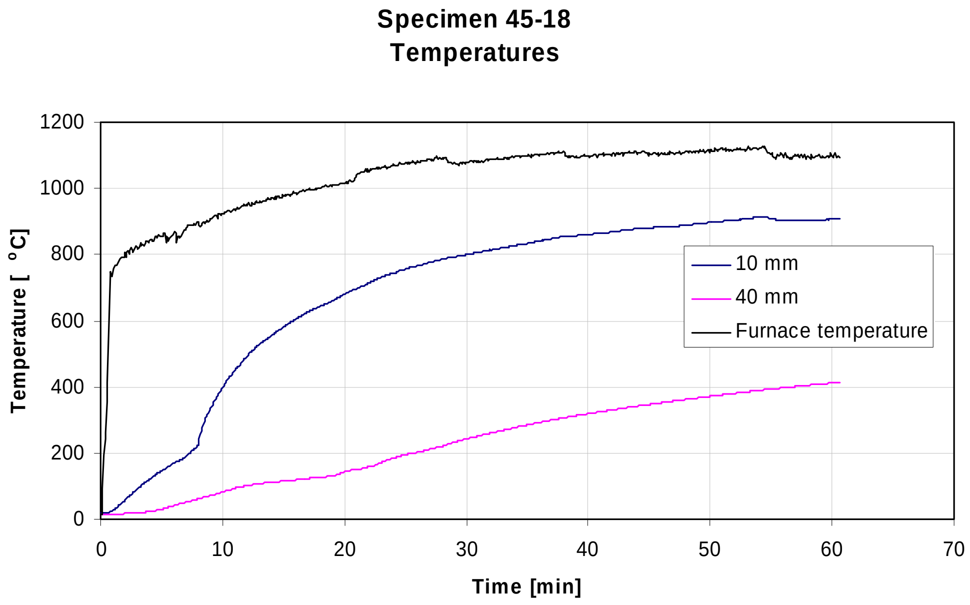


Figure A.537 Measured temperatures in furnace and in specimen 45-18.

Table A.291 Spalling measurements on specimen 45-18.

Position	0	100	200	300	400	500
0	0	0	1	0	0	0
100	0	2	11	3	3	0
200	0	4	6	10	4	0
300	0	2	13	2	1	0
400	0	5	6	5	2	0
500	0	3	5	8	7	0
600	0	0	0	0	0	0

Mean all	2
Mean inner	5
Max in diagram	13
Max measured	14

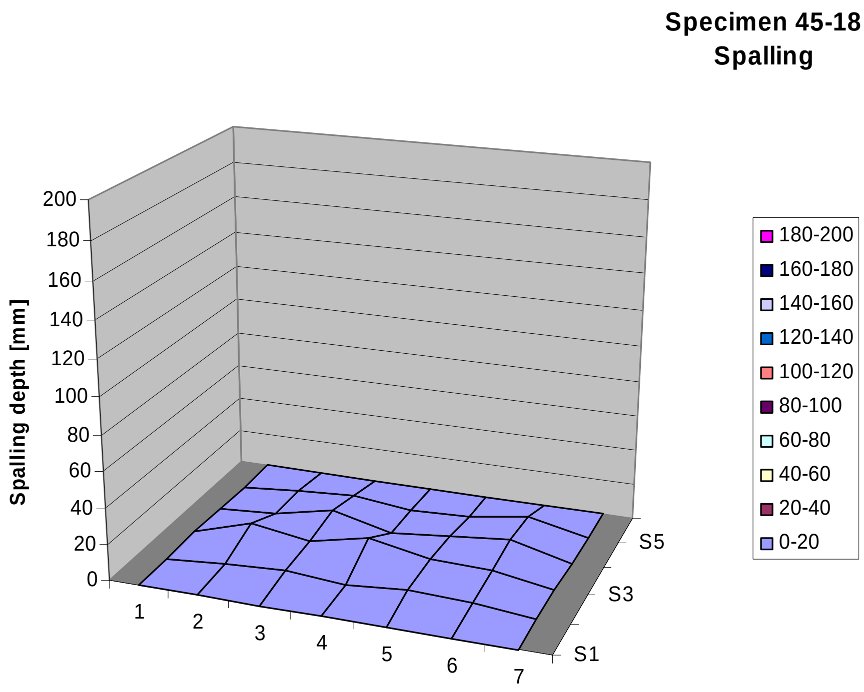


Figure A.538 Spalling measurements on specimen 45-18.

Table A.292 Observations made on specimen 45-18.

Time	Observation
0,00	Start of test
3,47	One small explosion
3,87	One small explosion
4,08	One small explosion
4,48	One small explosion
5,28	One explosion
5,53	Two small explosions
6,13	One small explosion
20,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-11-28	
Specimen:	45-18	
Load level:	148	kN/bar
Weight loss:	5,4	kg

Figure A.539 Specimen 45-18 after test.

Specimen 45-21

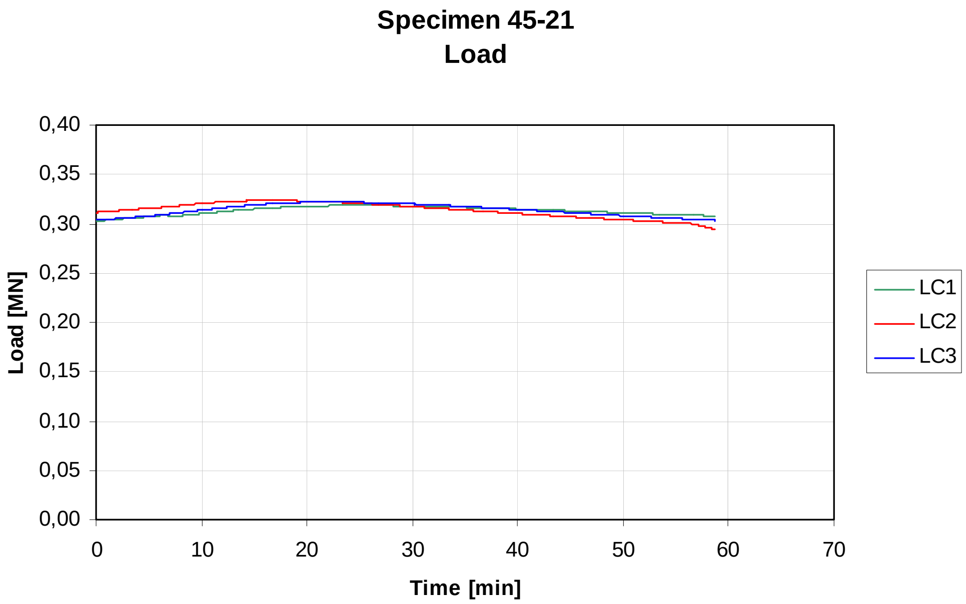


Figure A.540 Load measurements on specimen 45-21.

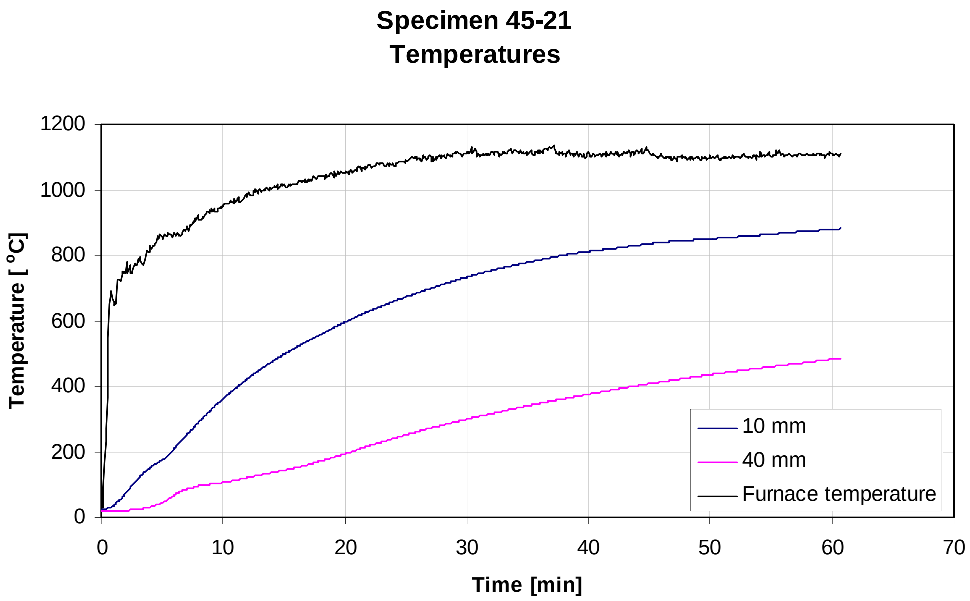


Figure A.541 Measured temperatures in furnace and in specimen 45-21.

Table A.293 Spalling measurements on specimen 45-21.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	3	6	4	1	0
200	0	12	18	8	9	0
300	0	10	10	6	11	0
400	0	14	13	6	10	0
500	0	4	2	0	0	0
600	0	0	0	0	0	0

Mean all	4
Mean inner	7
Max in diagram	18
Max measured	23

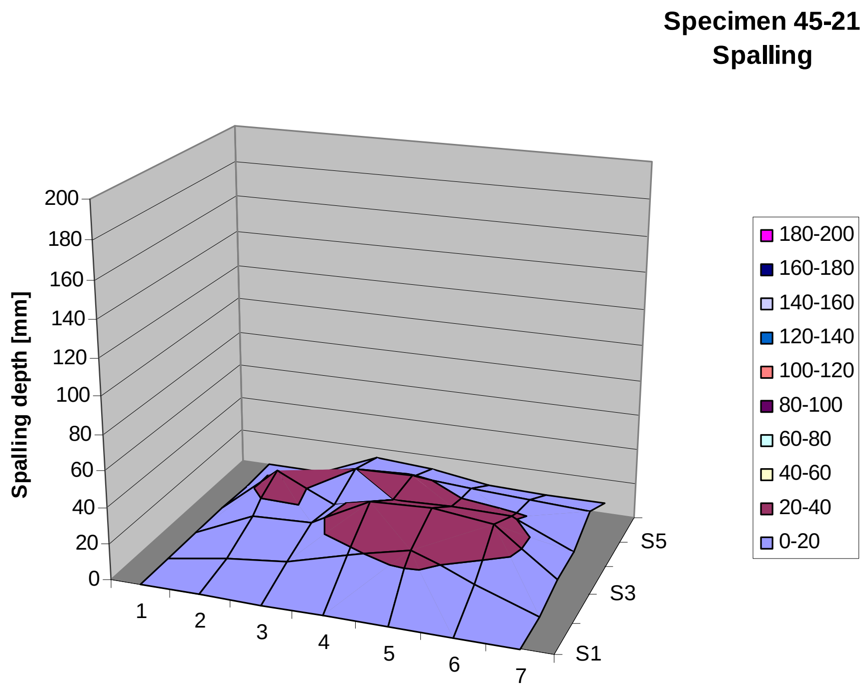


Figure A.542 Spalling measurements on specimen 45-21.

Table A.294 Observations made on specimen 45-21.

Time	Observation
0,00	Start of test
2,00	Repeated small explosions
2,17	Load measurement starts
7,00	Spalling stops
10,00	Cracks and water on front and back sides
60,00	Test terminates

Test date:	2007-09-04	
Specimen:	45-21	
Load level:	306	kN/bar
Weight loss:	4,4	kg

Figure A.543 Specimen 45-21 after test.

Specimen 45-22

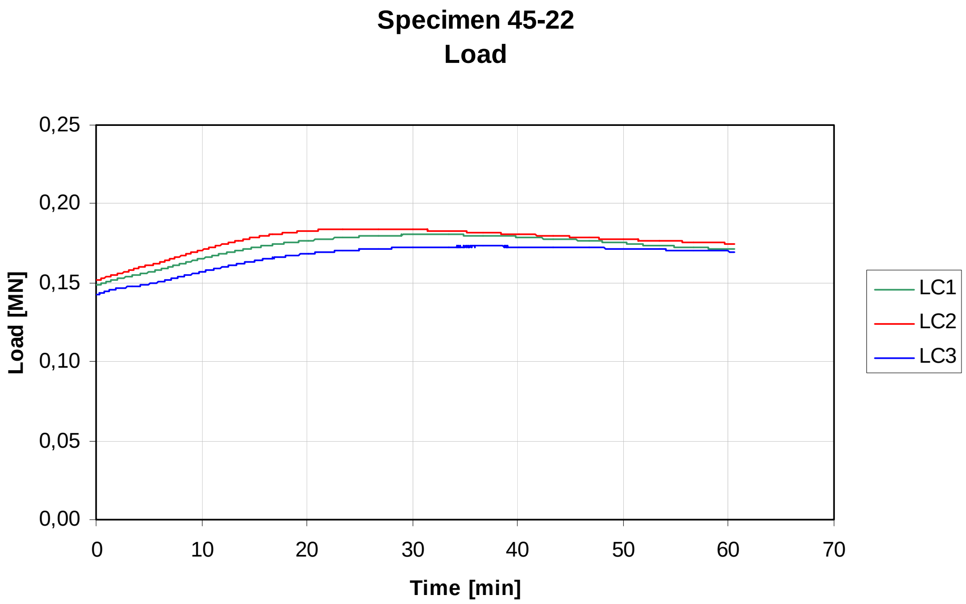


Figure A.544 Load measurements on specimen 45-22.

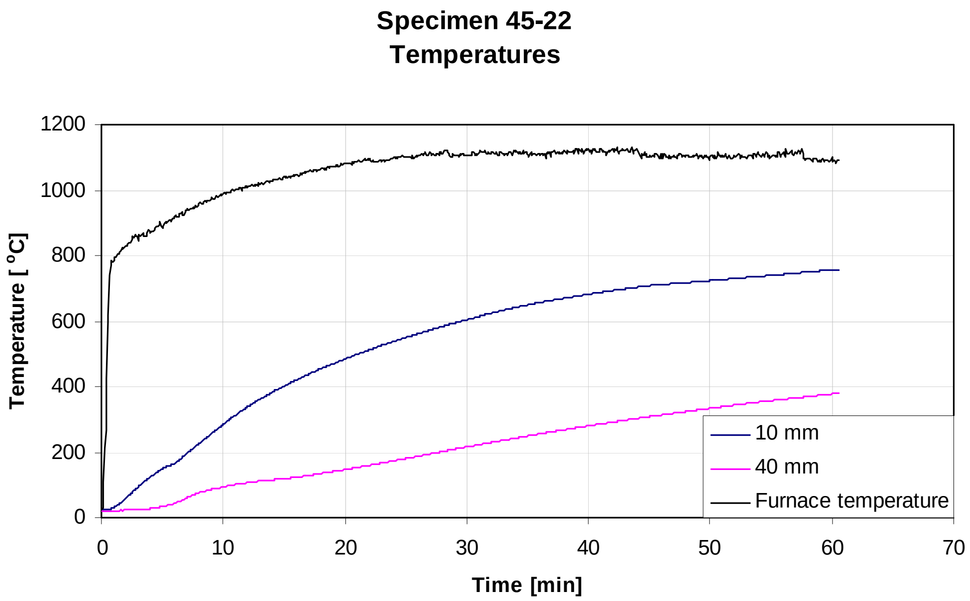


Figure A.545 Measured temperatures in furnace and in specimen 45-22.

Table A.295 Spalling measurements on specimen 45-22.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	4	1	0
200	0	0	1	2	4	0
300	0	2	5	2	2	0
400	0	5	8	3	5	0
500	0	3	4	2	1	0
600	0	0	0	0	0	0

Mean all	1
Mean inner	3
Max in diagram	8
Max measured	16

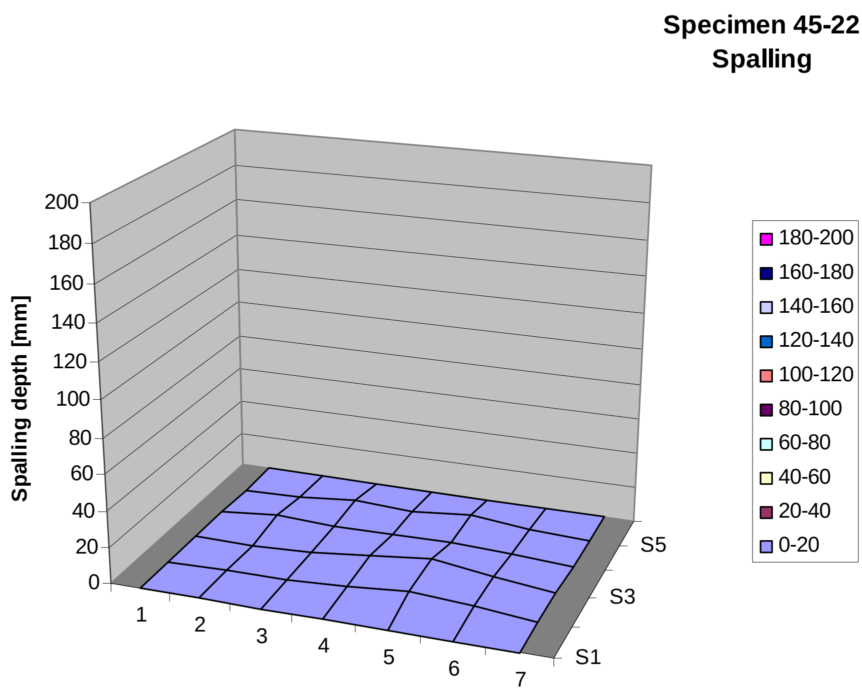


Figure A.546 Spalling measurements on specimen 45-22.

Table A.296 Observations made on specimen 45-22.

Time	Observation
0,00	Start of test
3,00	Repeated small explosions
4,92	One explosion
7,00	Spalling stops
8,00	Water on unexposed surface
11,00	Cracks and water on sides
60,00	Test terminates

Test date:	2007-09-03	
Specimen:	45-22	
Load level:	148	kN/bar
Weight loss:	4,3	kg

Figure A.547 Specimen 45-22 after test.

Specimen 45-23

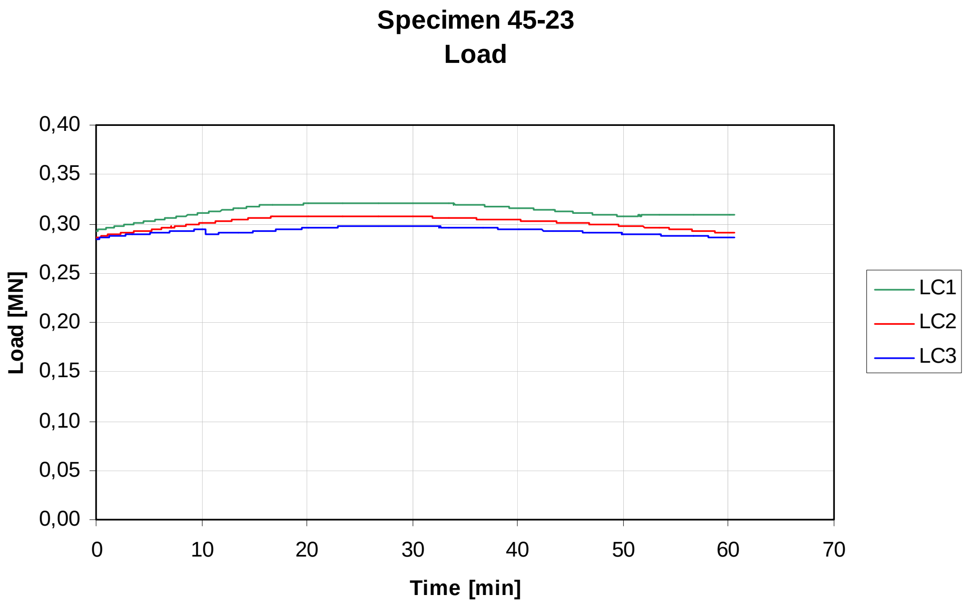


Figure A.548 Load measurements on specimen 45-23.

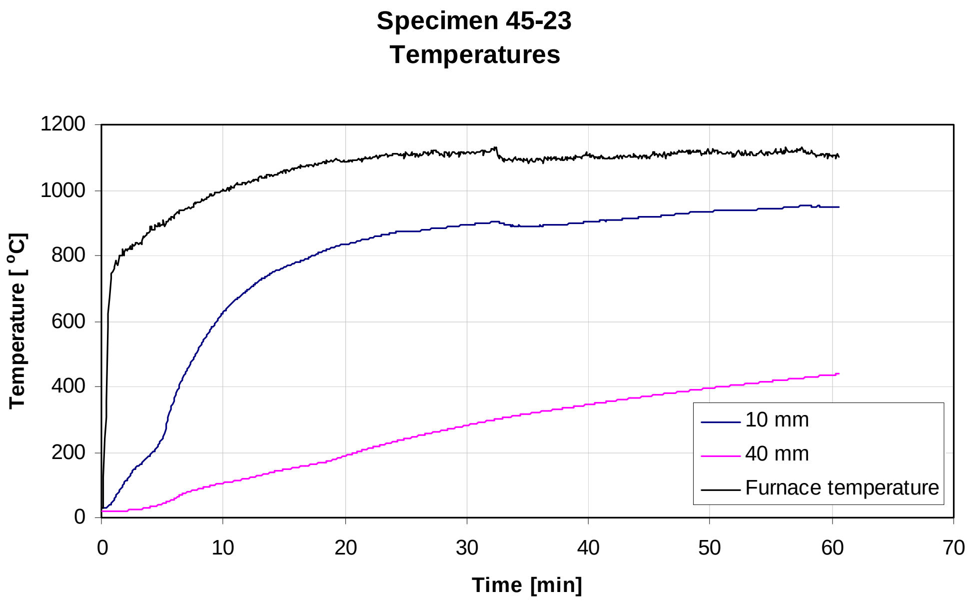


Figure A.549 Measured temperatures in furnace and in specimen 45-23.

Table A.297 Spalling measurements on specimen 45-23.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	9	7	2	0
200	0	6	8	14	7	0
300	0	12	13	6	2	0
400	0	13	15	2	5	0
500	0	16	22	4	3	0
600	0	0	0	0	0	0

Mean all	4
Mean inner	8
Max in diagram	22
Max measured	26

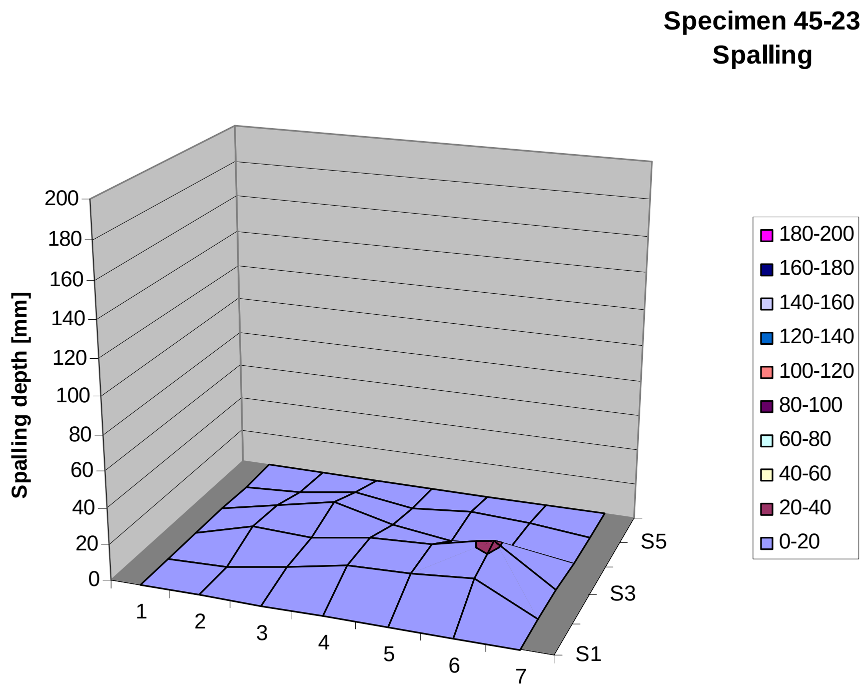


Figure A.550 Spalling measurements on specimen 45-23.

Table A.298 Observations made on specimen 45-23.

Time	Observation
0,00	Start of test
1,67	One small explosion
2,00	One small explosion
2,17	Two small explosions
2,83	Two small explosions
3,42	One explosion
4,17	Three small explosions
4,83	One explosion
6,50	One small explosion
6,50	Spalling stops
7,00	Water on back side
60,00	Test terminates

Test date:	2007-09-04	
Specimen:	45-23	
Load level:	288	kN/bar
Weight loss:	5,4	kg

Figure A.551 Specimen 45-23 after test.

Specimen 45-24

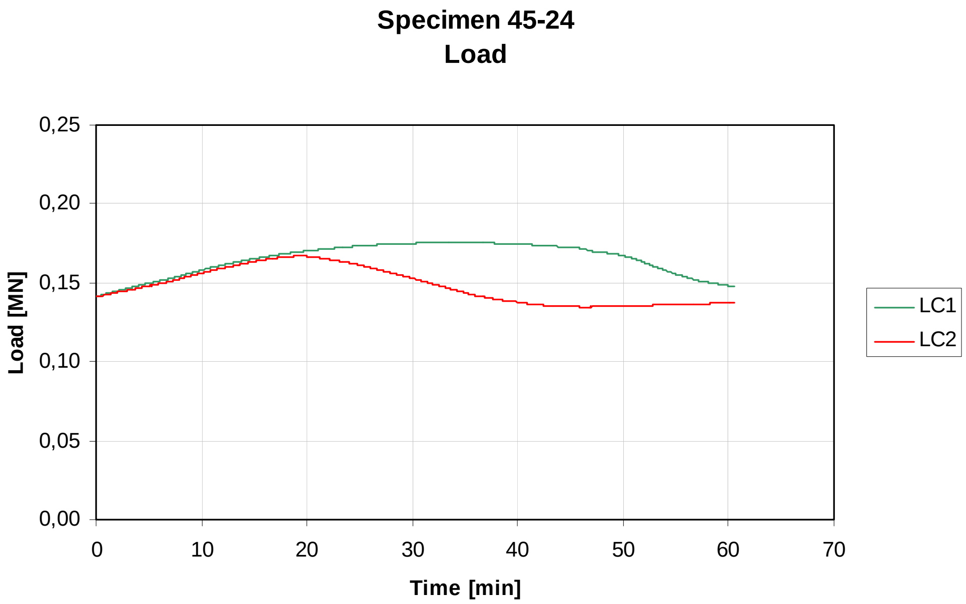


Figure A.552 Load measurements on specimen 45-24.

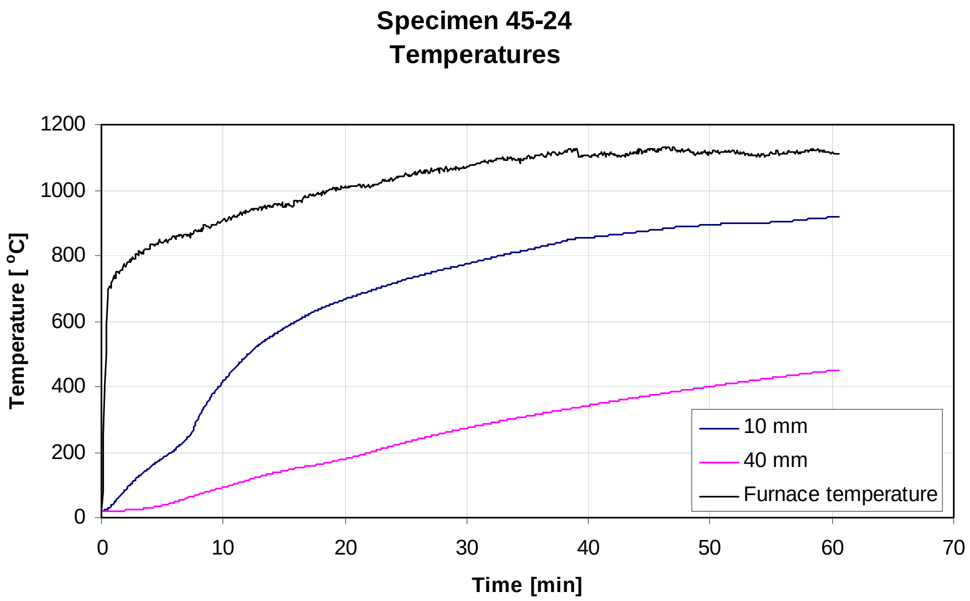


Figure A.553 Measured temperatures in furnace and in specimen 45-24.

Table A.299 Spalling measurements on specimen 45-24.

Position	0	100	200	300	400	500
0	0	0	1	0	0	0
100	0	1	10	9	0	0
200	0	2	14	13	0	0
300	0	3	5	14	2	0
400	0	1	2	12	3	0
500	0	0	0	4	2	0
600	0	0	0	0	0	0

Mean all	2
Mean inner	5
Max in diagram	14
Max measured	19

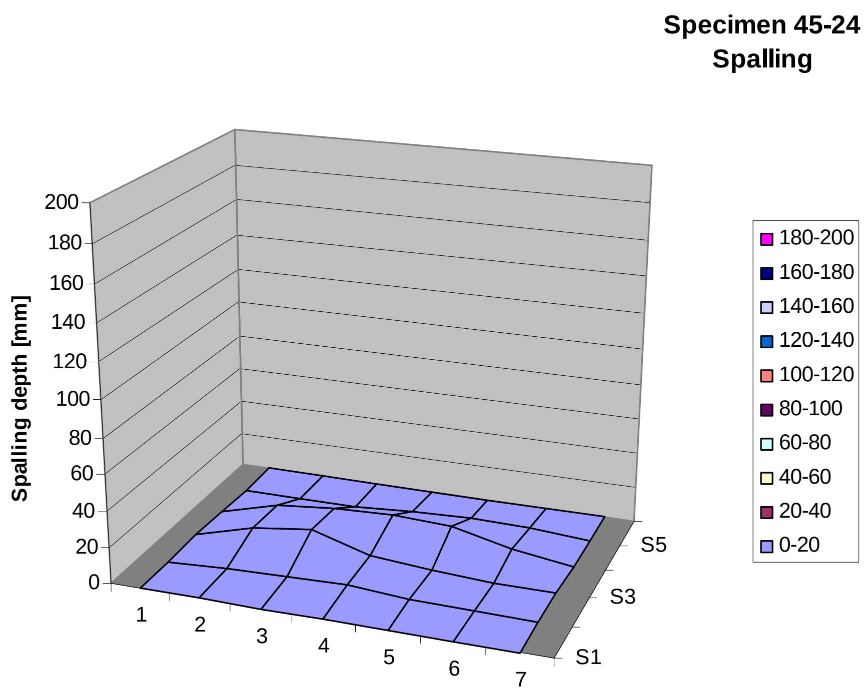


Figure A.554 Spalling measurements on specimen 45-24.

Table A.300 Observations made on specimen 45-24.

Time	Observation
0,00	Start of test
2,17	One small explosion
2,83	Two small explosions
3,17	One small explosion
3,33	One small explosion
4,83	Two small explosions
6,33	Two small explosions
7,00	Spalling stops
15,00	Cracks and water on sides
60,00	Test terminates

Test date:	2007-09-04	
Specimen:	45-24	
Load level:	94	kN/bar
Weight loss:	4,1	kg

Figure A.555 Specimen 45-24 after test.

Concrete 46

Table A.301 Concrete admixture recipe 46.

Recipe	**46**
Water (kg/m^3)	198
CEM II 42,5R A-LL (kg/m^3)	380
Limestone filler, Limus 25 (kg/m^3)	120
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	5,5
Sikament 20HE 50 (% of cement weight)	1,45
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	640
T50 (s)	3
Air (%)	3.4
Compressive strength, 28 days (MPa)	46.9

Specimen 46-9

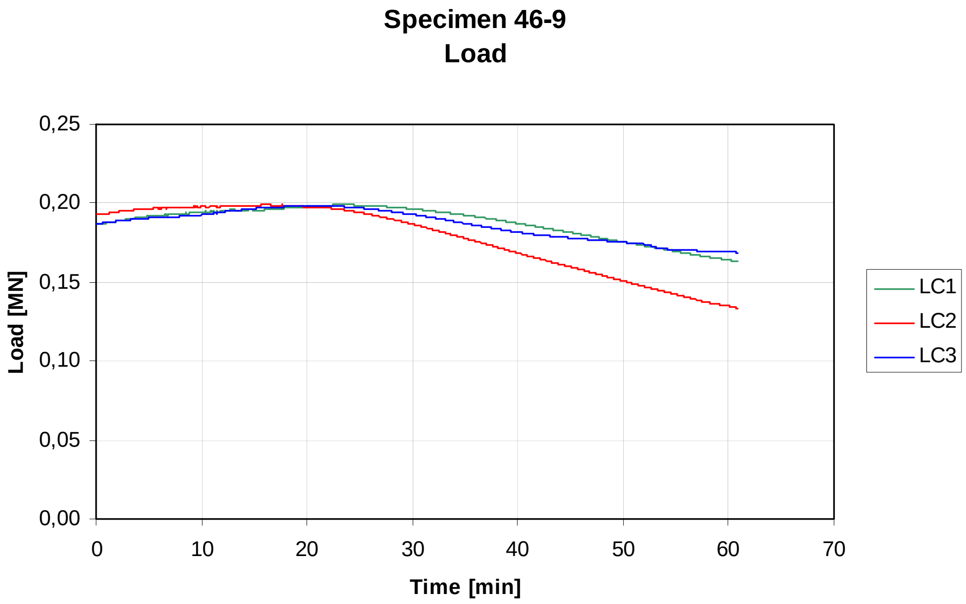


Figure A.556 Load measurements on specimen 46-9.

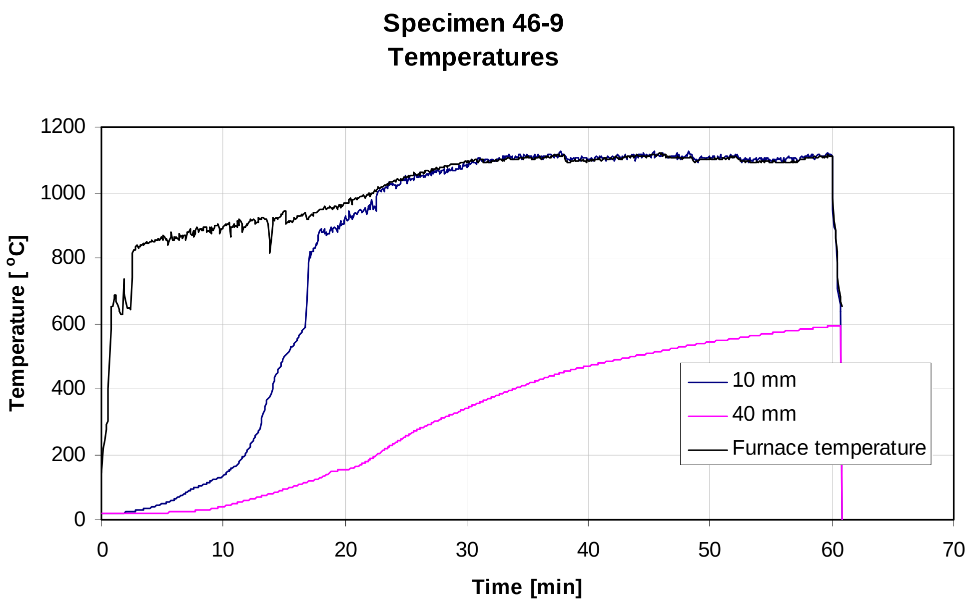


Figure A.557 Measured temperatures in furnace and in specimen 46-9.

Table A.302 Spalling measurements on specimen 46-9.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	13	22	18	16	10	0
200	15	21	27	27	25	3
300	11	32	39	37	22	4
400	8	46	54	35	29	2
500	13	28	34	31	22	3
600	0	3	5	1	4	0

Mean all	16
Mean inner	29
Max in diagram	54
Max measured	58

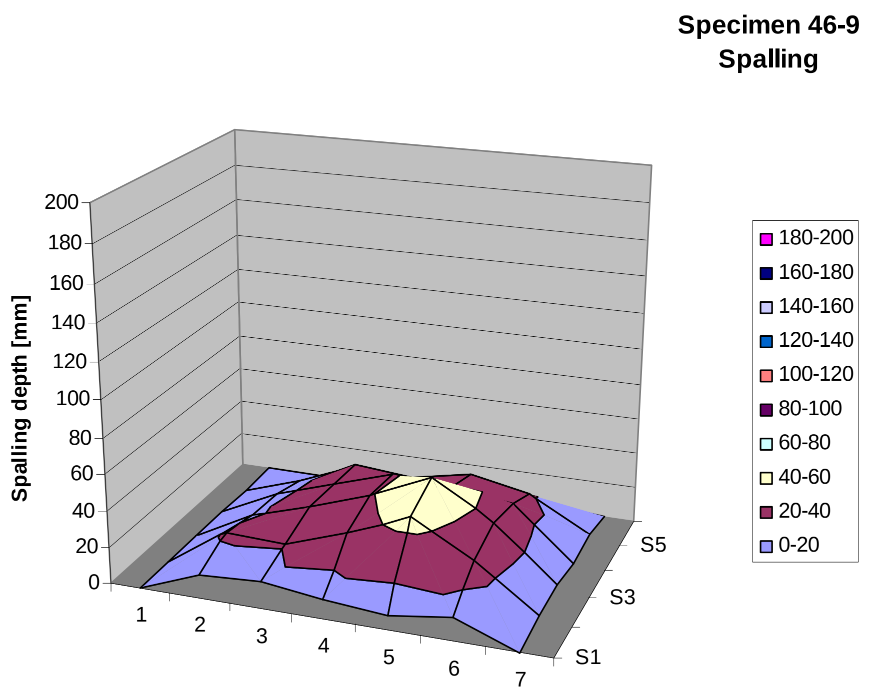


Figure A.558 Spalling measurements on specimen 46-9.

Table A.303 Observations made on specimen 46-9.

Time	Observation
0,00	Start of test
4,00	One explosion
4,17	One explosion
4,33	Several small explosions
4,50	Loud explosion
4,83	Repeated small explosions
15,83	Spalling stops
60,00	Test terminates

Test date:	2007-07-09	
Specimen:	46-9	
Load level:	189	kN/bar
Weight loss:	16,5	kg

Specimen 46-10

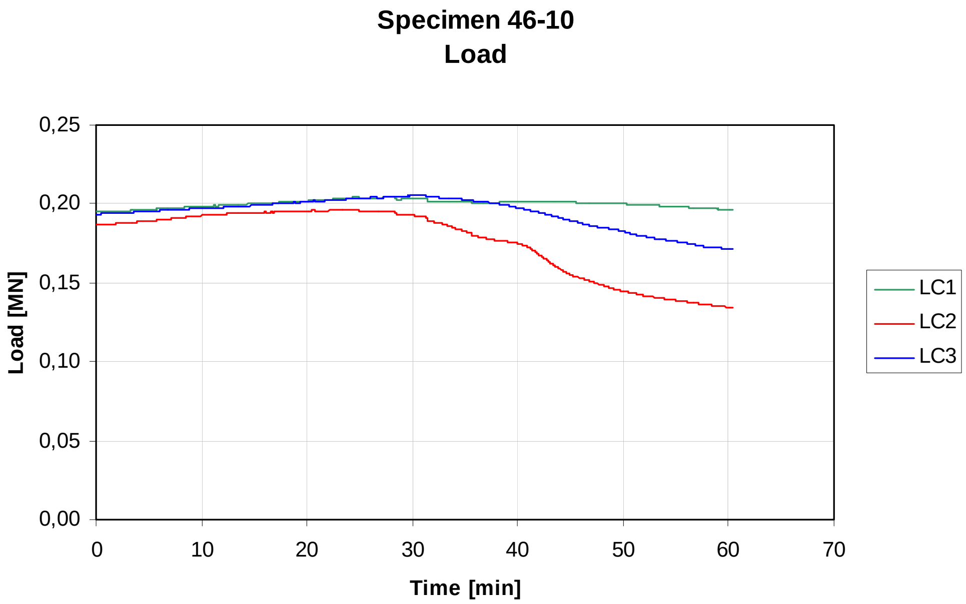


Figure A.559 Load measurements on specimen 46-10.

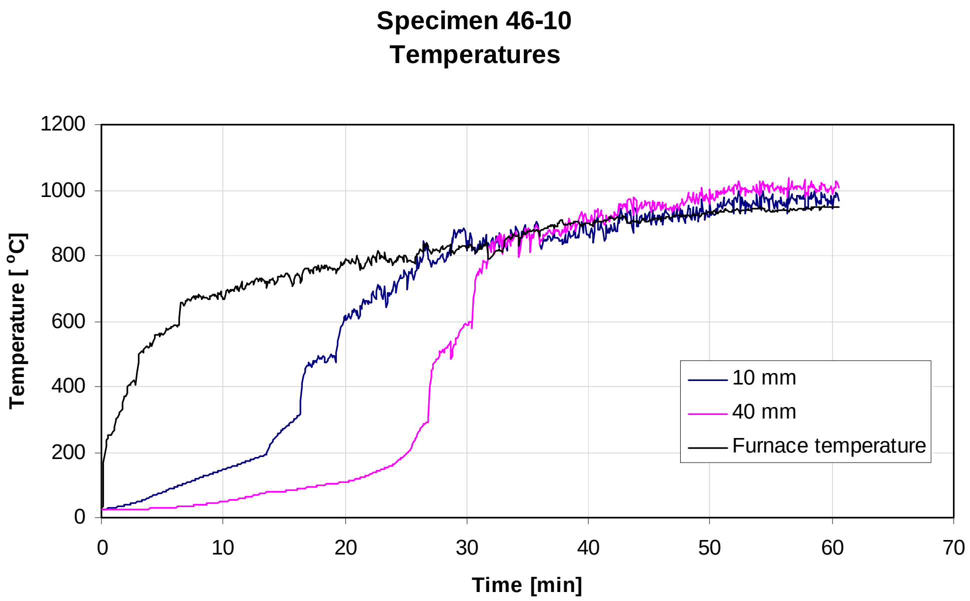


Figure A.560 Measured temperatures in furnace and in specimen 46-10.

Table A.304 Spalling measurements on specimen 46-10.

Position	0	100	200	300	400	500
0	0	1	10	13	3	2
100	0	2	45	38	20	4
200	1	27	54	54	44	6
300	1	43	58	61	41	9
400	3	40	57	61	47	17
500	1	16	41	53	41	5
600	1	1	2	0	0	1

Mean all	22
Mean inner	42
Max in diagram	61
Max measured	67

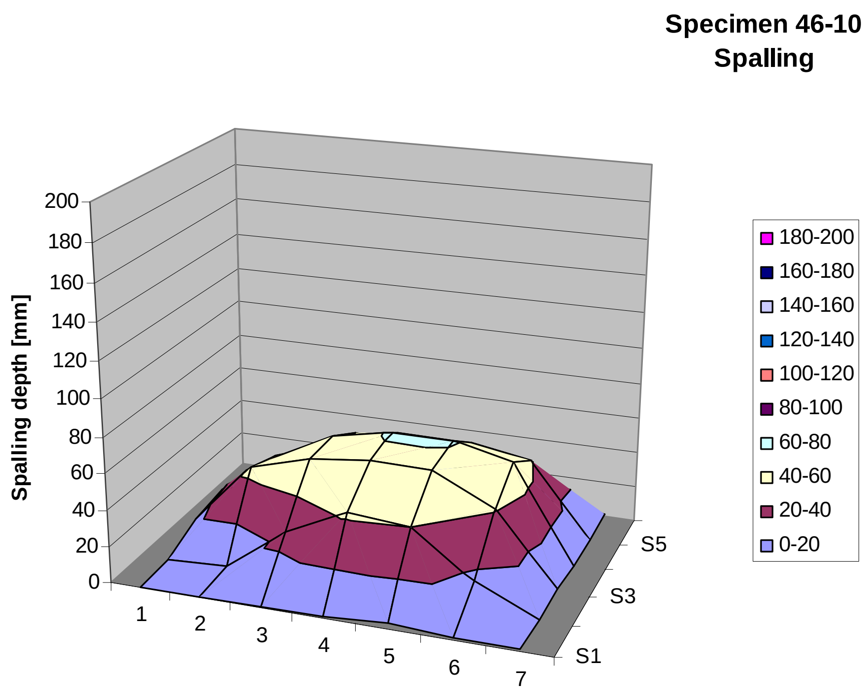


Figure A.561 Spalling measurements on specimen 46-10.

Table A.305 Observations made on specimen 46-10.

Time	Observation
0,00	Start of test
9,50	One small explosion
9,83	One small explosion
10,42	One small explosion
10,67	One small explosion
11,25	Two small explosions
11,67	Repeated small explosion
25,25	Loud explosion
30,00	Crack and water on front side
37,00	Spalling stops
60,00	Test terminates

Test date:	2007-06-21	
Specimen:	46-10	
Load level:	192	kN/bar
Weight loss:	19,2	kg

Figure A.562 Specimen 46-10 after test.

Specimen 46-11

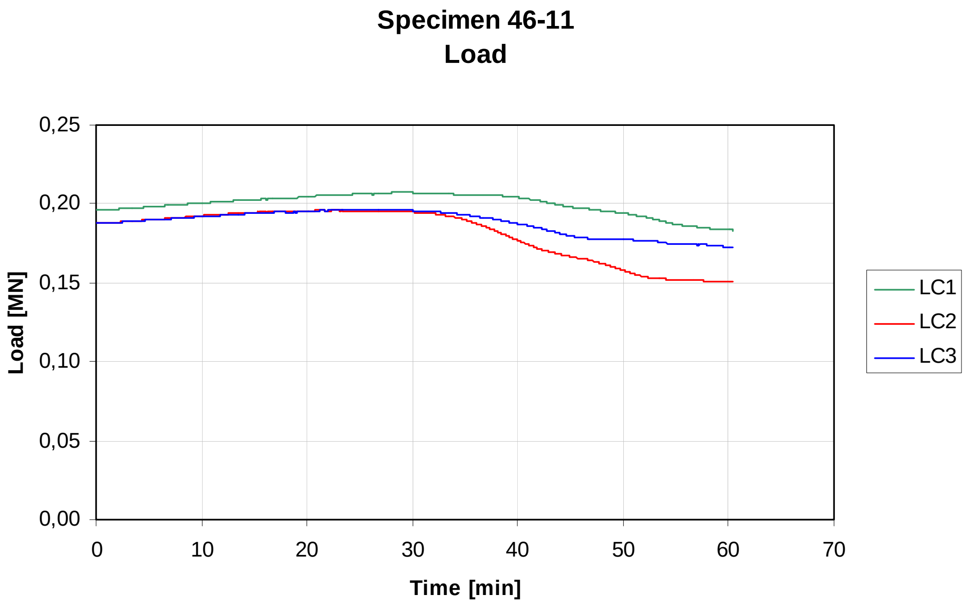


Figure A.563 Load measurements on specimen 46-11.

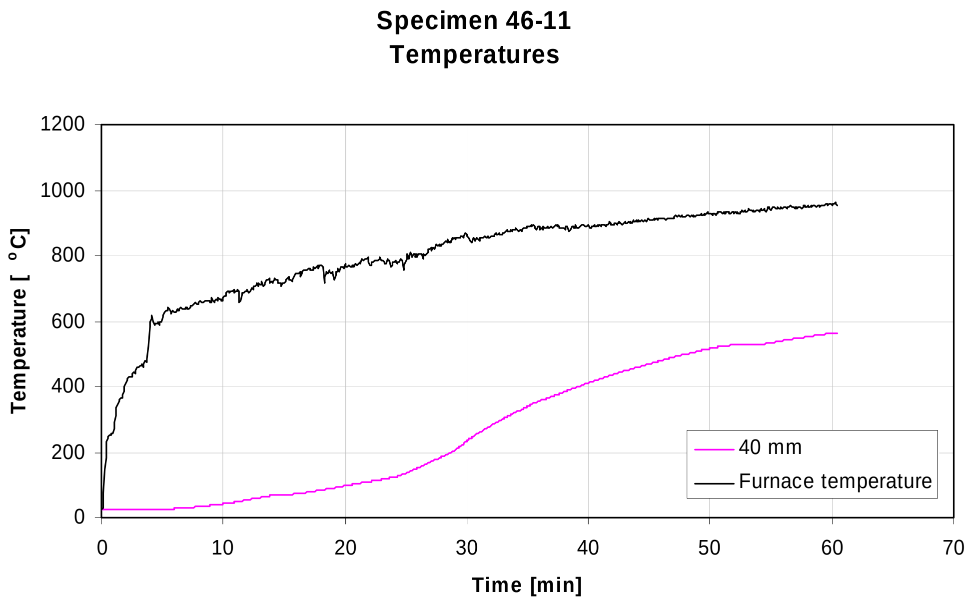


Figure A.564 Measured temperatures in furnace and in specimen 46-11.

Table A.306 Spalling measurements on specimen 46-11.

Position	0	100	200	300	400	500
0	0	4	0	7	6	0
100	2	14	7	24	21	13
200	2	25	37	36	24	14
300	0	29	35	29	27	6
400	5	29	37	29	29	7
500	0	25	18	17	20	0
600	0	3	0	0	0	0

Mean all	14
Mean inner	26
Max in diagram	37
Max measured	46

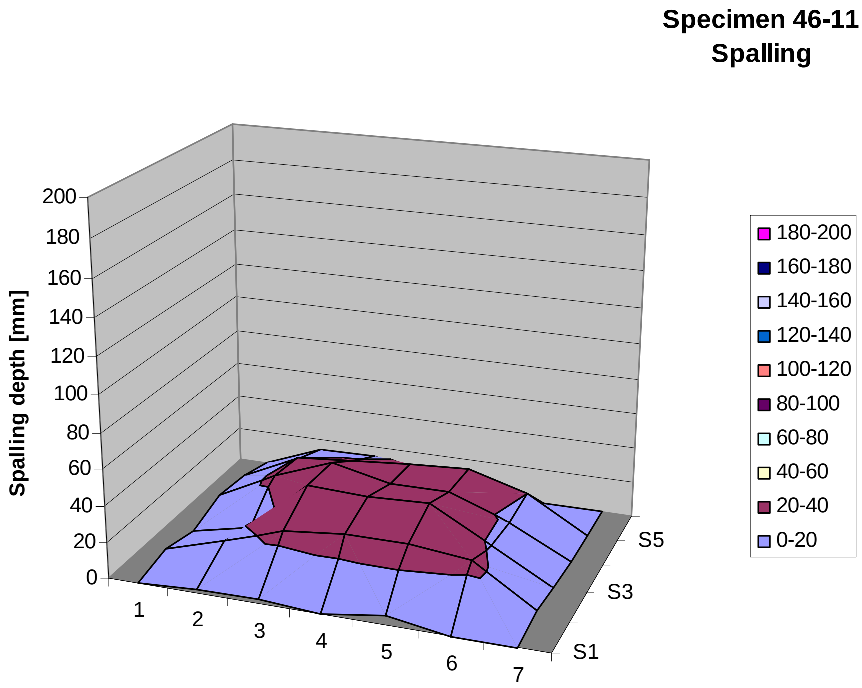


Figure A.565 Spalling measurements on specimen 46-11.

Table A.307 Observations made on specimen 46-11.

Time	Observation			
0,00	Start of test	Test date:	2007-06-25	
11,33	One loud explosion	Specimen:	46-11	
12,00	Two small explosions	Load level:	191	kN/bar
12,67	One small explosion	Weight loss:	13,3	kg
12,83	One small explosion			
13,00	One explosion			
13,33	Repeated small explosion			
32,00	Spalling stops			
60,00	Test terminates			

Specimen 46-12

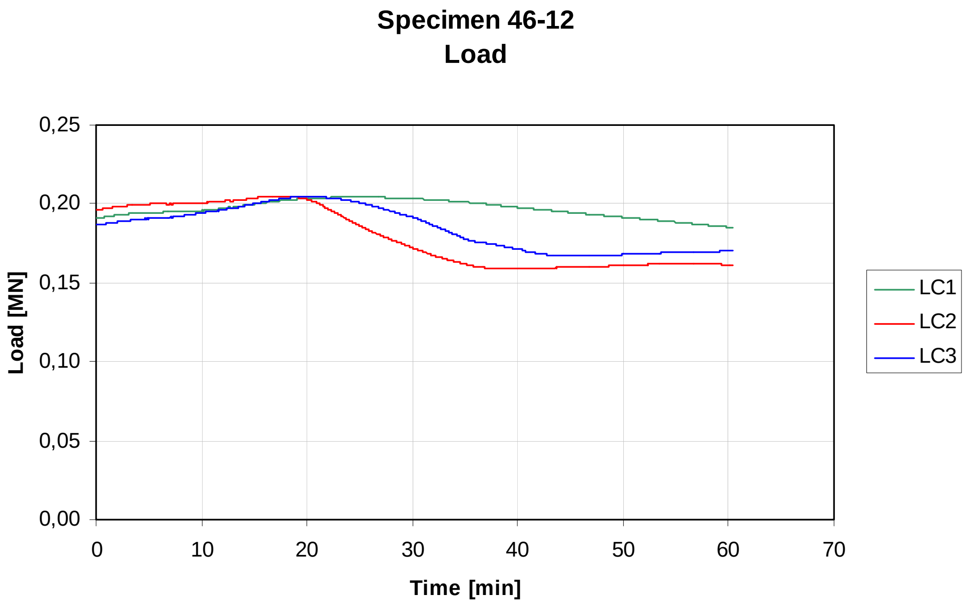


Figure A.566 Load measurements on specimen 46-12.

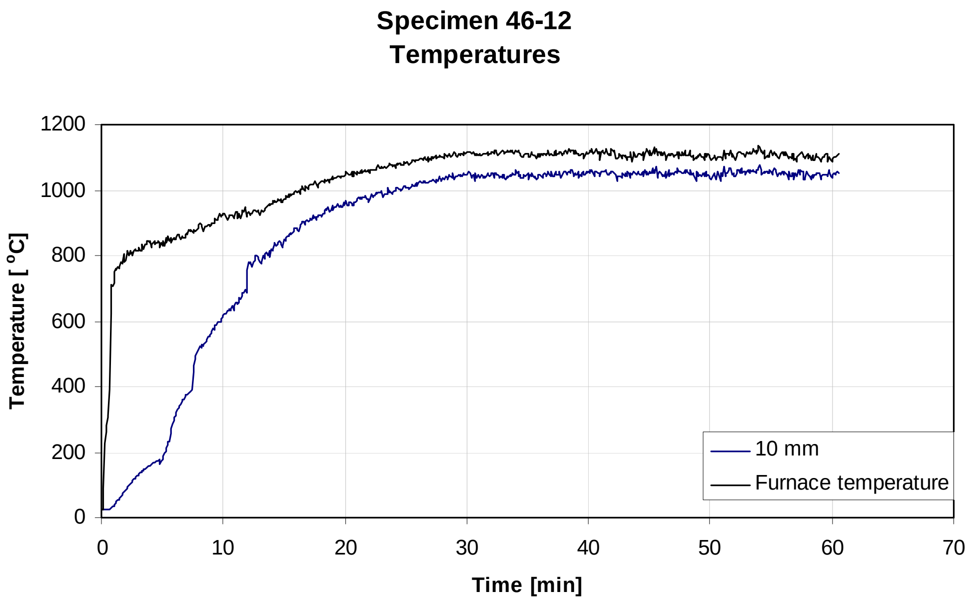


Figure A.567 Measured temperatures in furnace and in specimen 46-12.

Table A.308 Spalling measurements on specimen 46-12.

Position	0	100	200	300	400	500
0	0	1	1	1	1	0
100	0	13	7	21	21	0
200	0	30	10	38	38	0
300	0	20	24	29	29	1
400	3	24	26	37	37	0
500	1	18	22	30	30	0
600	0	0	0	0	0	0

Mean all	12
Mean inner	25
Max in diagram	38
Max measured	43

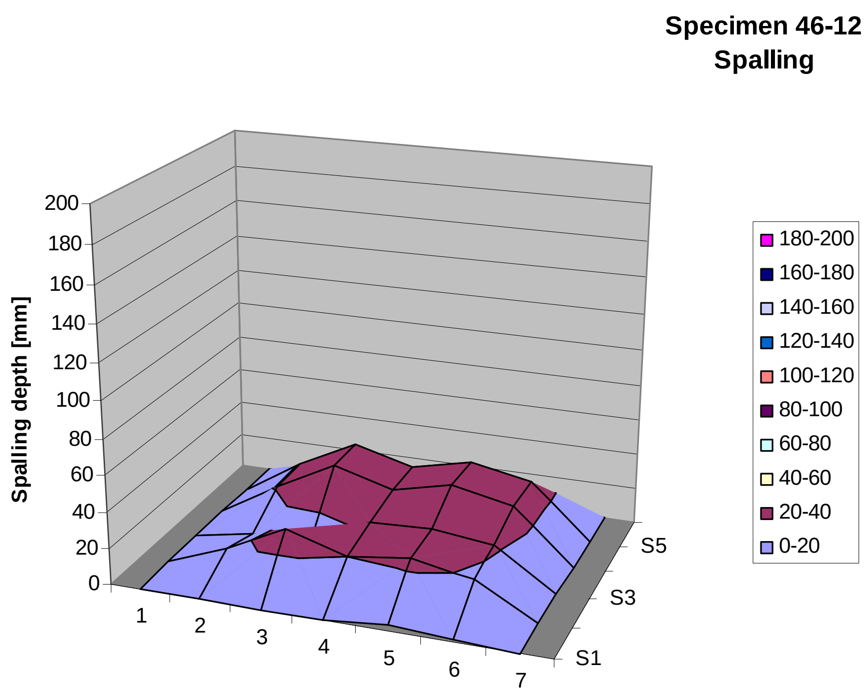


Figure A.568 Spalling measurements on specimen 46-12.

Table A.309 Observations made on specimen 46-12.

Time	Observation
0,00	Start of test
3,00	Two small explosions
3,25	One small explosion
3,50	Repeated small explosions
15,00	Spalling stops
20,00	Cracks and water on sides and unexposed surface
60,50	Test terminates

Test date:	2007-07-05	
Specimen:	46-12	
Load level:	191	kN/bar
Weight loss:	12,0	kg

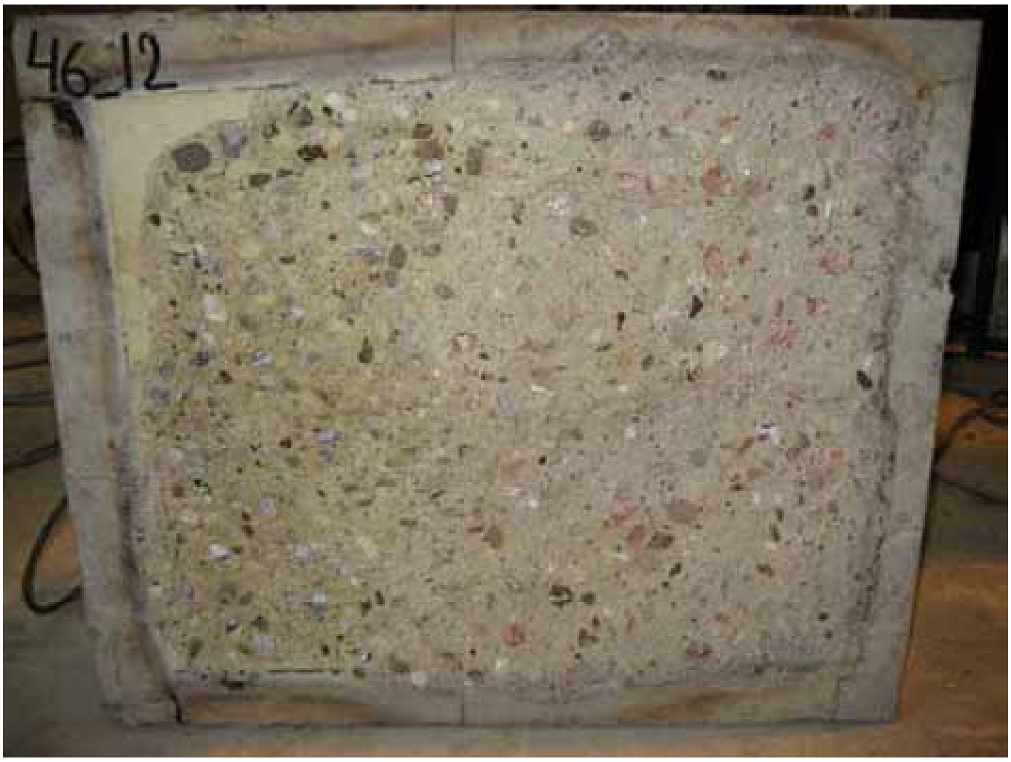


Figure A.569 Specimen 46-12 after test.

Specimen 46-13A

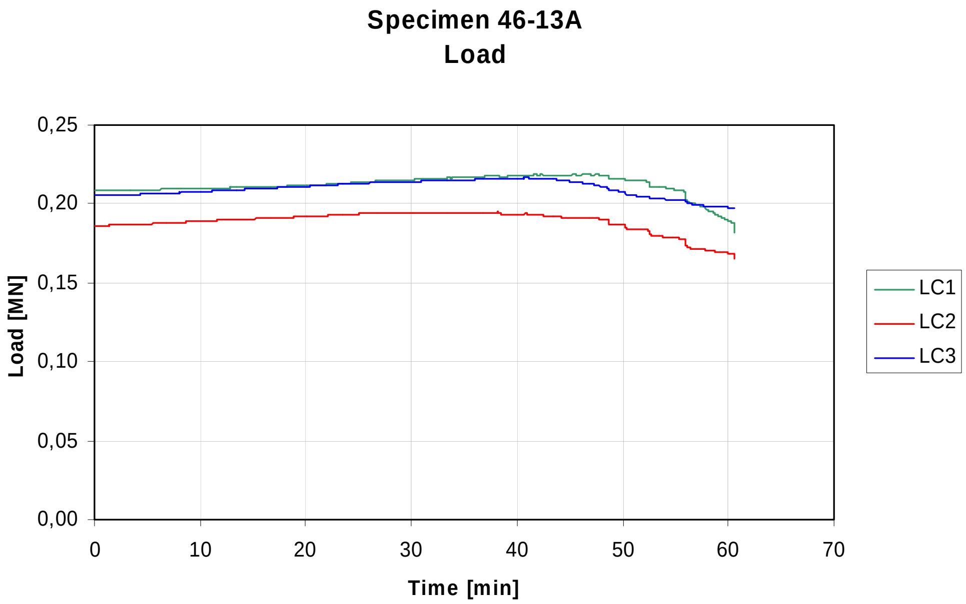


Figure A.570 Load measurements on specimen 46-13A.

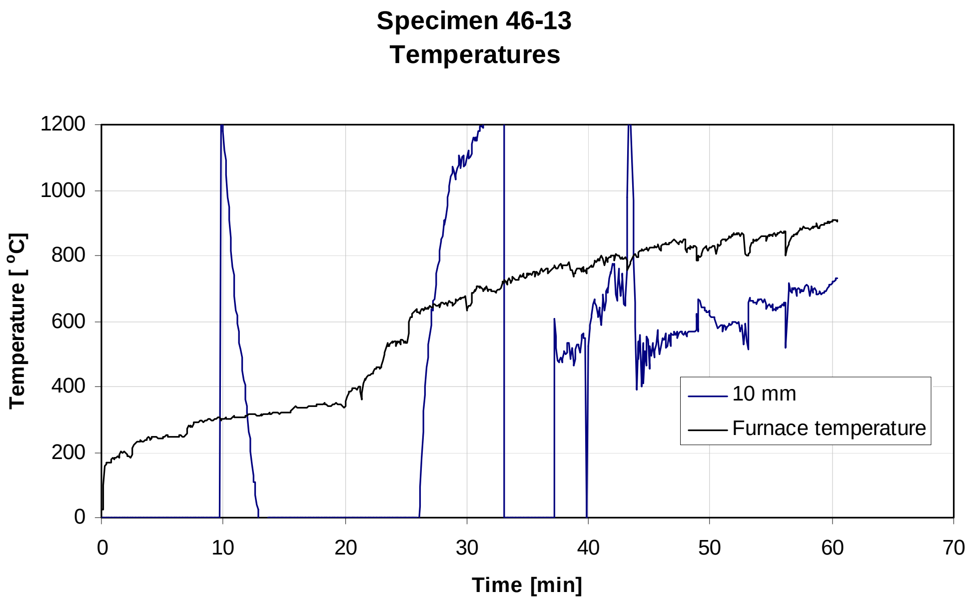


Figure A.571 Measured temperatures in furnace and in specimen 46-13A.

Table A.310 Spalling measurements on specimen 46-13A.

Position	0	100	200	300	400	500
0	0	5	0	0	1	0
100	7	40	50	29	12	0
200	27	70	69	66	28	0
300	35	75	71	56	19	1
400	42	63	66	56	37	2
500	32	44	50	30	22	4
600	17	9	16	5	3	1

Mean all	28
Mean inner	48
Max in diagram	75
Max measured	77

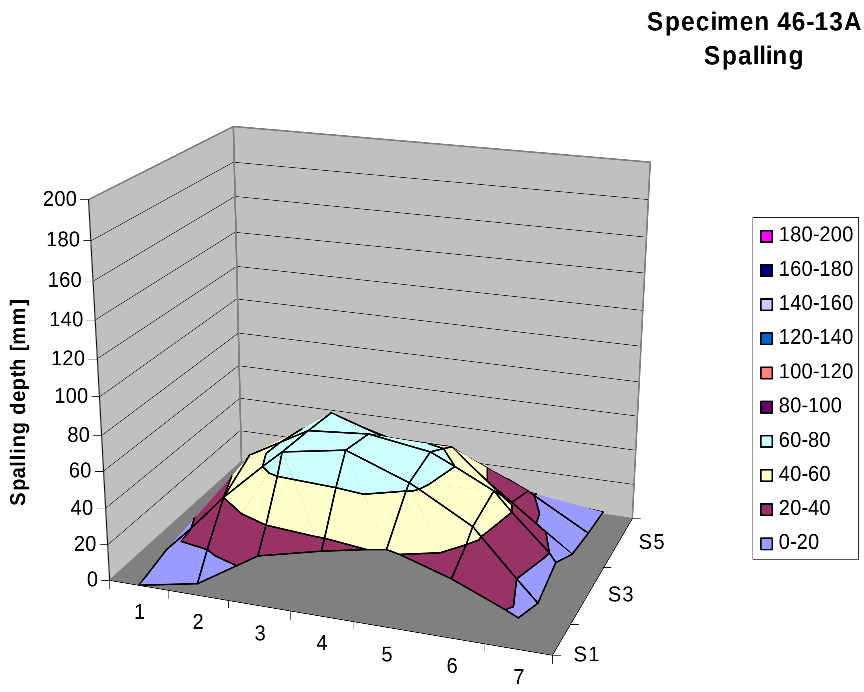


Figure A.572 Spalling measurements on specimen 46-13A.

Table A.311 Observations made on specimen 46-13A.

Time	Observation			
		Test date:	2007-07-04	
0,00	Start of test	Specimen:	46-13A	
28,83	One explosion	Load level:	200	kN/bar
29,67	One small explosion	Weight loss:	22,6	kg
29,92	One loud explosion			
30,75	One small explosion			
31,25	Reperated small explosions			
40,00	Cracks and water on front side and unexposed surface			
48,83	One loud explosion			
52,75	One loud explosion			
56,17	One loud explosion			
57,00	Spalling stops			
60,50	Test terminates			

Figure A.573 Specimen 46-13A after test.

Specimen 46-13B

Table A.312 Spalling measurements on specimen 46-13B.

Position	0	100	200	300	400	500
0	0	0	0	1	1	0
100	0	12	11	16	21	2
200	0	14	20	27	23	3
300	0	0	17	19	15	1
400	0	0	0	3	16	3
500	0	0	0	1	2	0
600	0	0	0	0	0	0

Mean all	5
Mean inner	11
Max in diagram	27
Max measured	30

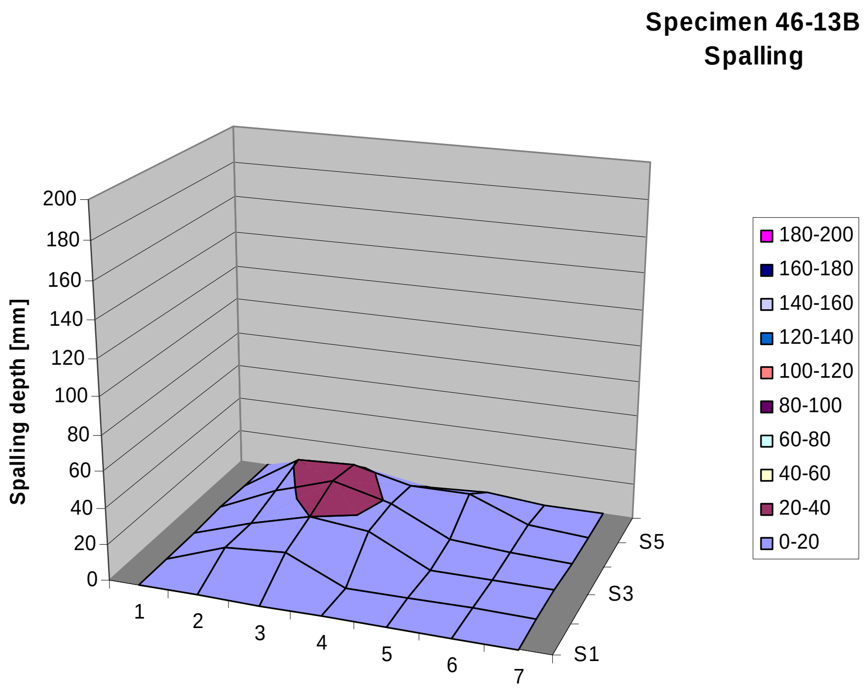


Figure A.574 Spalling measurements on specimen 46-13B.

Table A.313 Observations made on specimen 46-13B.

Time	Observation			
0,00	Start of test	Test date:	2007-06-18	
10,17	One small explosion	Specimen:	46-13B	
13,67	One explosion	Load level:	0	kN/bar
14,50	One small explosion	Weight loss:	6,1	kg
15,08	One small explosion			
16,00	Two small explosions			
16,33	Two explosions			
17,83	Load explosion			
18,00	One explosion			
19,25	One small explosion, repeated explosions			
25,00	Spalling stops			
30,00	Cracks and water on sides			
60,00	Test terminates			

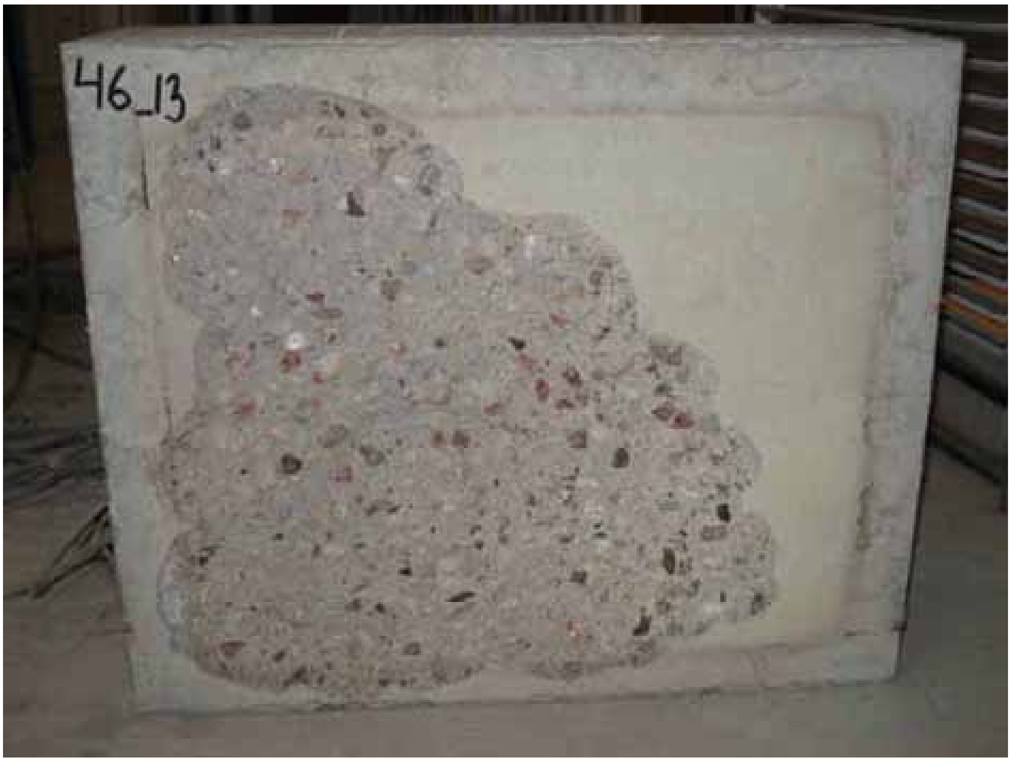


Figure A.575 Specimen 46-13B after test.

Specimen 46-14A

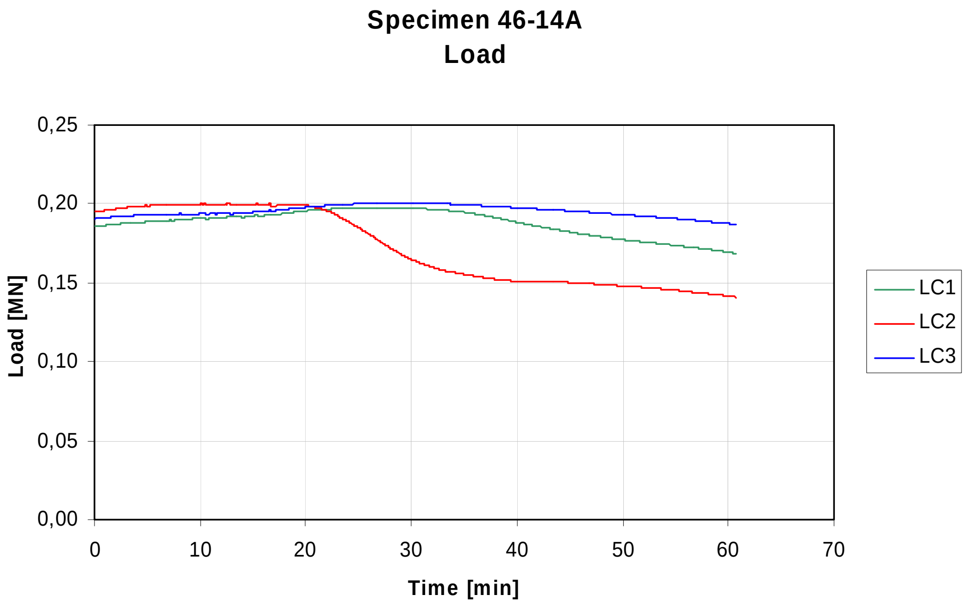


Figure A.576 Load measurements on specimen 46-14A.

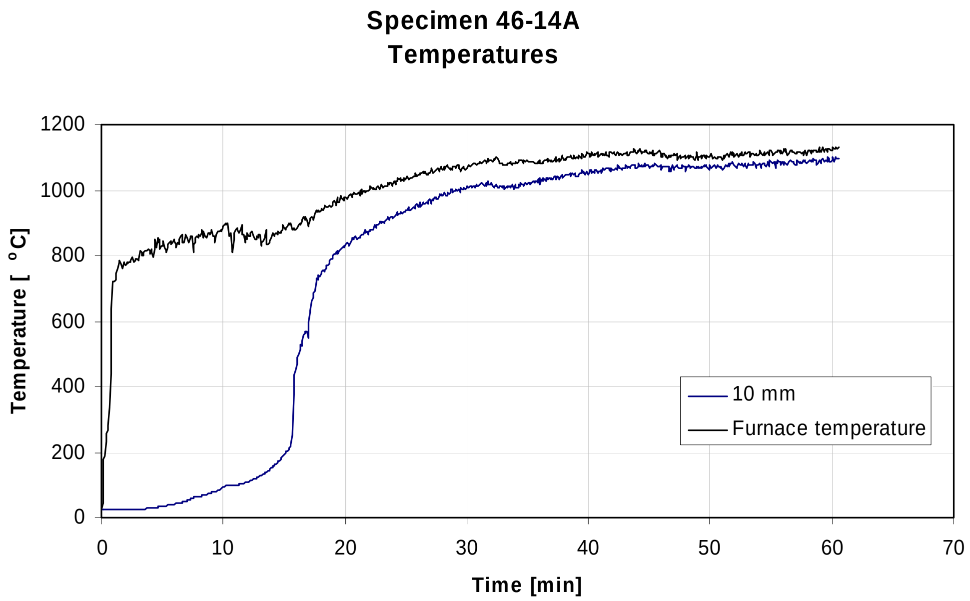


Figure A.577 Measured temperatures in furnace and in specimen 46-14A

Table A.314 Spalling measurements on specimen 46-14A.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	9	14	13	13	9	0
200	18	41	41	48	32	0
300	14	44	49	52	39	0
400	14	34	51	55	40	3
500	6	21	46	48	26	8
600	0	0	0	5	12	0

Mean all	19
Mean inner	36
Max in diagram	55
Max measured	58

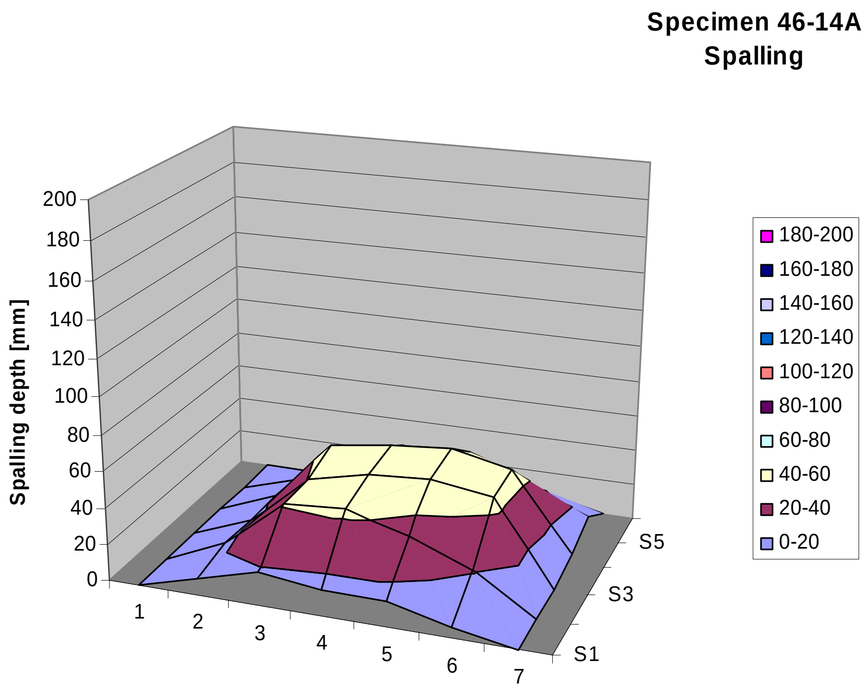


Figure A.578 Spalling measurements on specimen 46-14A.

Table A.315 Observations made on specimen 46-14A.

Time	Observation
0,00	Start of test
3,40	One small explosion
4,08	One small explosion
4,17	Two small explosions, repeated explosions
10,75	One explosion
17,00	Spalling stops
20,00	Cracks and water on sides
60,50	Test terminates

Test date:	2007-07-06	
Specimen:	46-14A	
Load level:	190	kN/bar
Weight loss:	16,1	kg

Figure A.579 Specimen 46-14A after test.

Specimen 14B

Table A.316 Spalling measurements on specimen 46-14B.

Position	0	100	200	300	400	500
0	0	3	3	0	0	0
100	0	24	21	22	20	0
200	0	19	23	24	17	1
300	0	9	26	32	28	0
400	3	23	19	17	16	0
500	2	17	18	16	18	3
600	0	3	0	0	2	0

Mean all	10
Mean inner	20
Max in diagram	32
Max measured	39

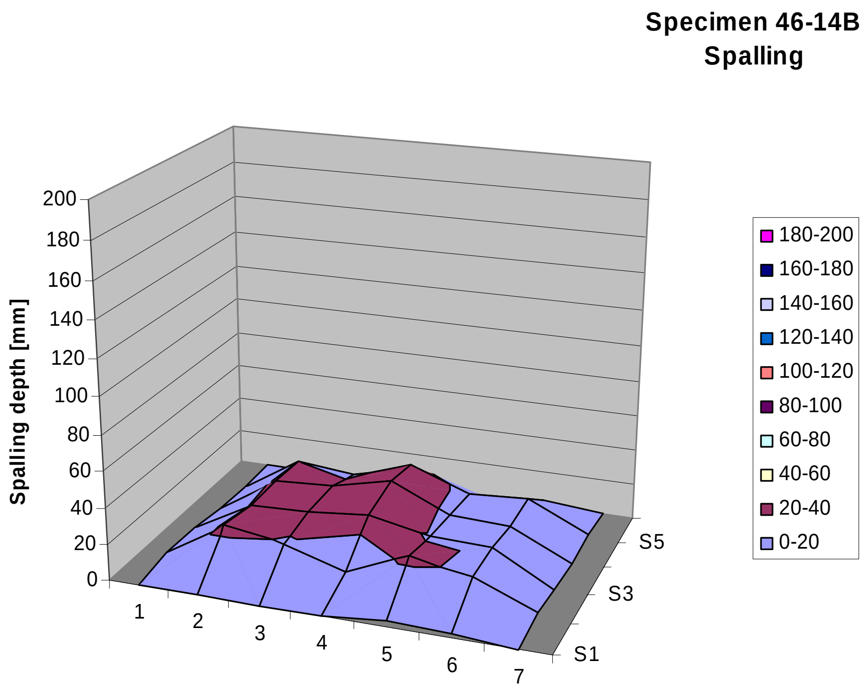


Figure A.580 Spalling measurements on specimen 46-14B.

Table A.317 Observations made on specimen 46-14B.

Time	Observation
0,00	Start of test
14,92	One explosion
16,08	Three explosions
17,00	Two small explosions
17,42	Two small explosions
18,08	One small explosion
21,00	One explosion
25,00	Cracks and water on sides
28,00	Spalling stopped
60,50	Test terminates

Test date:	2007-06-19	
Specimen:	46-14B	
Load level:	0	kN/bar
Weight loss:	11,7	kg

Figure A.581 Specimen 46-14B after test.

Specimen 46-16A

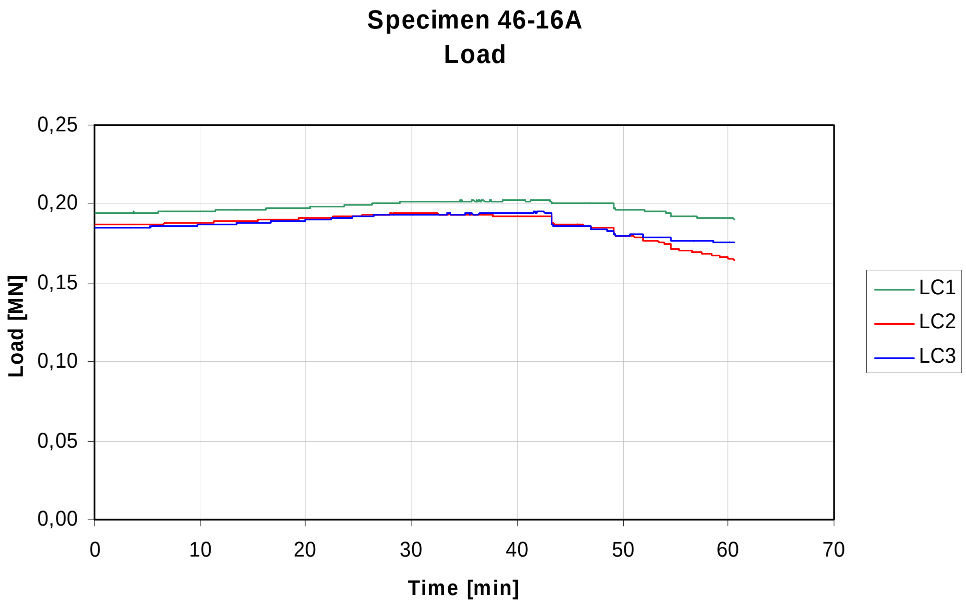


Figure A.582 Load measurements on specimen 46-16A.

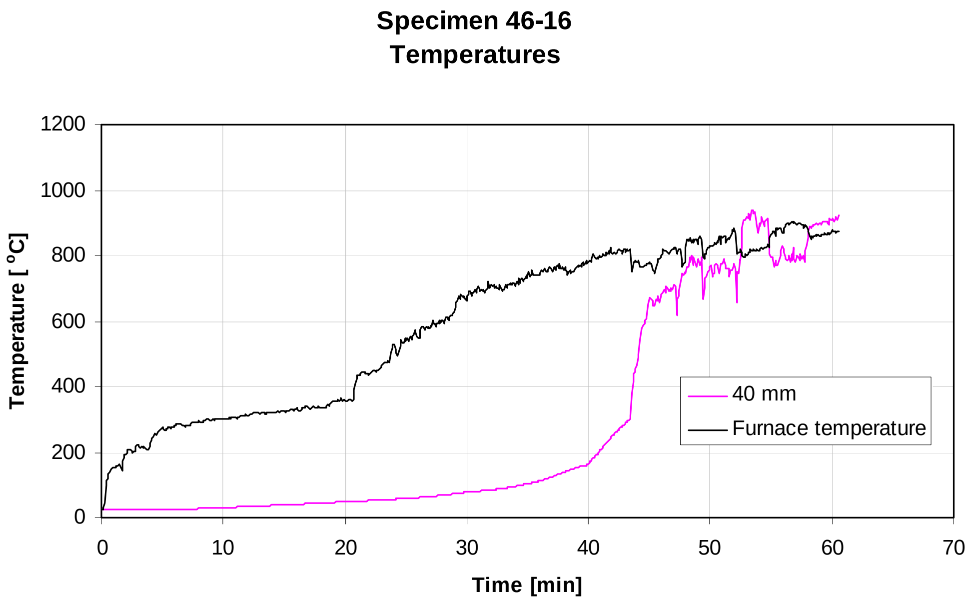


Figure A.583 Measured temperatures in furnace and in specimen 46-16A

Table A.318 Spalling measurements on specimen 46-16A.

Position	0	100	200	300	400	500
0	0	1	4	1	1	0
100	3	33	37	35	24	10
200	2	37	64	70	51	25
300	0	39	67	73	53	24
400	6	42	51	57	45	20
500	4	28	23	33	22	1
600	0	7	1	0	0	0

Mean all	24
Mean inner	44
Max in diagram	73
Max measured	84

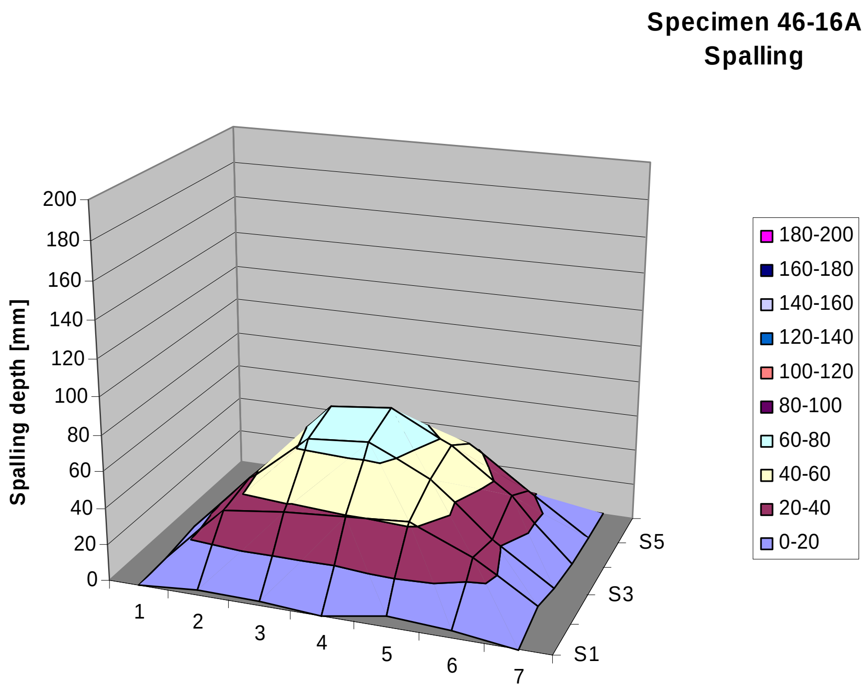


Figure A.584 Spalling measurements on specimen 46-16A.

Table A.319 Observations made on specimen 46-16A

Time	Observation			
0,00	Start of test	Test date:	2007-06-26	
28,50	One small explosion	Specimen:	46-16A	
29,83	Two small explosions	Load level:	188	kN/bar
30,33	Reperated small explosions	Weight loss:	20,3	kg
45,00	Cracks and water on front side and unexposed surface			
49,50	One loud explosion			
57,00	Spalling stops			
60,50	Test terminates			

Figure A.585 Specimen 46-16A after test.

Specimen 46-16B

Table A.320 Spalling measurements on specimen 46-16B.

Position	0	100	200	300	400	500
0	0	0	0	3	3	0
100	0	13	17	19	23	20
200	3	21	26	37	32	30
300	7	36	42	41	35	21
400	16	34	44	46	40	21
500	8	24	27	38	23	1
600	0	0	0	0	2	1

Mean all	18
Mean inner	31
Max in diagram	46
Max measured	56

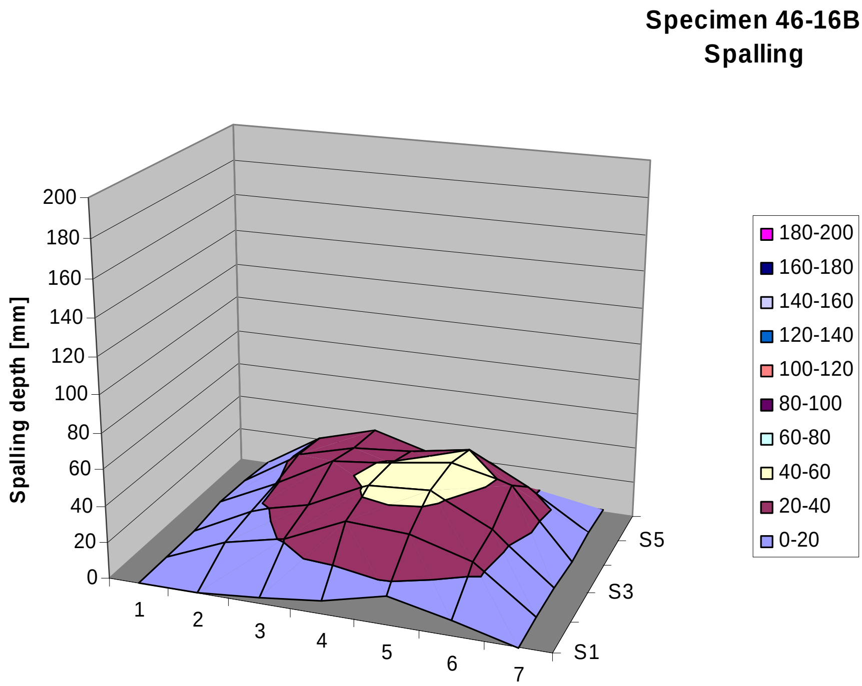


Figure A.586 Spalling measurements on specimen 46-16B.

Table A.321 Observations made on specimen 46-16B.

Time	Observation
0,00	Start of test
10,28	One small explosion
11,27	One small explosion
11,30	One explosion
12,17	One small explosion, continuous spalling
30,00	Spalling stops
60,50	Test terminates

Test date:	2007-10-23	
Specimen:	46-16B	
Load level:	207	kN/bar
Weight loss:	18,1	kg

Figure A.587 Specimen 46-16B after test.

Specimen 46-17

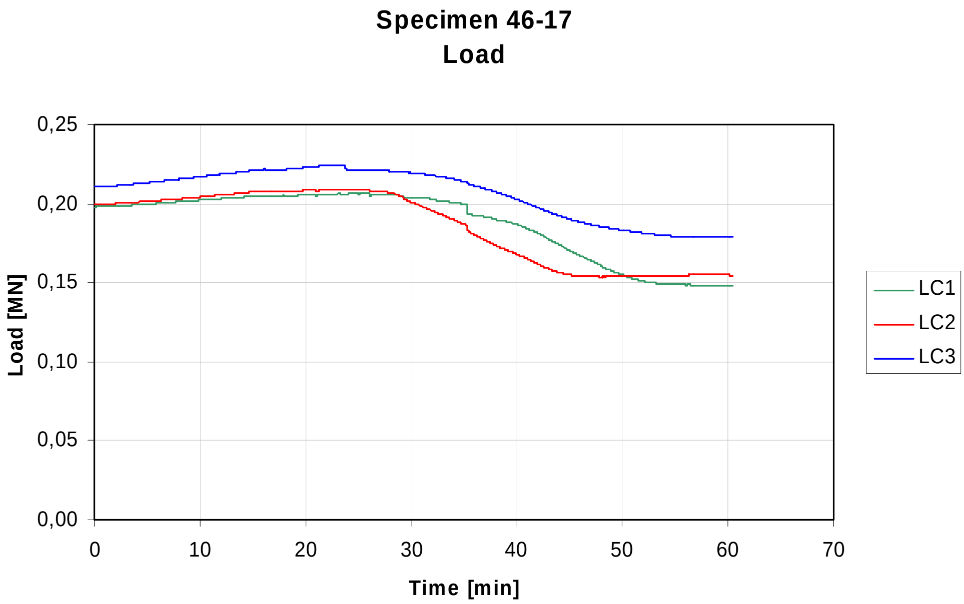


Figure A.588 Load measurements on specimen 46-17.

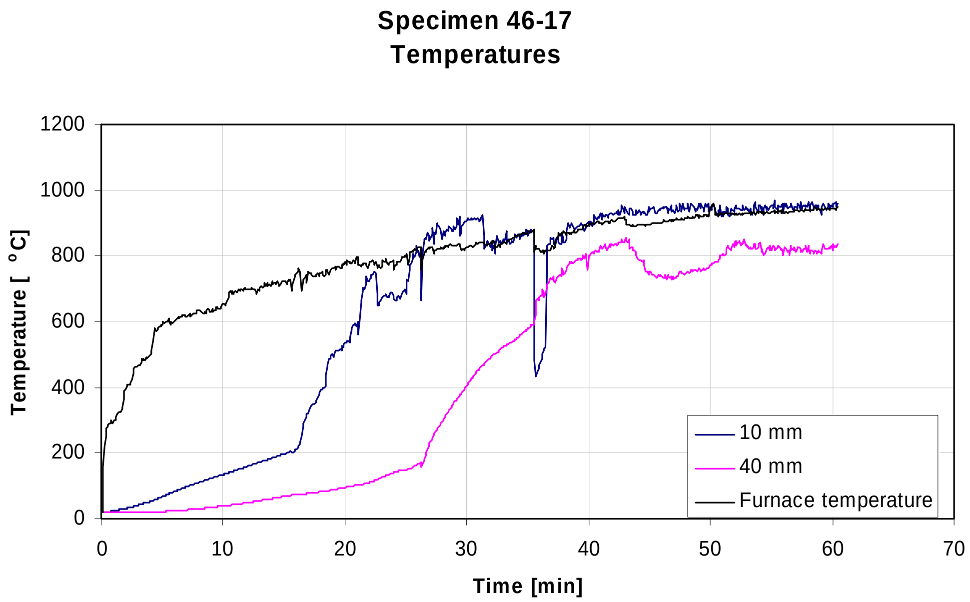


Figure A.589 Measured temperatures in furnace and in specimen 46-17.

Table A.322 Spalling measurements on specimen 46-17.

Position	0	100	200	300	400	500
0	4	0	1	7	8	17
100	19	40	19	27	32	17
200	33	55	54	25	29	15
300	29	52	53	24	22	9
400	28	55	61	39	20	9
500	24	52	48	35	14	3
600	0	0	0	0	7	3

Mean all	24
Mean inner	38
Max in diagram	61
Max measured	75

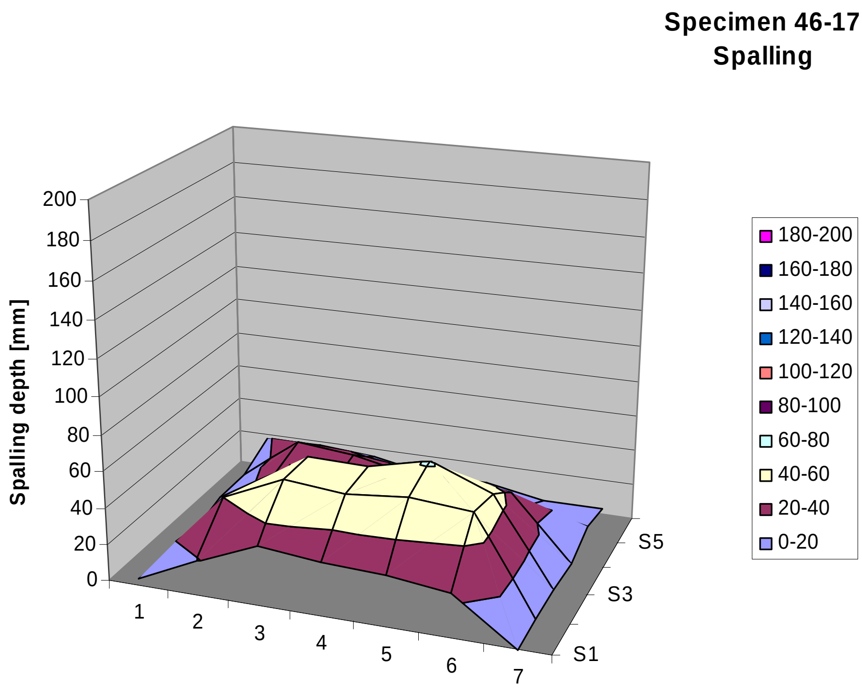


Figure A.590 Spalling measurements on specimen 46-17.

Table A.323 Observations made on specimen 46-17.

Time	Observation			
0,00	Start of test	Test date:	2007-10-29	
10,07	One small explosion	Specimen:	46-17	
12,07	One small explosion	Load level:	203	kN/bar
12,33	Two small explosions	Weight loss:	21,9	kg
12,67	Two explosions			
14,22	One small explosion			
14,50	One small explosion			
14,72	One small explosion, continuous spalling			
16,42	One loud explosion			
24,00	One loud explosion			
33,00	One loud explosion			
35,00	Cracks and water on sides			
37,00	Spalling stopped			
60,00	test terminated			

Figure A.591 Specimen 46-17 after test.

Specimen 46-18

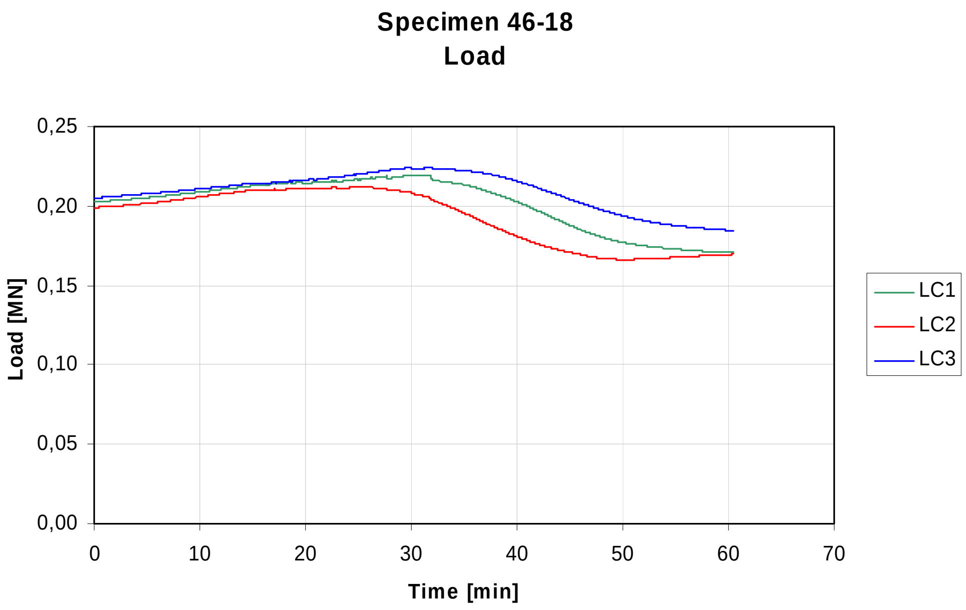


Figure A.592 Load measurements on specimen 46-18.

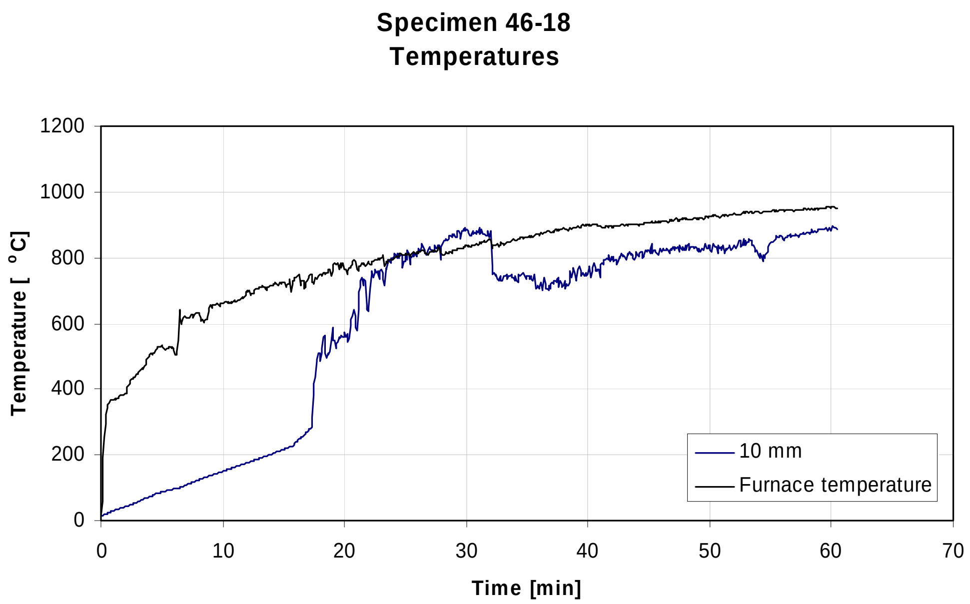


Figure A.593 Measured temperatures in furnace and in specimen 46-18.

Table A.324 Spalling measurements on specimen 46-18.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	10	27	32	29	30	0
200	22	42	34	27	33	0
300	25	32	19	12	24	0
400	11	30	15	19	24	0
500	2	23	19	18	15	0
600	0	0	0	0	2	0

Mean all	14
Mean inner	25
Max in diagram	42
Max measured	52

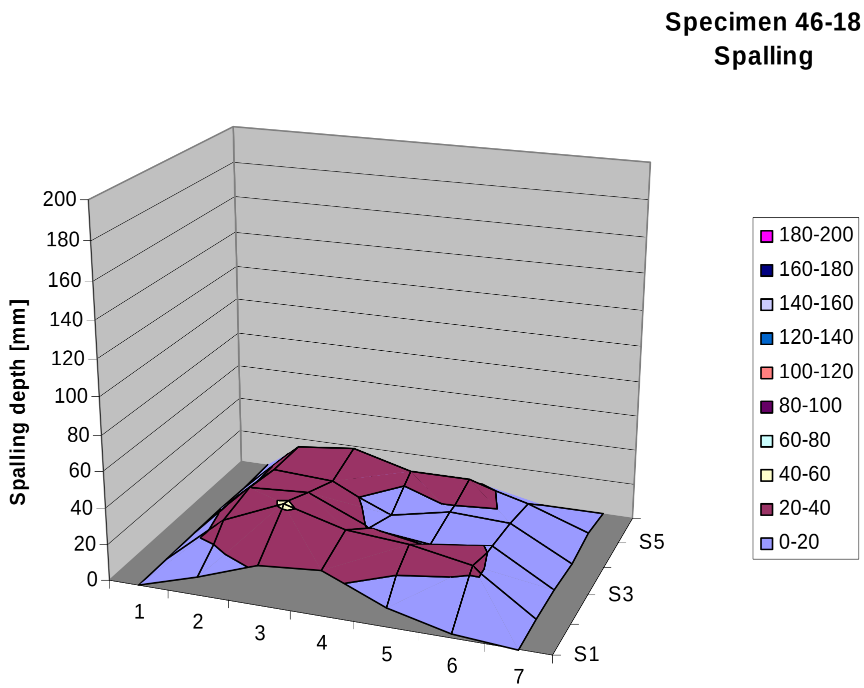


Figure A.594 Spalling measurements on specimen 46-18.

Table A.325 Observations made on specimen 46-18.

Time	Observation
0,00	Start of test
12,25	One explosion
13,37	One small explosion
13,50	One small explosion
14,08	One small explosion
15,18	One explosion
15,57	One loud explosion
16,28	One small explosion, continuous spalling
30,42	Cracks and water on sides
32,25	Spalling stopped
60,00	Test terminated

Test date:	2007-12-05	
Specimen:	46-18	
Load level:	202	kN/bar
Weight loss:	14,4	kg

Figure A.595 Specimen 46-18 after test.

Specimen 46-19

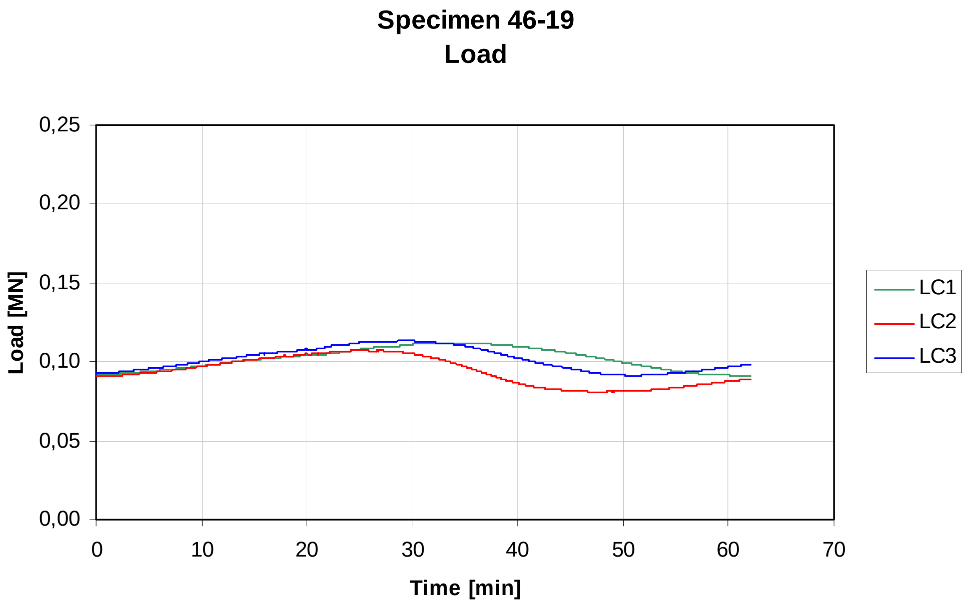


Figure A.596 Load measurements on specimen 46-19.

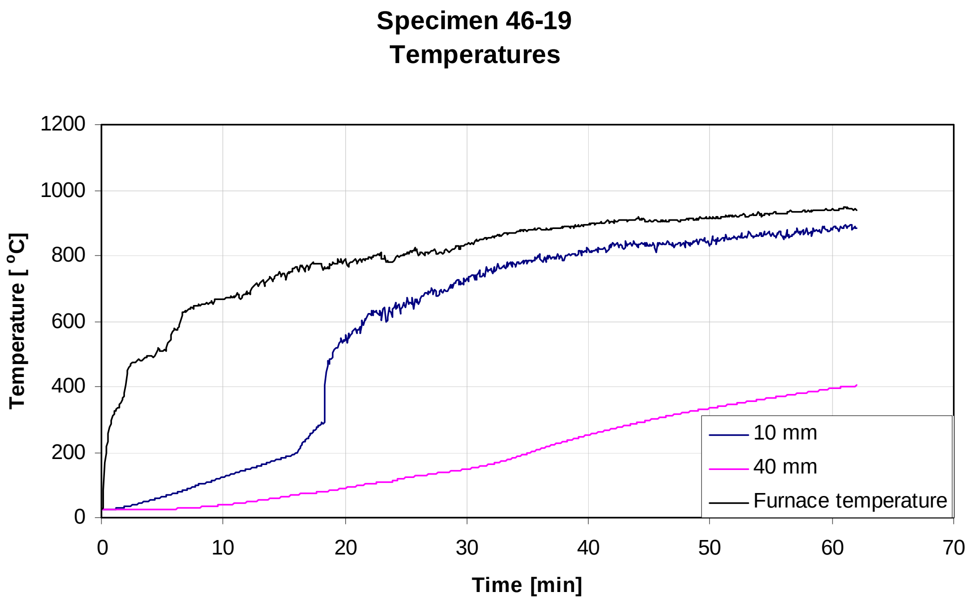


Figure A.597 Measured temperatures in furnace and in specimen 46-19.

Table A.326 Spalling measurements on specimen 46-19.

Position	0	100	200	300	400	500
0	0	0	0	1	2	1
100	0	9	12	8	30	9
200	0	9	20	28	31	36
300	0	20	18	28	28	33
400	1	24	25	27	28	14
500	0	3	31	23	25	8
600	0	1	1	2	4	1

Mean all	13
Mean inner	21
Max in diagram	36
Max measured	49

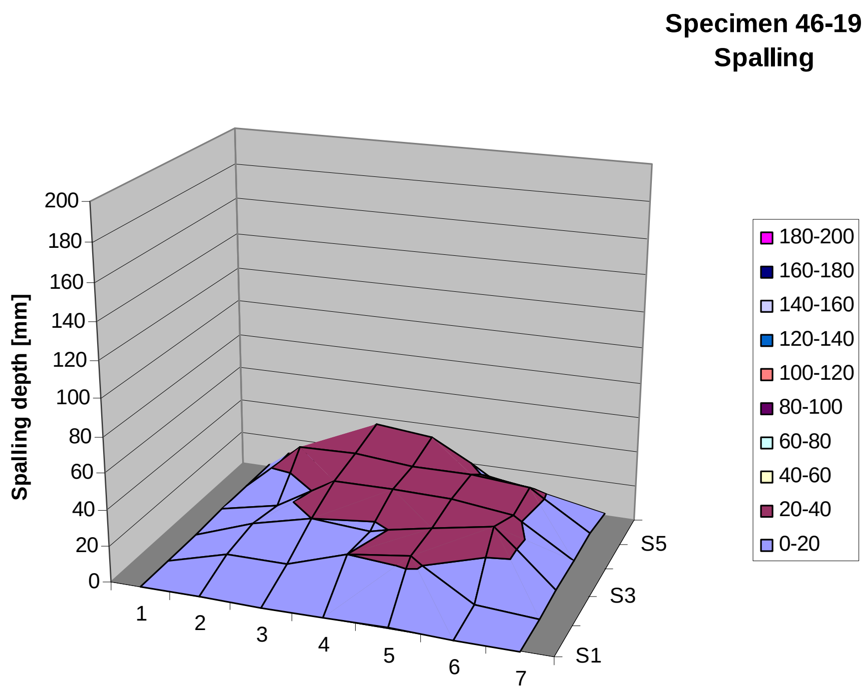


Figure A.598 Spalling measurements on specimen 46-19.

Table A.327 Observations made on specimen 46-19.

Time	Observation
0,00	Start of test
11,33	One explosion
12,92	One explosion
13,28	One small explosion
14,00	Two small explosions
14,70	Three small explosions
15,08	Repeated explosions
16,08	Loud explosion
30,00	Spalling stops
35,00	Some water on unexposed surface
60,00	Test terminates

Test date:	2007-06-20	
Specimen:	46-19	
Load level:	92	kN/bar
Weight loss:	12,4	kg

Figure A.599 Specimen 46-19 after test.

Specimen 46-20A

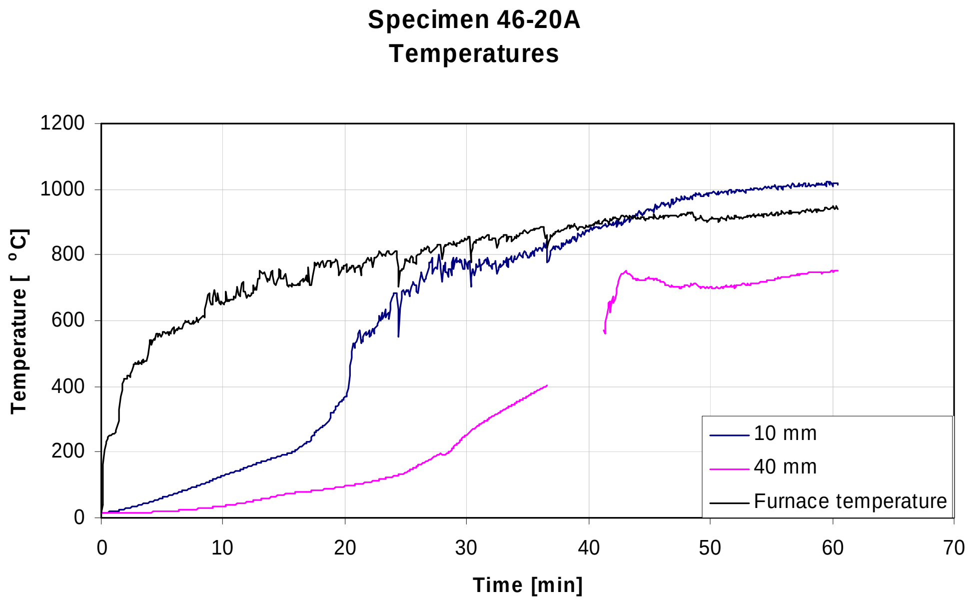


Figure A.600 Measured temperatures in furnace and in specimen 46-20A.

Table A.328 Spalling measurements on specimen 46-20A.

Position	0	100	200	300	400	500
0	0	2	7	6	6	1
100	0	12	17	16	19	4
200	27	49	42	32	24	12
300	34	57	51	34	30	23
400	36	52	60	34	26	21
500	24	51	45	28	15	2
600	0	0	0	0	0	0

Mean all	21
Mean inner	35
Max in diagram	60
Max measured	68

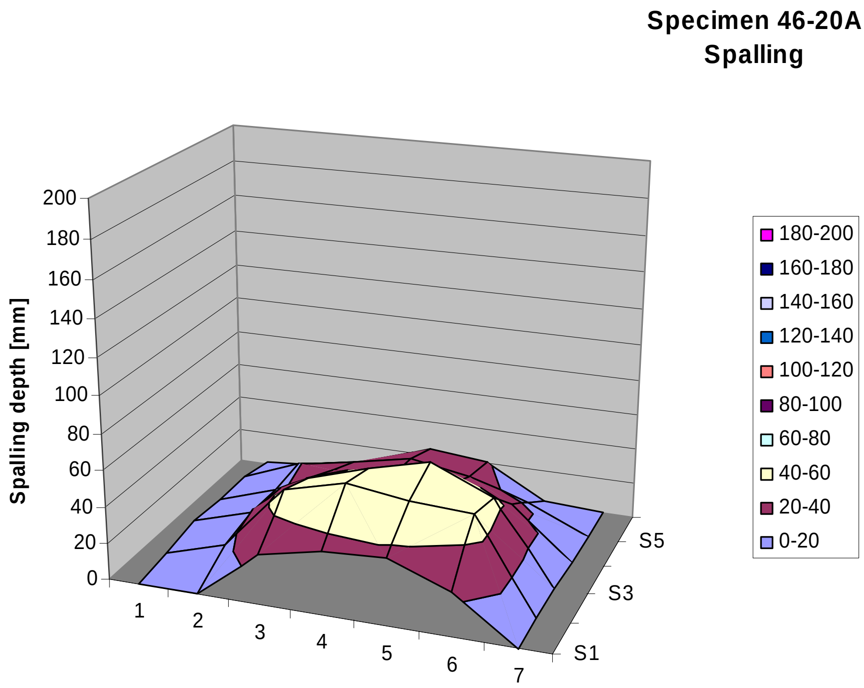


Figure A.601 Spalling measurements on specimen 46-20A.

Table A.329 Observations made on specimen 46-20A.

Time	Observation			
0,00	Start of test	Test date:	2007-12-13	
11,72	Several explosions	Specimen:	46-20A	
12,22	Two small explosions	Load level:	104	kN/bar
12,58	Two small explosions	Weight loss:	20,2	kg
14,00	Two small explosions, contiuous spalling			
24,45	Loud explosion			
30,00	Cracks and water on sides			
39,08	Spalling stops			
60,00	Test terminates			

Figure A.602 Specimen 46-20A after test.

Specimen 46-20B

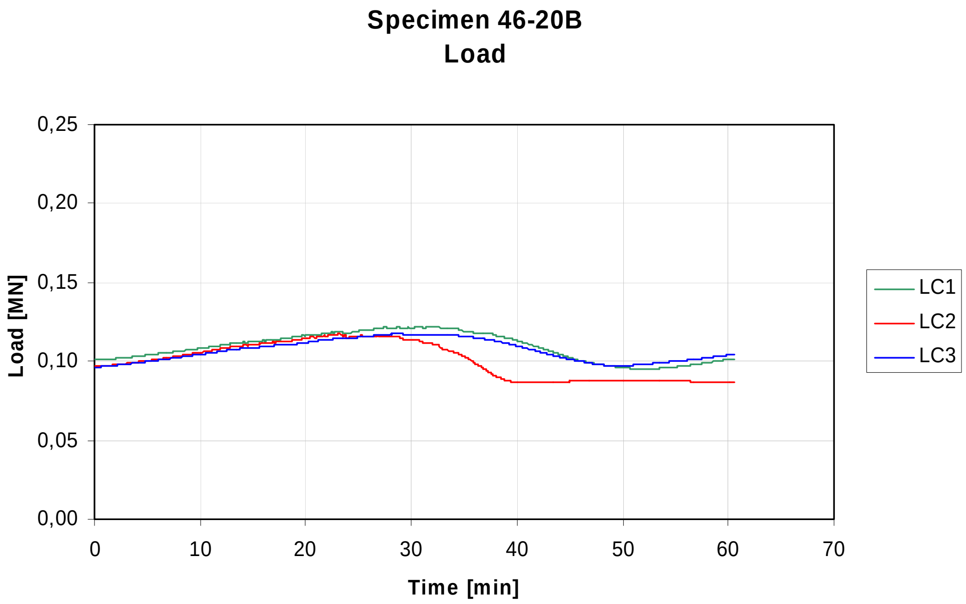


Figure A.603 Load measurements on specimen 46-20B.

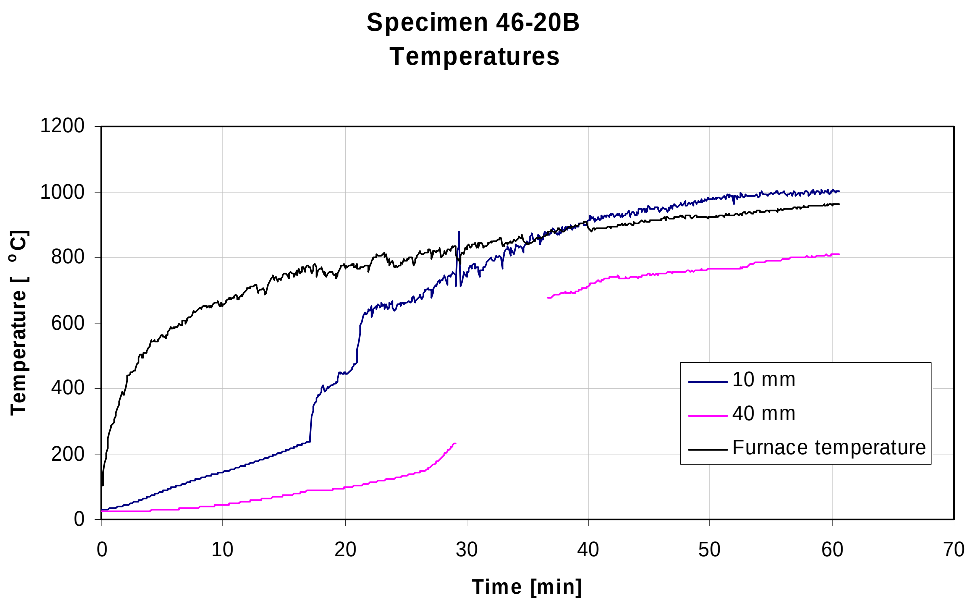


Figure A.604 Measured temperatures in furnace and in specimen 46-20B.

Table A.330 Spalling measurements on specimen 46-20B.

Position	0	100	200	300	400	500
0	0	4	1	4	2	1
100	2	31	36	43	30	13
200	27	53	71	49	46	14
300	30	43	61	54	52	8
400	10	42	38	46	43	10
500	0	18	25	31	36	13
600	0	0	0	3	9	0

Mean all	24
Mean inner	42
Max in diagram	71
Max measured	76

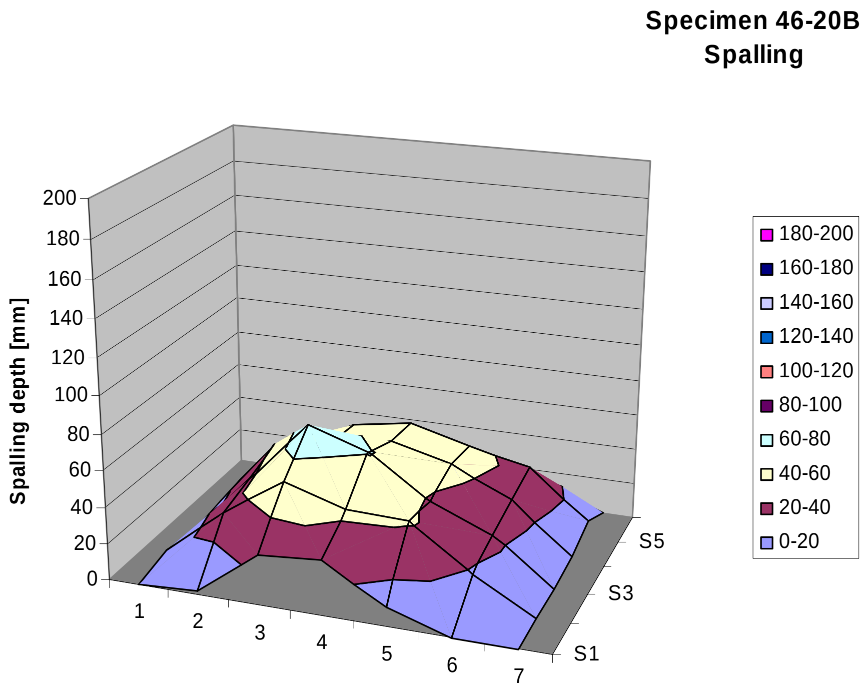


Figure A.605 Spalling measurements on specimen 46-20B.

Table A.331 Observations made on specimen 46-20B.

Time	Observation			
0,00	Start of test	Test date:	2007-06-20	
9,92	One explosion	Specimen:	46-20B	
11,17	One small explosion	Load level:	98	kN/bar
11,67	One small explosion	Weight loss:	22,8	kg
12,83	One small explosion			
13,33	Loud explosion			
14,17	Repeated explosions			
18,00	Loud explosion			
21,00	Loud explosion			
35,00	Spalling stops			
60,00	Test terminates			

Figure A.606 Specimen 46-20B after test.

Specimen 46-21

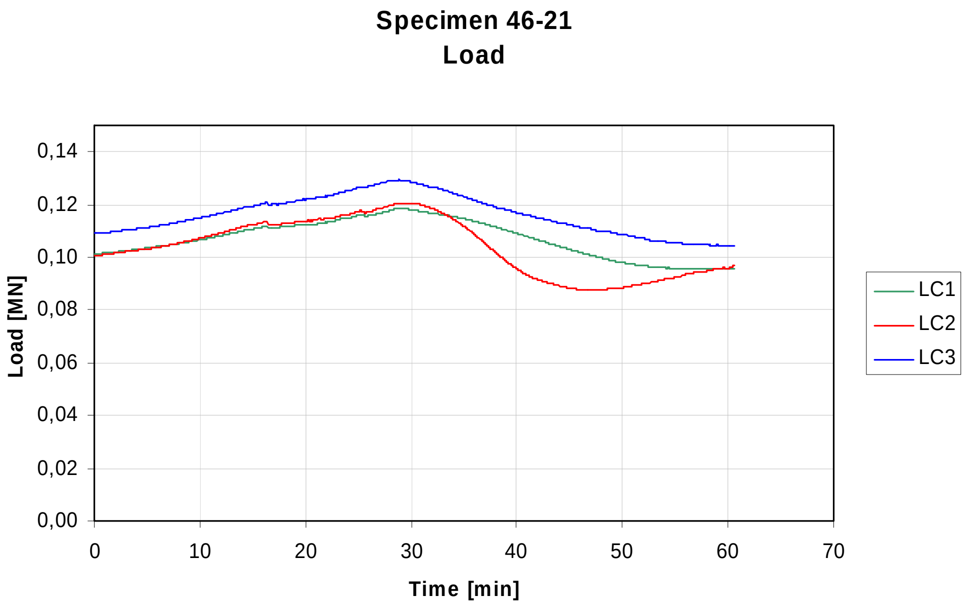


Figure A.607 Load measurements on specimen 46-21.

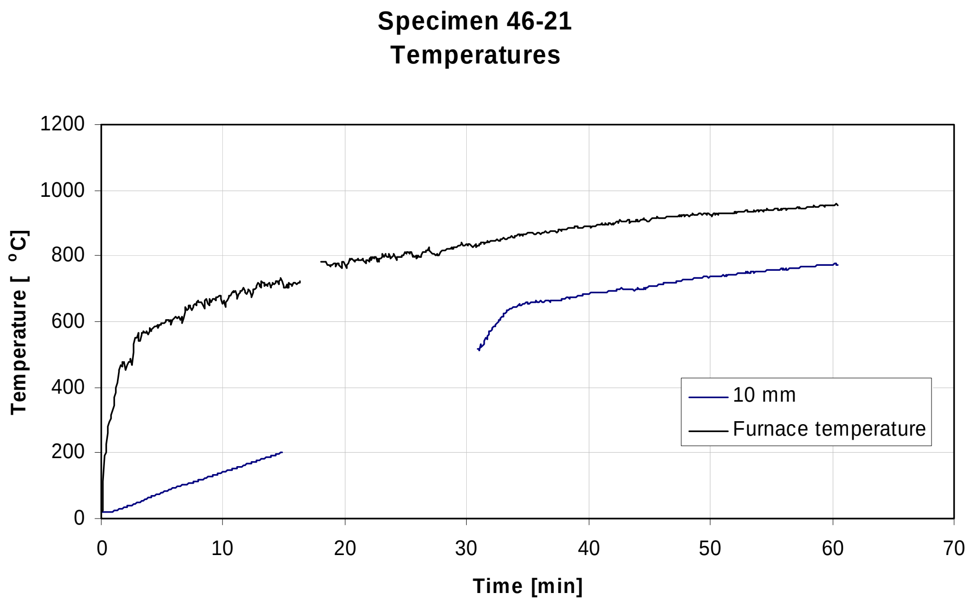


Figure A.608 Measured temperatures in furnace and in specimen 46-21.

Table A.332 Spalling measurements on specimen 46-21.

Position	0	100	200	300	400	500
0	0	0	0	2	4	0
100	0	12	24	43	17	2
200	1	16	33	37	24	3
300	3	21	28	31	20	2
400	2	25	28	29	21	0
500	0	20	26	22	17	1
600	0	0	2	0	1	1

Mean all	12
Mean inner	25
Max in diagram	43
Max measured	49

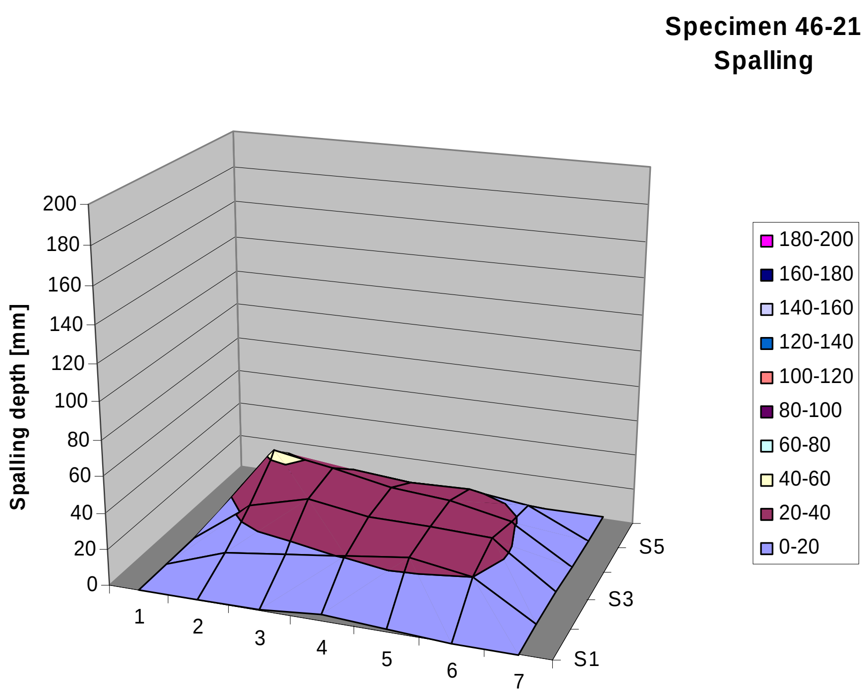


Figure A.609 Spalling measurements on specimen 46-21.

Table A.333 Observations made on specimen 46-21.

Time	Observation
0,00	Start of test
14,92	One explosion
16,67	Repeated explosions
30,00	Spalling stops
30,00	Cracks and water on sides
60,50	Test terminates

Test date:	2007-12-04	
Specimen:	46-21	
Load level:	104	kN/bar
Weight loss:	11,4	kg

Figure A.610 Specimen 46-21 after test.

Specimen 46-22

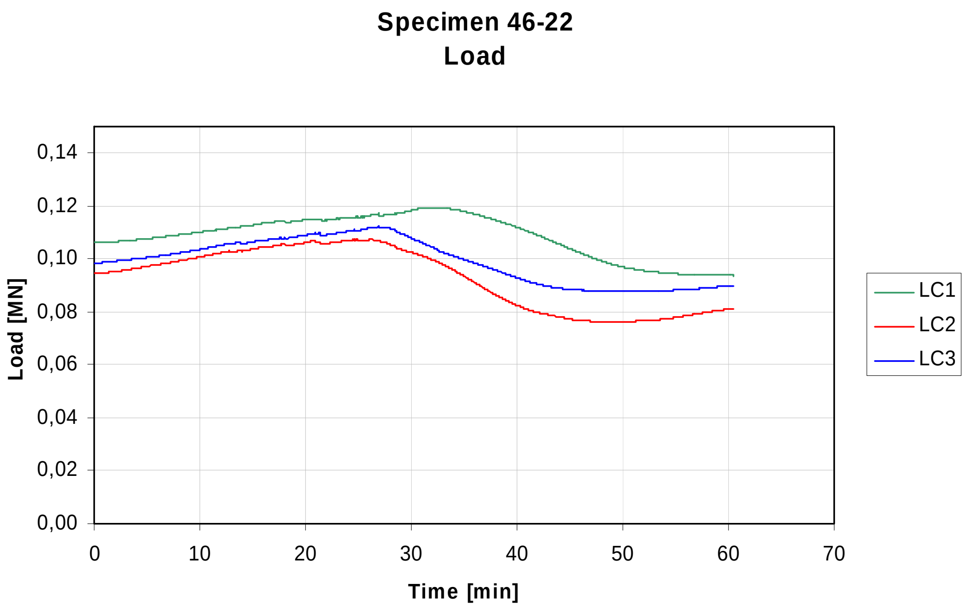


Figure A.611 Load measurements on specimen 46-22.

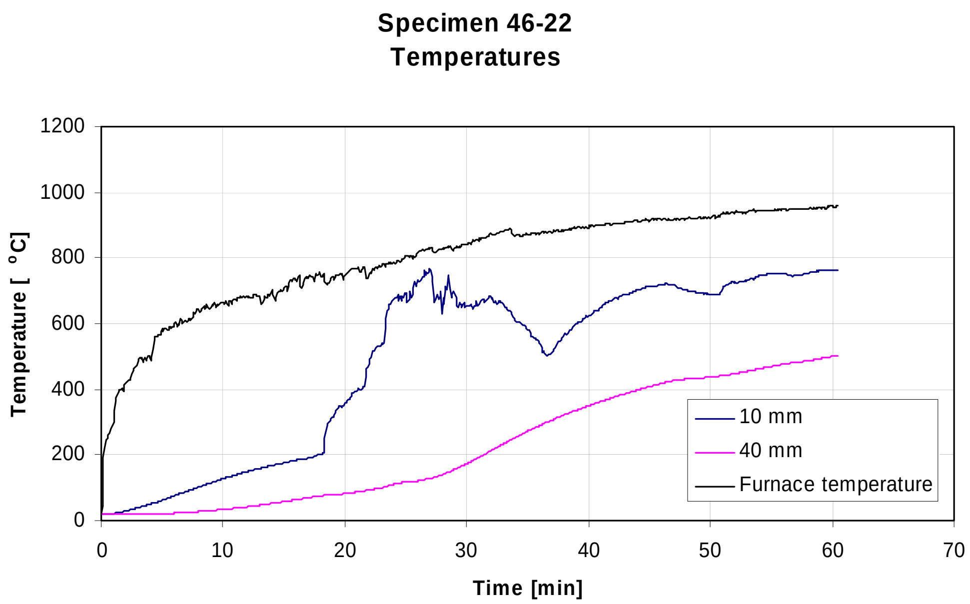


Figure A.612 Measured temperatures in furnace and in specimen 46-22.

Table A.334 Spalling measurements on specimen 46-22.

Position	0	100	200	300	400	500
0	0	1	2	3	4	1
100	12	24	23	36	26	0
200	7	33	43	34	31	6
300	3	27	30	25	23	15
400	0	25	32	29	29	24
500	5	23	11	18	18	5
600	0	6	0	2	1	1

Mean all	15
Mean inner	27
Max in diagram	43
Max measured	51

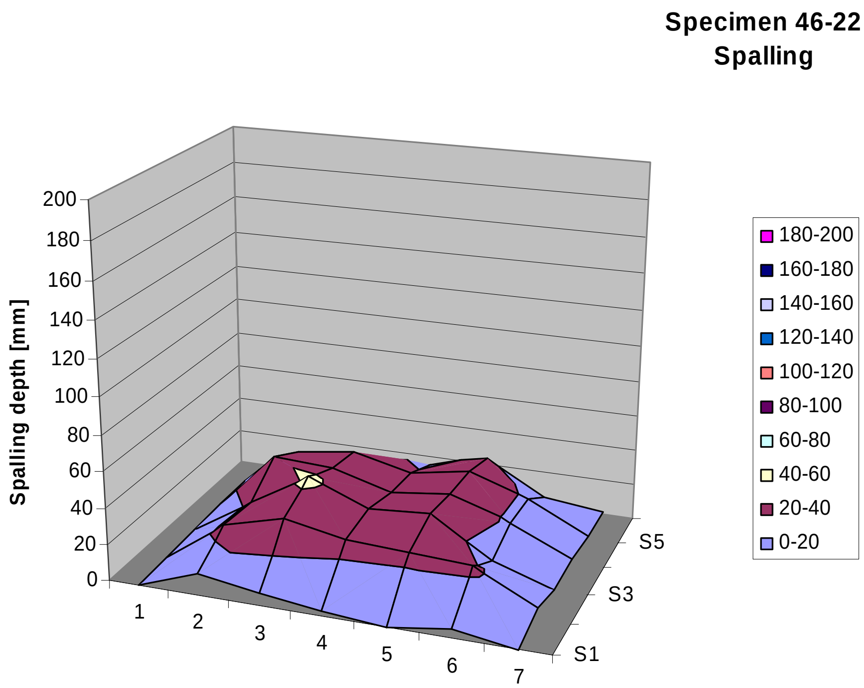


Figure A.613 Spalling measurements on specimen 46-22.

Table A.335 Observations made on specimen 46-22.

Time	Observation	Test date:	2007-10-22	
0,00	Start of test	Specimen:	46-22	
13,03	One explosion	Load level:	100	kN/bar
14,08	One explosion	Weight loss:	13,4	kg
14,25	One small explosion			
15,22	One small explosion, continuous spalling			
29,00	Spalling stopped			
30,00	Water on top surface			
40,00	Cracks and water on sides			
60,50	Test terminated			

Figure A.614 Specimen 46-22 after test.

Specimen 46-23

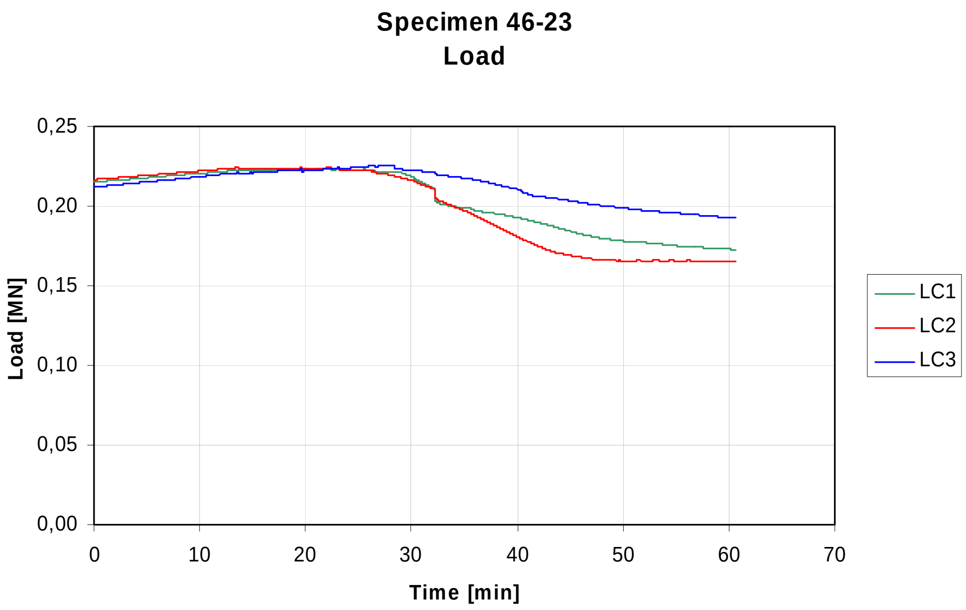


Figure A.615 Load measurements on specimen 46-23.

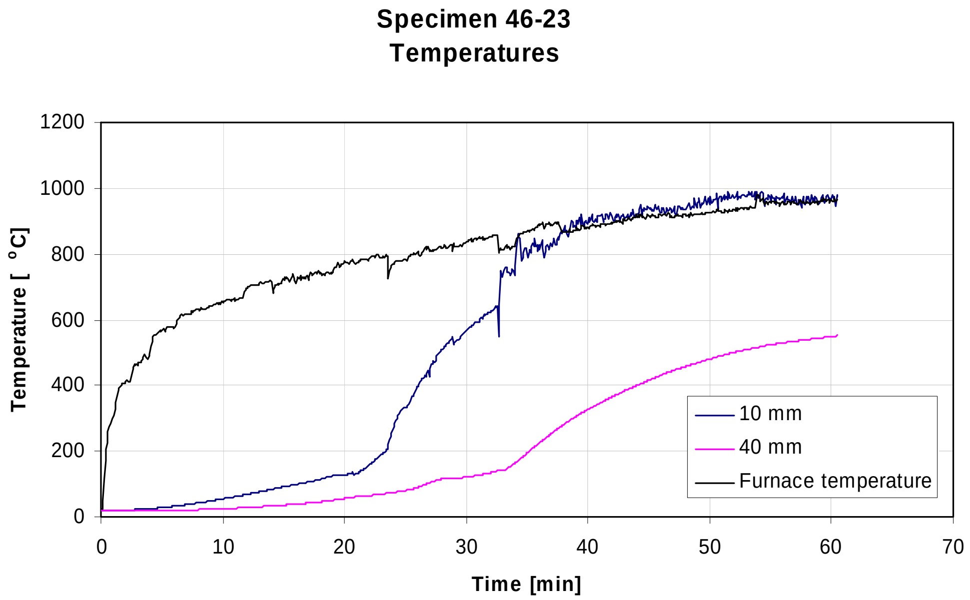


Figure A.616 Measured temperatures in furnace and in specimen 46-23.

Table A.336 Spalling measurements on specimen 46-23.

Position	0	100	200	300	400	500
0	0	0	4	5	0	0
100	23	28	40	31	11	0
200	24	41	52	47	24	7
300	29	46	44	45	32	9
400	30	55	42	33	35	11
500	22	34	26	26	33	10
600	0	0	0	4	0	0

Mean all	21
Mean inner	36
Max in diagram	55
Max measured	65

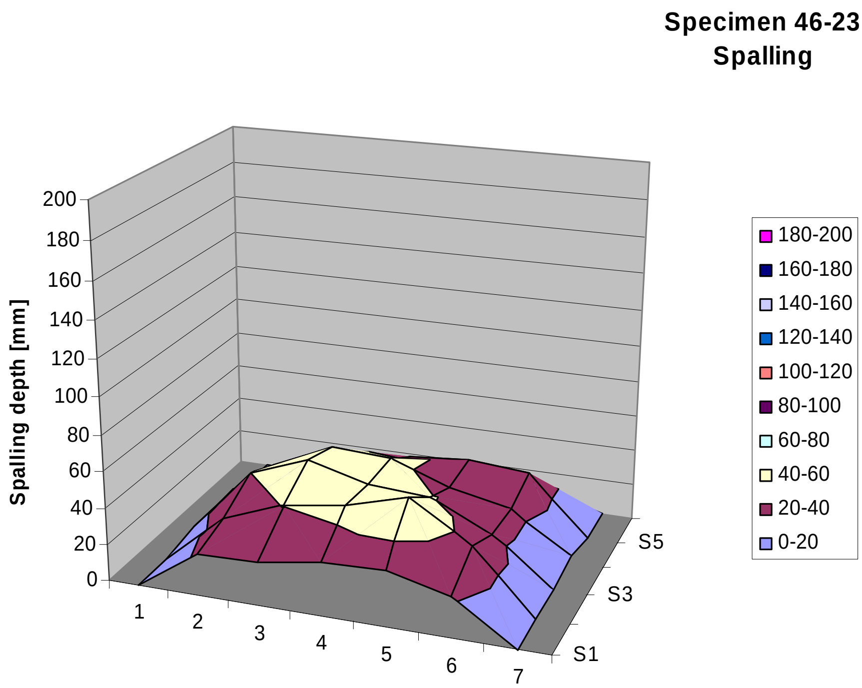


Figure A.617 Spalling measurements on specimen 46-23.

Table A.337 Observations made on specimen 46-23.

Time	Observation			
0,00	Start of test	Test date:	2007-12-05	
14,05	One explosion	Specimen:	46-23	
14,98	One small explosion	Load level:	215	kN/bar
15,35	One small explosion	Weight loss:	21,3	kg
15,83	One small explosion, continuous spalling			
30,00	Cracks and water on sides			
38,00	Spalling stopped			
61,17	Test terminated			

Figure A.618 Specimen 46-23 after test.

Specimen 46-24

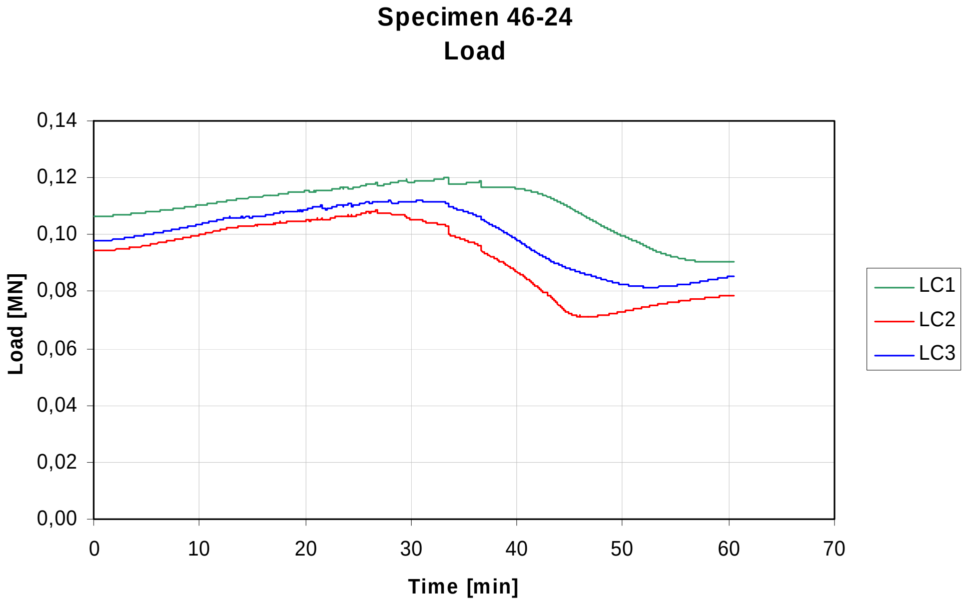


Figure A.619 Load measurements on specimen 46-24.

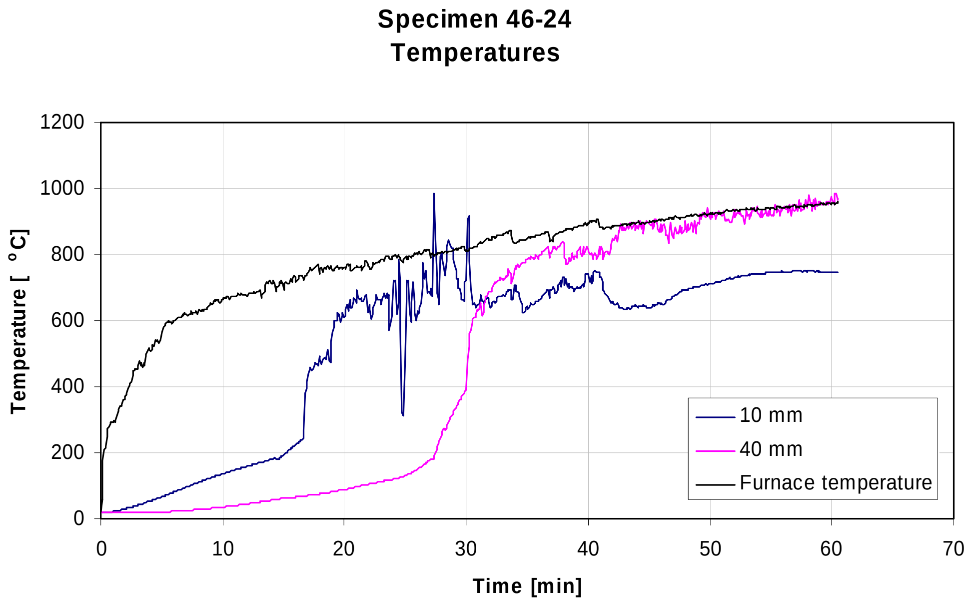


Figure A.620 Measured temperatures in furnace and in specimen 46-24.

Table A.338 Spalling measurements on specimen 46-24.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	19	25	4	38	19
200	3	34	57	57	40	22
300	18	55	66	65	44	29
400	3	55	49	48	51	32
500	0	37	36	22	27	9
600	0	2	0	0	2	1

Mean all	23
Mean inner	41
Max in diagram	66
Max measured	72

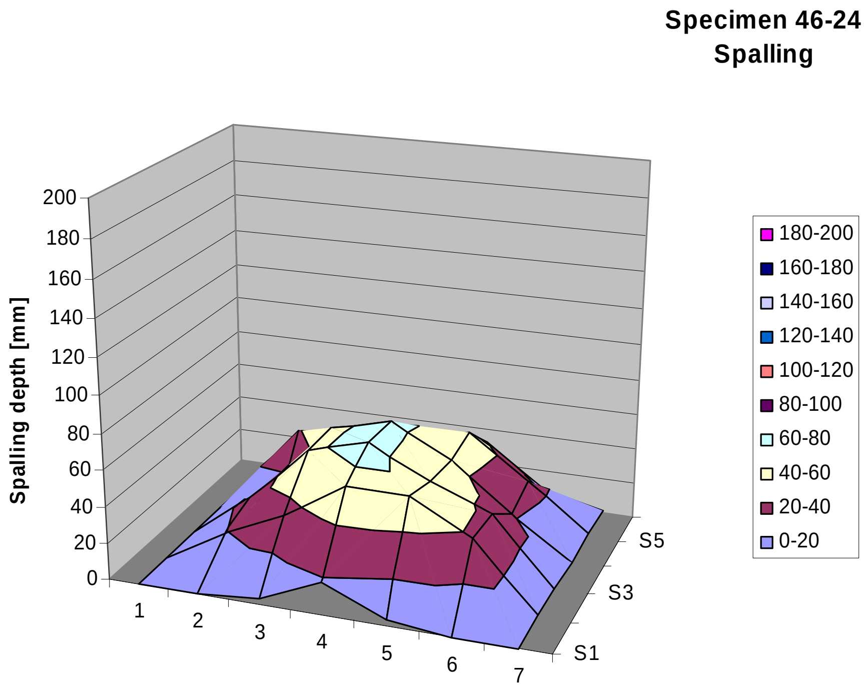


Figure A.621 Spalling measurements on specimen 46-24.

Table A.339 Observations made on specimen 46-24.

Time	Observation
0,00	Start of test
13,08	One small explosion
14,25	One small explosion, continuous spalling
36,00	Spalling stopped
60,50	Test terminated

Test date:	2007-10-23	
Specimen:	46-24	
Load level:	99	kN/bar
Weight loss:	20,3	kg

Figure A.622 Specimen 46-24 after test.

Specimen 46-25

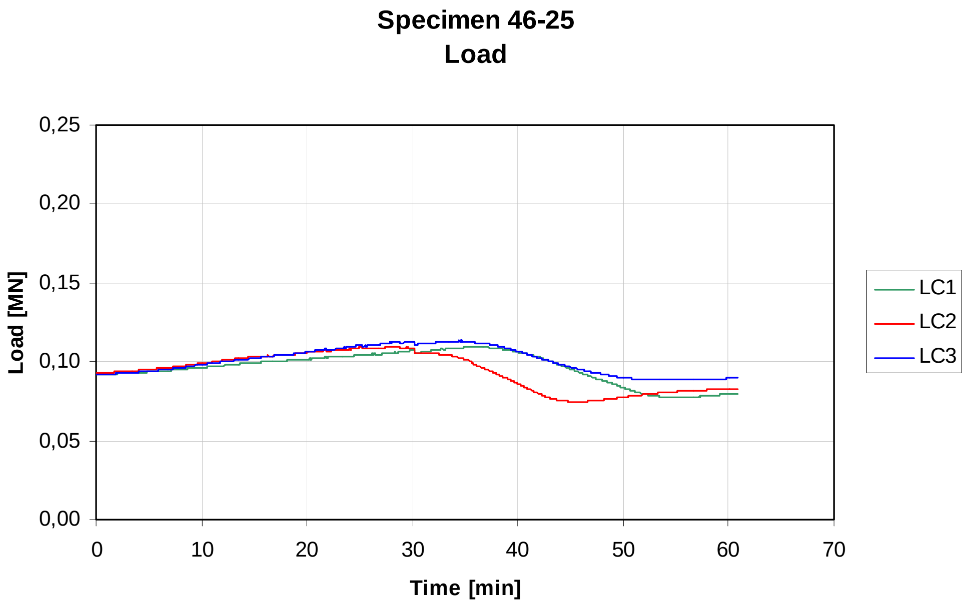


Figure A.623 Load measurements on specimen 46-25.

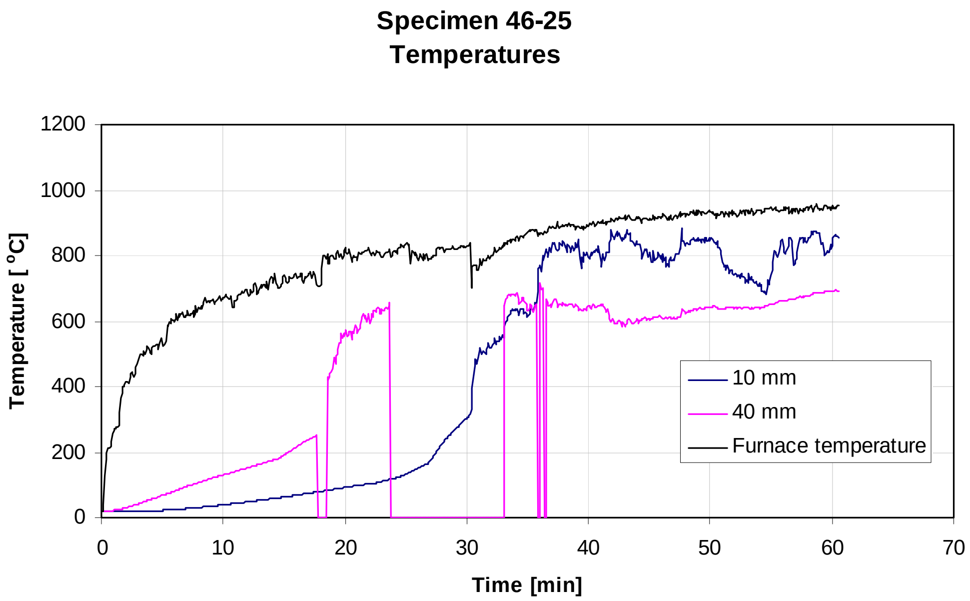


Figure A.624 Measured temperatures in furnace and in specimen 46-25.

Table A.340 Spalling measurements on specimen 46-25.

Position	0	100	200	300	400	500
0	0	0	0	0	1	0
100	2	41	37	50	33	3
200	9	52	64	52	50	25
300	24	50	64	51	49	24
400	25	54	52	40	47	6
500	0	33	37	21	23	8
600	0	2	9	5	0	0

Mean all	25
Mean inner	45
Max in diagram	64
Max measured	70

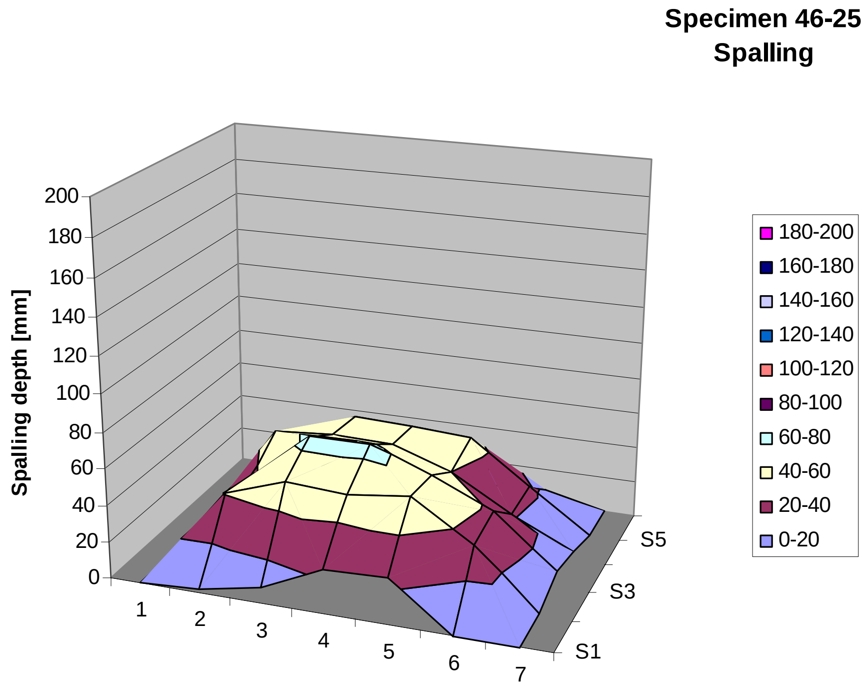


Figure A.625 Spalling measurements on specimen 46-25.

Table A.341 Observations made on specimen 46-25.

Time	Observation
0,00	Start of test
10,75	One explosion
12,67	One small explosion, continuous spalling
14,33	One loud explosion
30,33	Water on top surface
40,00	Spalling stopped
40,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-03-29	
Specimen:	46-25	
Load level:	92	kN/bar
Weight loss:	20,0	kg

Figure A.626 Specimen 46-25 after test.

Specimen 46-26

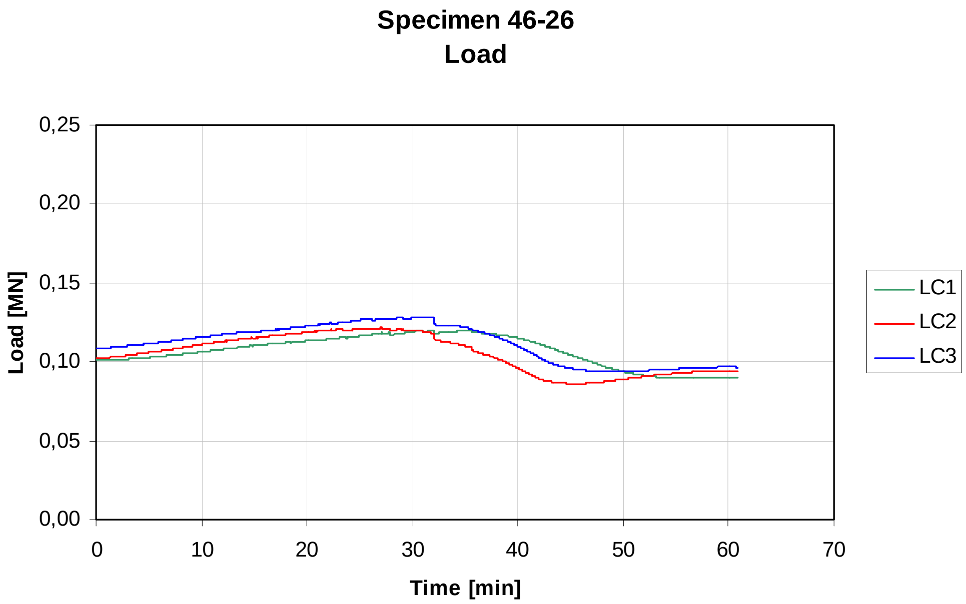


Figure A.627 Load measurements on specimen 46-26.

Table A.342 Spalling measurements on specimen 46-26.

Position	0	100	200	300	400	500
0	0	1	1	2	0	0
100	2	21	32	39	30	8
200	14	45	57	44	55	33
300	19	68	68	59	64	26
400	5	48	58	54	63	15
500	6	27	16	19	19	1
600	0	6	1	1	1	1

Mean all	25
Mean inner	44
Max in diagram	68
Max measured	80

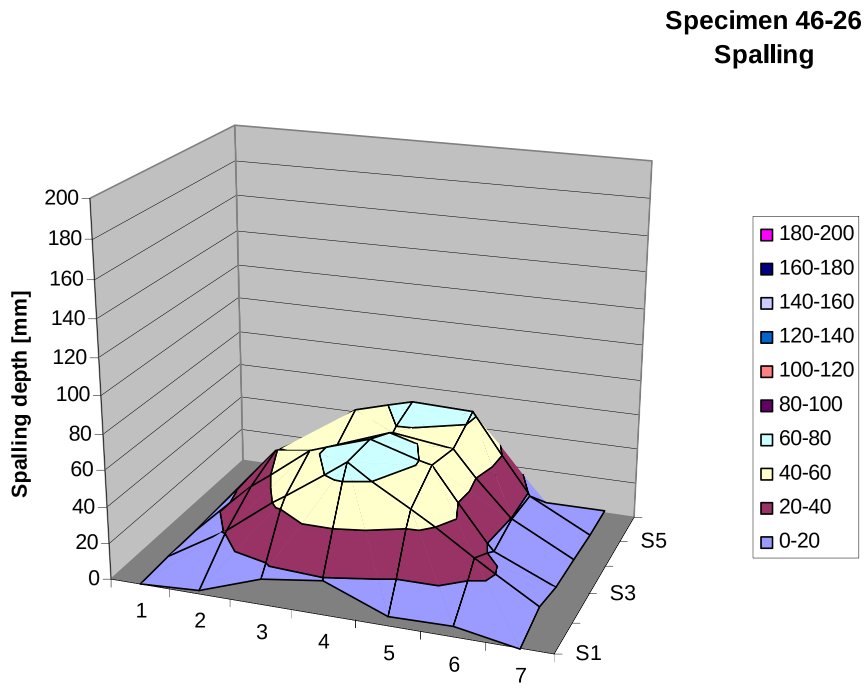


Figure A.628 Spalling measurements on specimen 46-26.

Table A.343 Observations made on specimen 46-26.

Time	Observation
0,00	Start of test
11,00	One small explosion, continuous spalling
12,50	One loud explosion
14,33	One loud explosion
30,00	Water on top surface
35,00	Cracks and water on sides
37,00	Spalling stopped
60,50	Test terminated

Test date:	2007-03-29	
Specimen:	46-26	
Load level:	104	kN/bar
Weight loss:	21,7	kg

Figure A.629 Specimen 46-26 after test.

Specimen 46-27

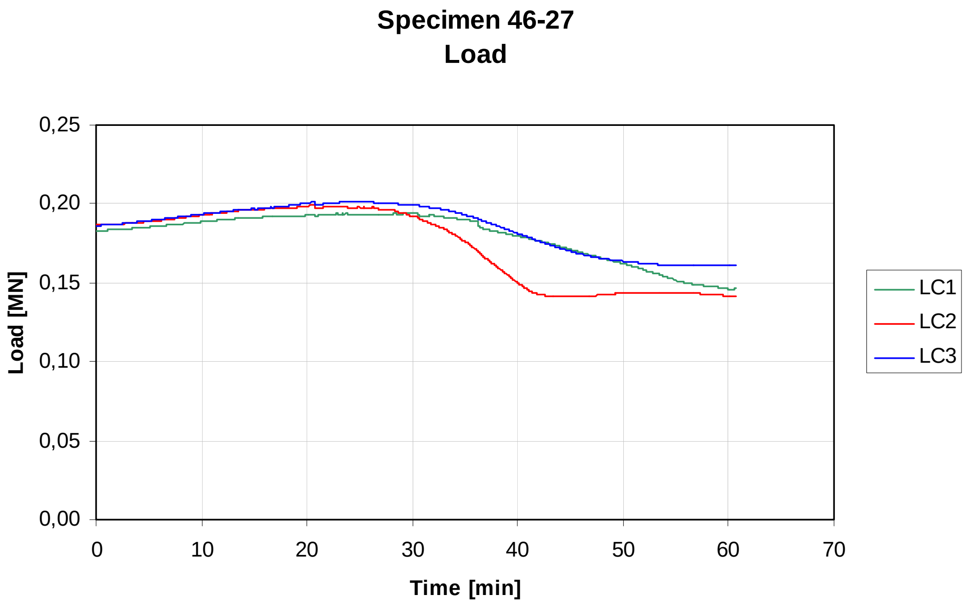


Figure A.630 Load measurements on specimen 46-27.

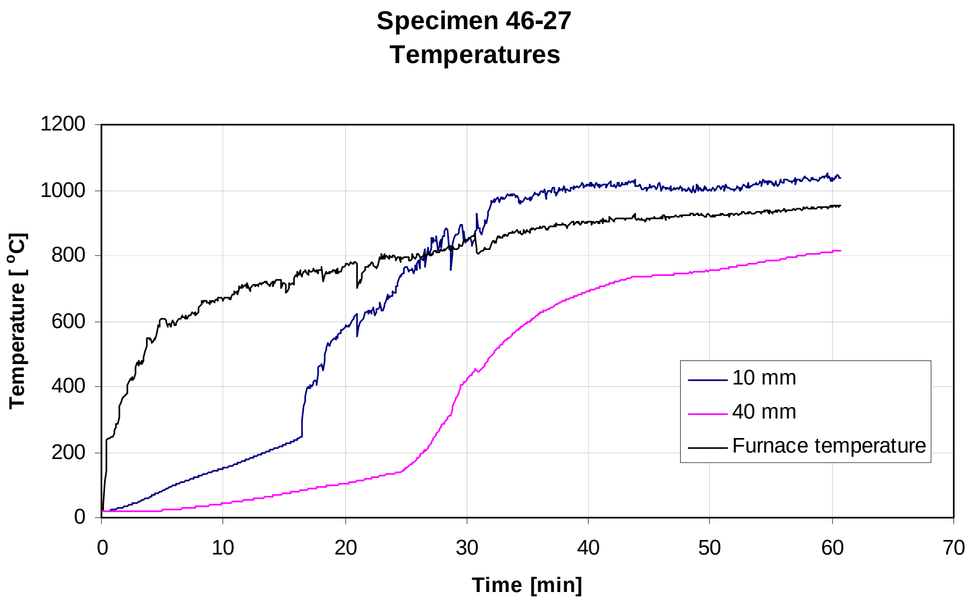


Figure A.631 Measured temperatures in furnace and in specimen 46-27.

Table A.344 Spalling measurements on specimen 46-27.

Position	0	100	200	300	400	500
0	0	0	2	3	0	0
100	10	41	54	37	25	0
200	19	51	50	57	45	2
300	30	46	40	57	42	6
400	13	22	32	48	29	0
500	0	18	24	49	19	0
600	0	0	0	0	0	0

Mean all	21
Mean inner	39
Max in diagram	57
Max measured	61

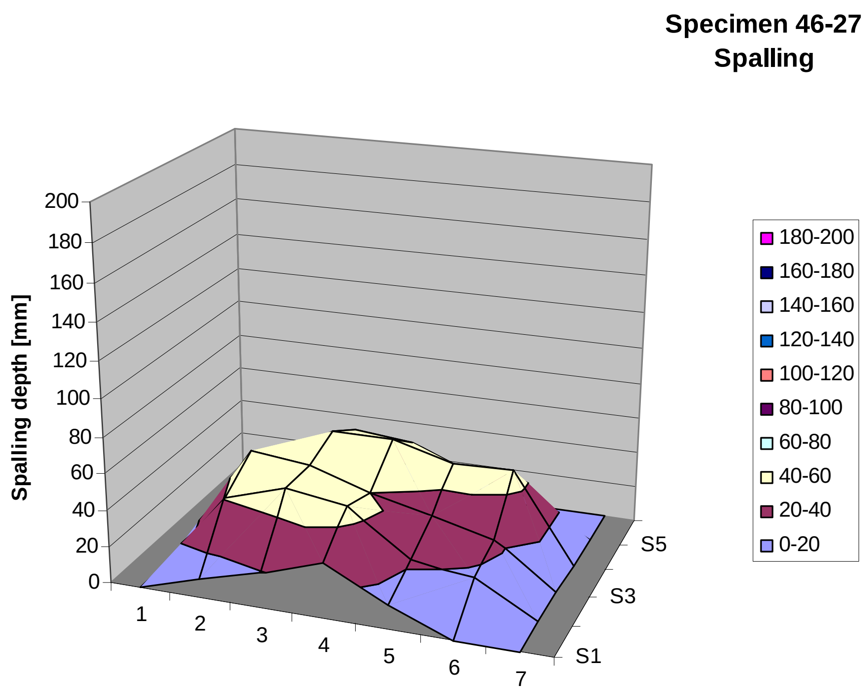


Figure A.632 Spalling measurements on specimen 46-27.

Table A.345 Observations made on specimen 46-27.

Time	Observation
0,00	Start of test
11,17	One small explosion
12,00	One loud explosion
13,67	One explosion
14,00	One explosion, continuous spalling
21,00	One loud explosion
30,00	One loud explosion, large crack formed
36,50	One loud explosion, large crack formed
37,00	Spalling stopped
60,67	Test terminated

Test date:	2007-03-30	
Specimen:	46-27	
Load level:	185	kN/bar
Weight loss:	16,7	kg

Figure A.633 Specimen 46-27 after test.

Specimen 46-28

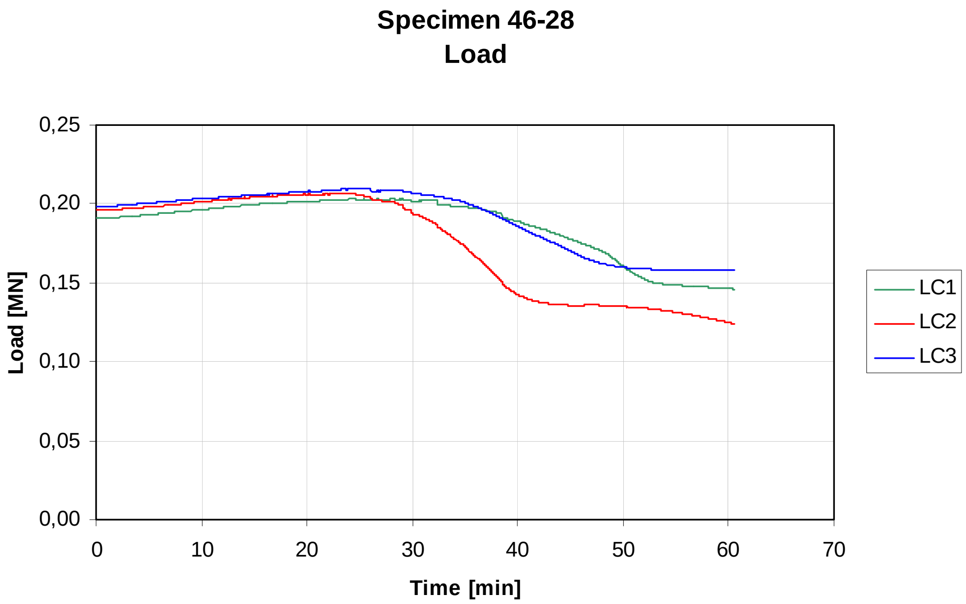


Figure A.634 Load measurements on specimen 46-28.

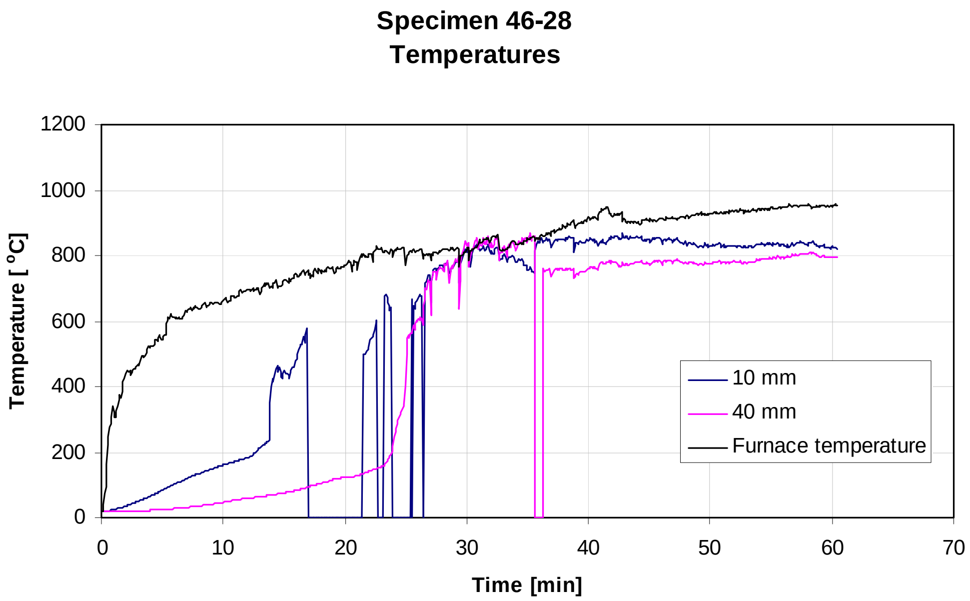


Figure A.635 Measured temperatures in furnace and in specimen 46-28.

Table A.346 Spalling measurements on specimen 46-28.

Position	0	100	200	300	400	500
0	0	0	4	2	1	1
100	17	40	57	49	27	1
200	20	58	73	68	49	11
300	18	53	67	65	56	24
400	37	49	58	61	64	5
500	36	44	28	46	44	0
600	0	0	0	0	0	0

Mean all	29
Mean inner	53
Max in diagram	73
Max measured	76

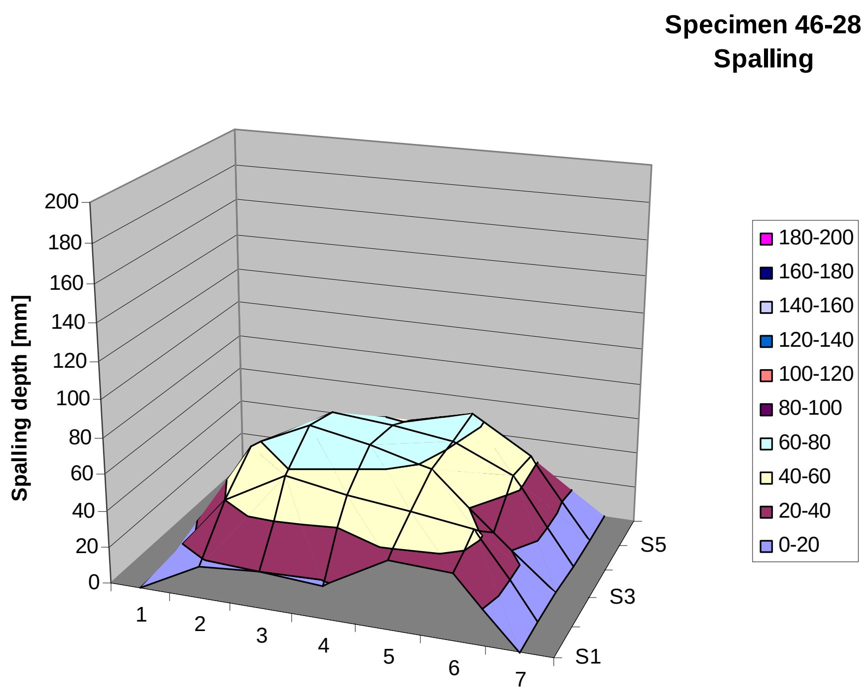


Figure A.636 Spalling measurements on specimen 46-28.

Table A.347 Observations made on specimen 46-28.

Time	Observation
0,00	Start of test
10,25	One explosion
11,25	One explosion, continuous spalling
15,33	One loud explosion
41,00	Spalling stopped
41,00	Cracks and water on sides
55,00	Water on top surface
60,50	Test terminated

Test date:	2007-04-02	
Specimen:	46-28	
Load level:	195	kN/bar
Weight loss:	24,8	kg

Figure A.637 Specimen 46-28 after test.

Concrete 47

Table A.348 Concrete admixture recipe 47.

Recipe	**47**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	140
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	9,00
Sikament 20HE 50 (% of cement weight)	2,14
Fiber, Sika Crackstop, ϕ=18 μm, l=12 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	580
T50 (s)	7
Air (%)	2.9
Compressive strength, 28 days (MPa)	72.6

Specimen 47-1

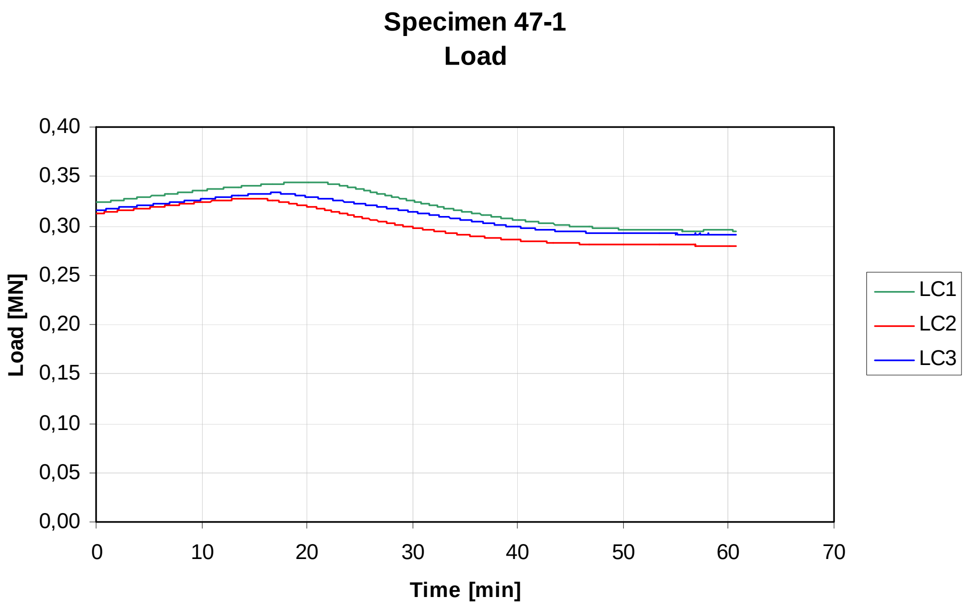


Figure A.638 Load measurements on specimen 47-1.

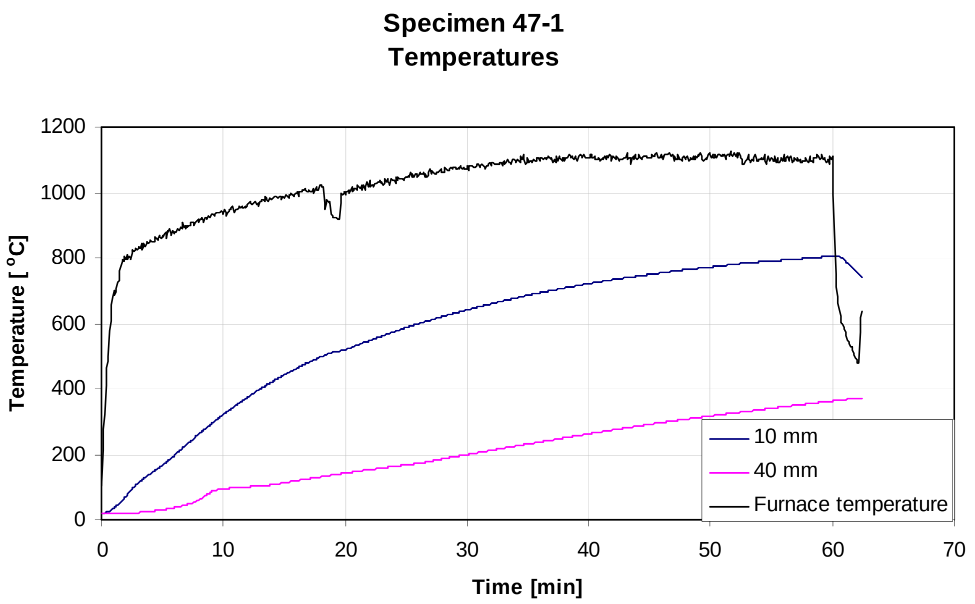


Figure A.639 Measured temperatures in furnace and in specimen 47-1.

Table A.349 Spalling measurements on specimen 47-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

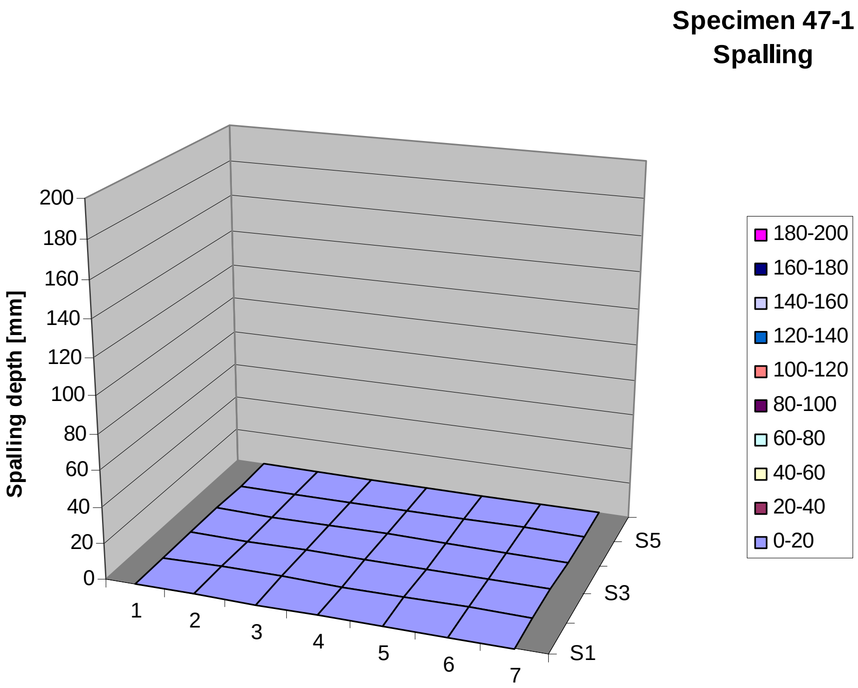


Figure A.640 Spalling measurements on specimen 47-1.

Table A.350 Observations made on specimen 47-1.

Time	Observation			
0,00	Start of test	Test date:	2007-07-12	
60,50	Test terminated	Specimen:	47-1	
		Load level:	317	kN/bar
		Weight loss:	3,0	kg

Specimen 47-2

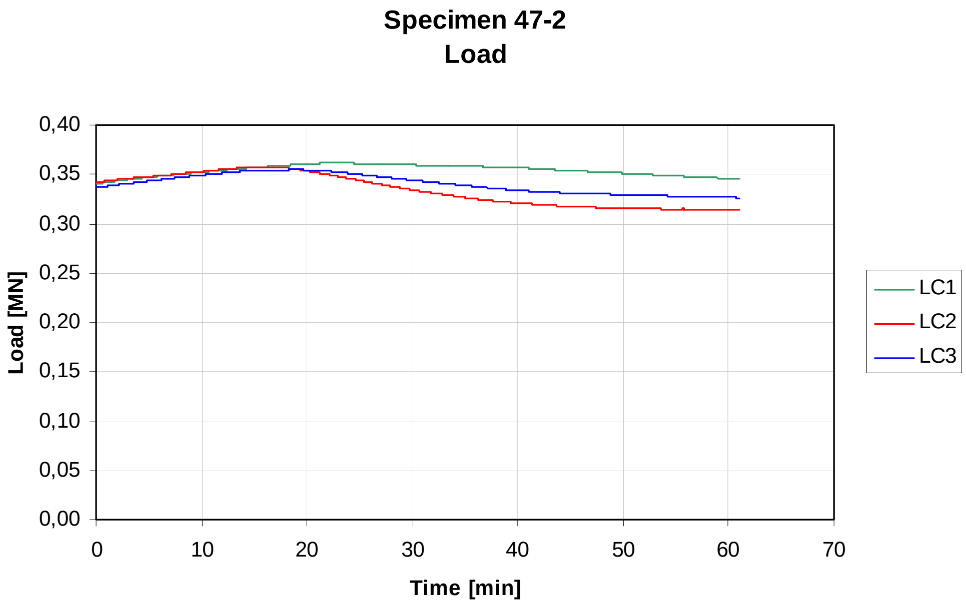


Figure A.641 Load measurements on specimen 47-2.

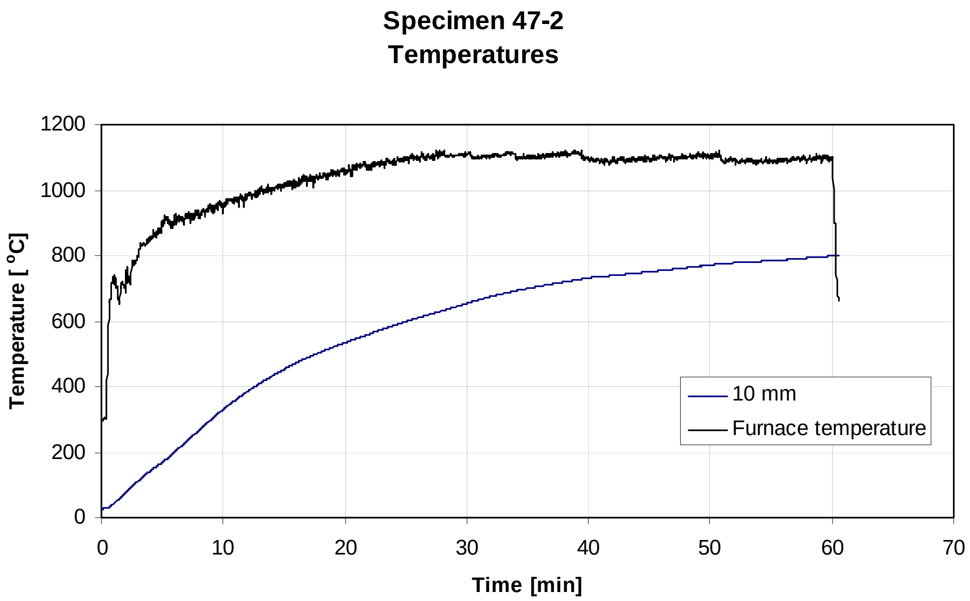


Figure A.642 Measured temperatures in furnace and in specimen 47-2.

Table A.351 Spalling measurements on specimen 47-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

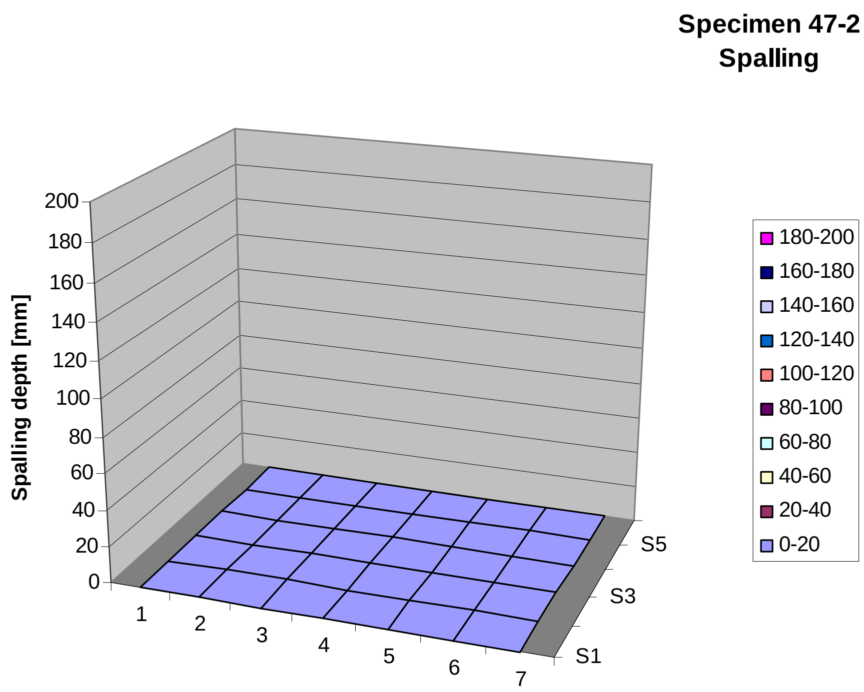


Figure A.643 Spalling measurements on specimen 47-2.

Table A.352 Observations made on specimen 47-2.

Time	Observation
0,00	Start of test
35,00	Crack on sides
60,50	Test terminated

Test date:	2007-07-12	
Specimen:	47-2	
Load level:	340	kN/bar
Weight loss:	3,1	kg

Concrete 50

Table A.353 Concrete admixture recipe 50.

Recipe	**50**
Water (kg/m^3)	198
CEM II 42,5R A-LL (kg/m^3)	380
Limestone filler, Limus 25 (kg/m^3)	60
Water-powder ratio, w/p	0,45
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	6,6
Sikament 20HE 50 (% of cement weight)	1,74
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	1,5
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	580
T50 (s)	3
Air (%)	6
Compressive strength, 28 days (MPa)	35.5

Specimen 50-1

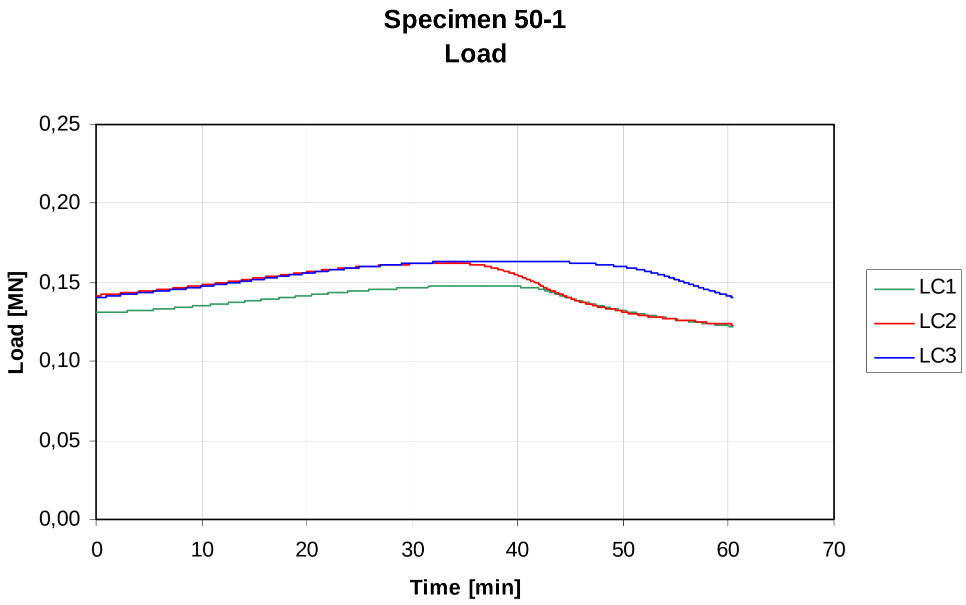


Figure A.644 Load measurements on specimen 50-1.

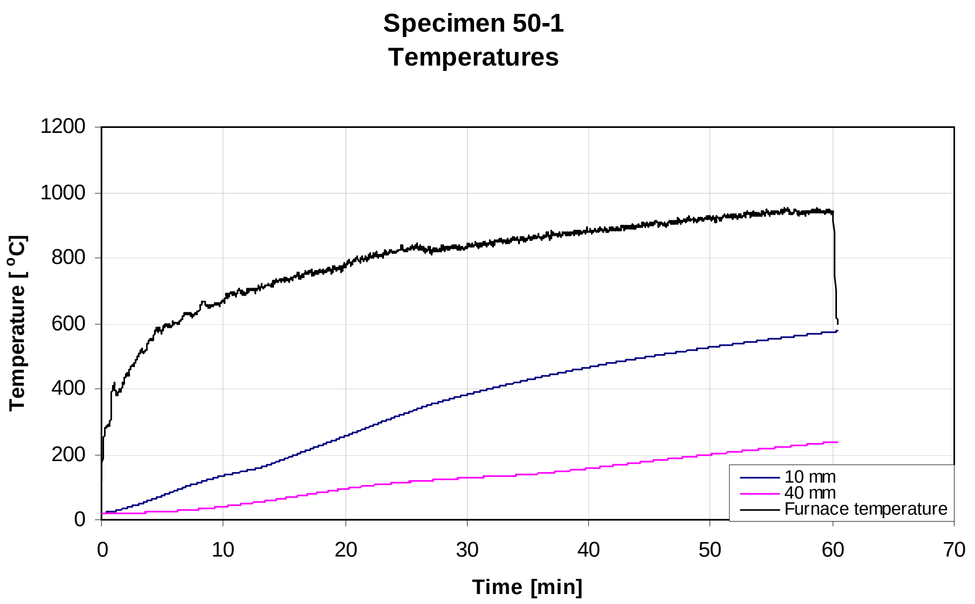


Figure A.645 Measured temperatures in furnace and in specimen 50-1.

Table A.354 Spalling measurements on specimen 50-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

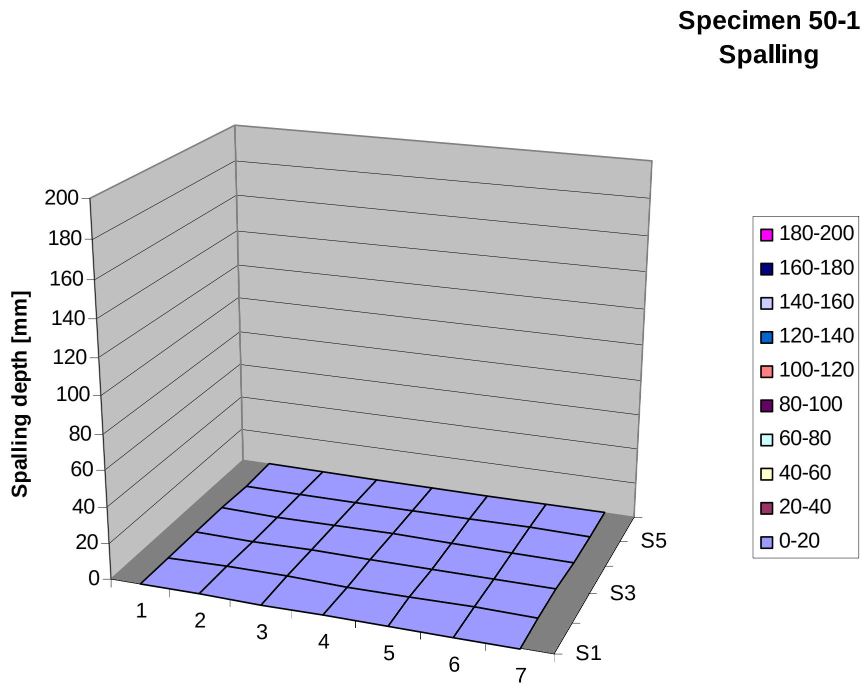


Figure A.646 Spalling measurements on specimen 50-1.

Table A.355 Observations made on specimen 50-1.

Time	Observation			
0,00	Start of test	Test date:	2007-07-13	
30,00	Water on top surface	Specimen:	50-1	
60,00	Test terminated	Load level:	138	kN/bar
		Weight loss:	-.	kg

Specimen 50-2

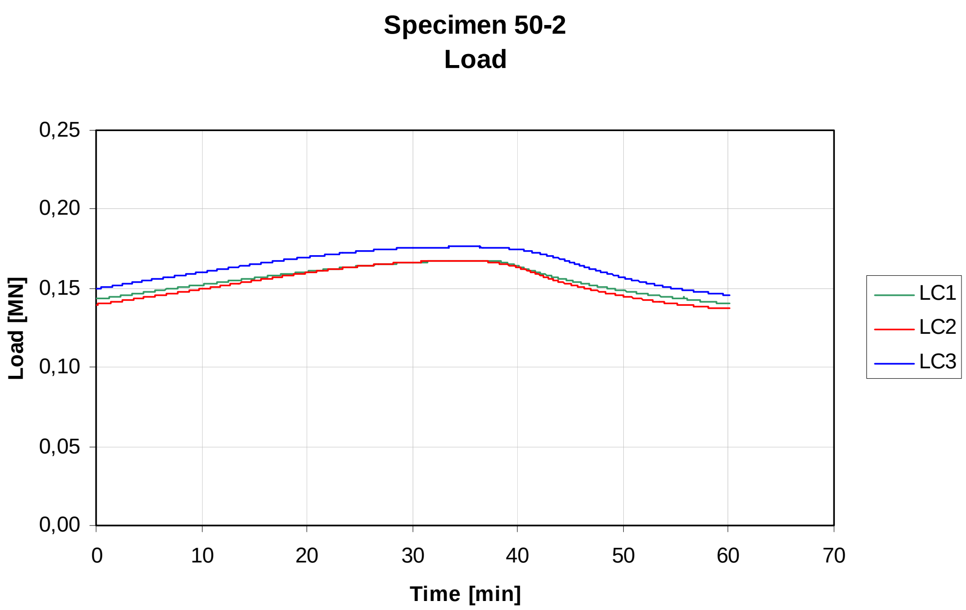


Figure A.647 Load measurements on specimen 50-2.

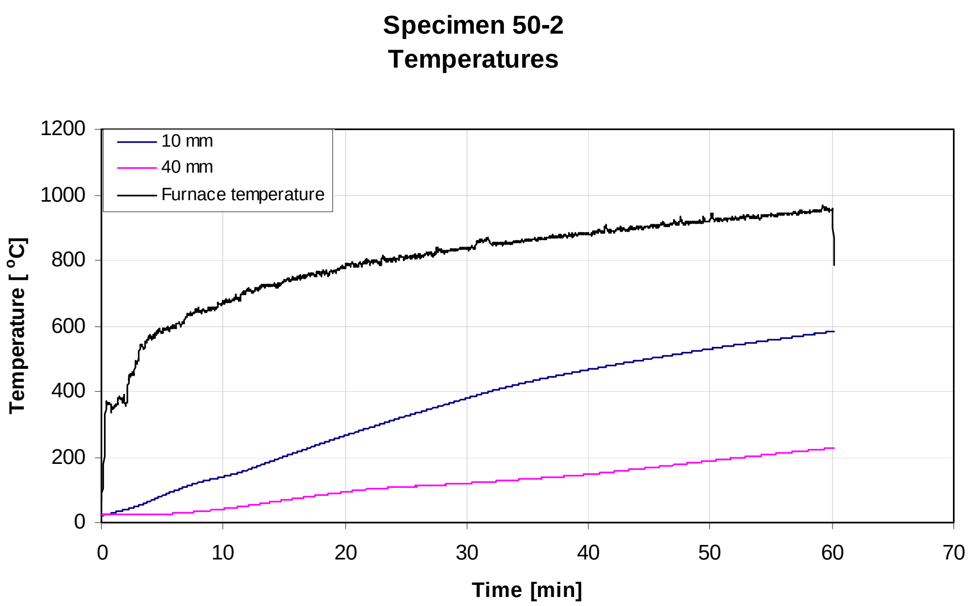


Figure A.648 Measured temperatures in furnace and in specimen 50-2.

Table A.356 Spalling measurements on specimen 50-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

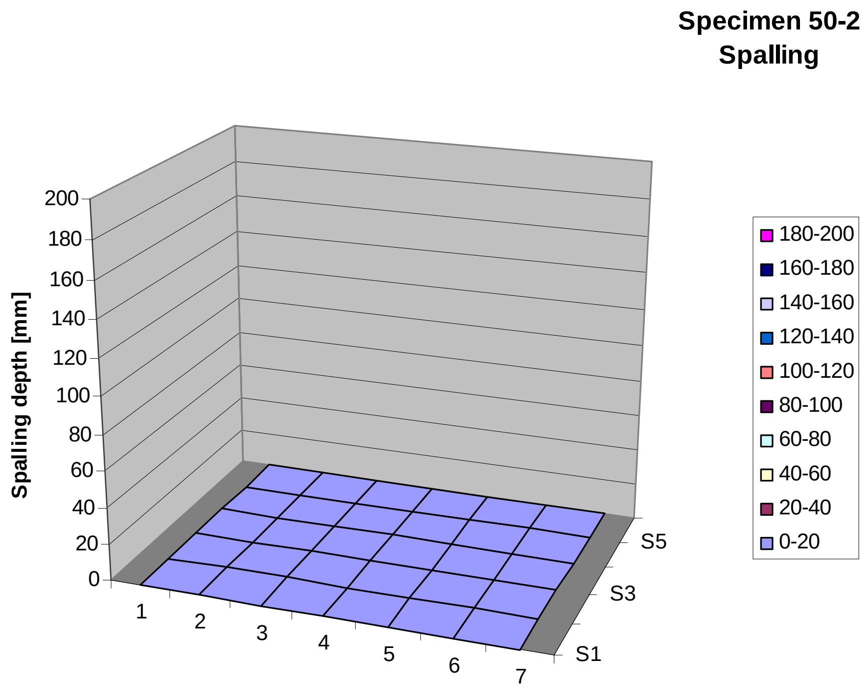


Figure A.649 Spalling measurements on specimen 50-2.

Table A.357 Observations made on specimen 50-2.

Time	Observation
0,00	Start of test
31,00	Water on top surface
60,00	Test terminated

Test date:	2007-07-13	
Specimen:	50-2	
Load level:	144	kN/bar
Weight loss:	1,3	kg

Concrete 51

Table A.358 Concrete admixture recipe 51.

Recipe	51
Water (kg/m^3)	220
CEM I 42,5N BV/LA/SR (kg/m^3)	550
Limestone filler, Limus 25 (kg/m^3)	0
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	5,00
Sikament 20HE 50 (% of cement weight)	0,91
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	1,35
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	680
T50 (s)	3
Air (%)	4.5
Compressive strength, 28 days (MPa)	61.5

Specimen 51-3

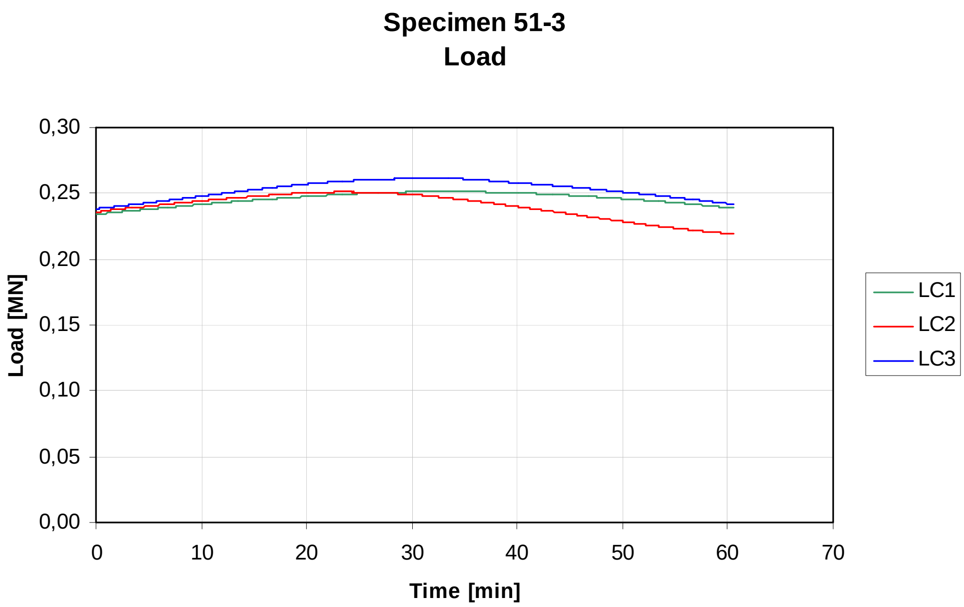


Figure A.650 Load measurements on specimen 51-3.

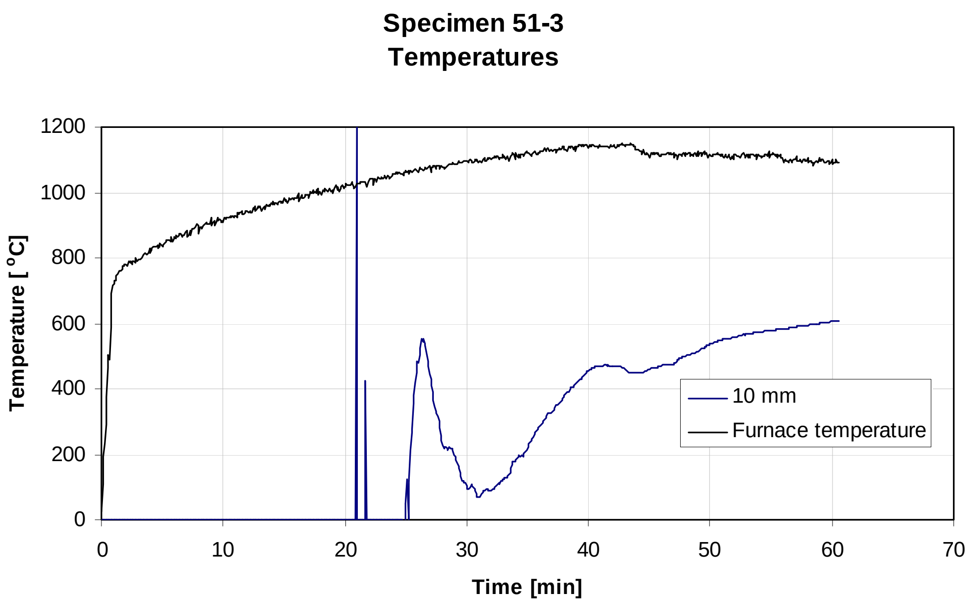


Figure A.651 Measured temperatures in furnace and in specimen 51-3.

Table A.359 Spalling measurements on specimen 51-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

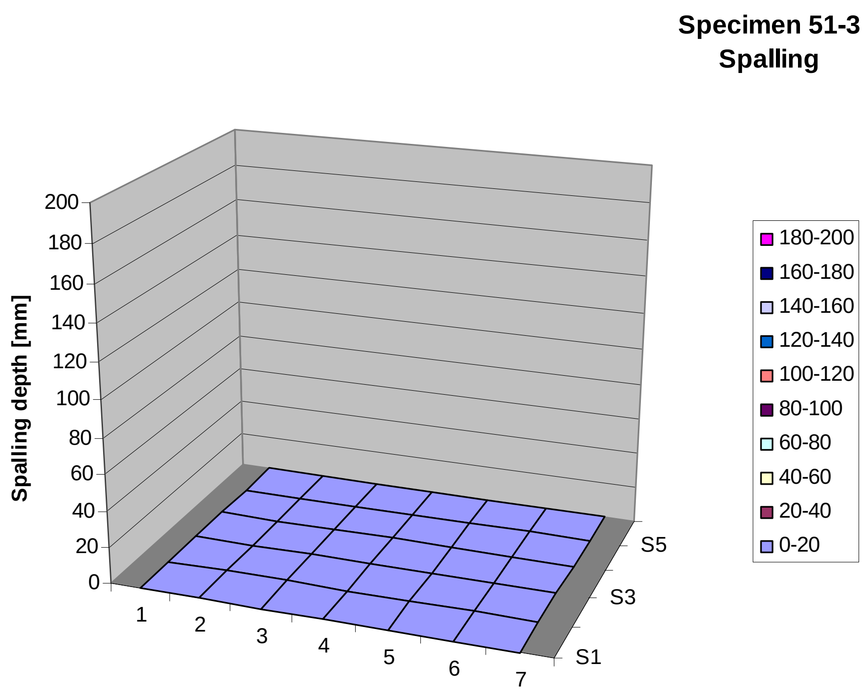


Figure A.652 Spalling measurements on specimen 51-3.

Table A.360 Observations made on specimen 51-3.

Time	Observation			
0,00	Start of test			
60,50	Test terminated			

Test date:	2007-08-20	
Specimen:	51-3	
Load level:	236	kN/bar
Weight loss:	2,9	kg

Figure A.653 Specimen 51-3 after test.

Specimen 51-4

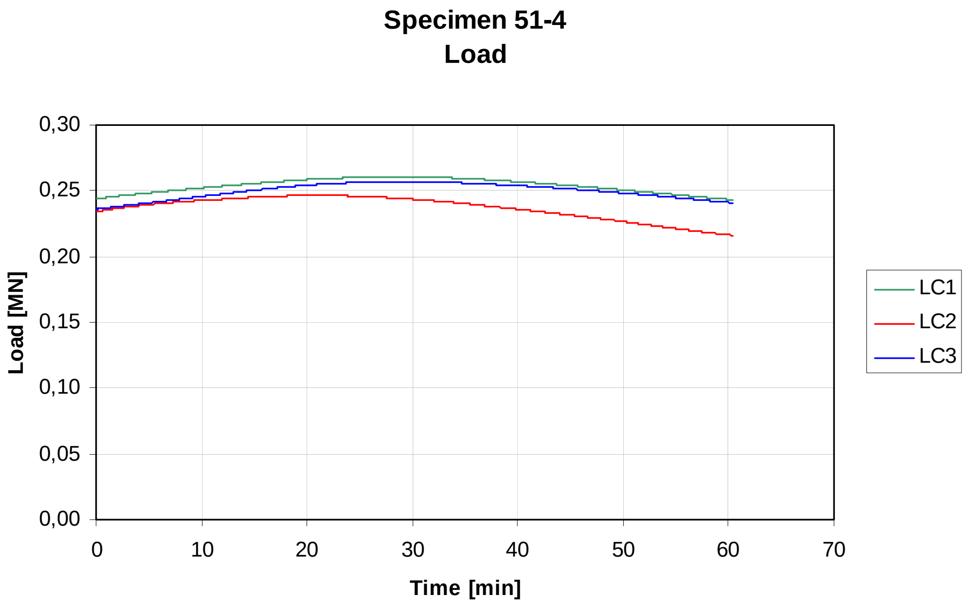


Figure A.654 Load measurements on specimen 51-4.

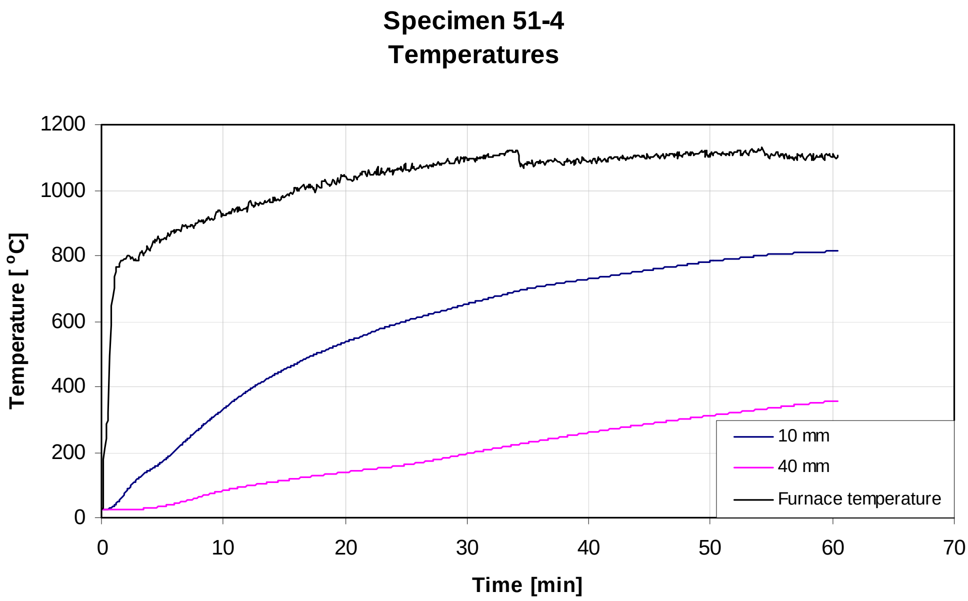


Figure A.655 Measured temperatures in furnace and in specimen 51-4.

Table A.361 Spalling measurements on specimen 51-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

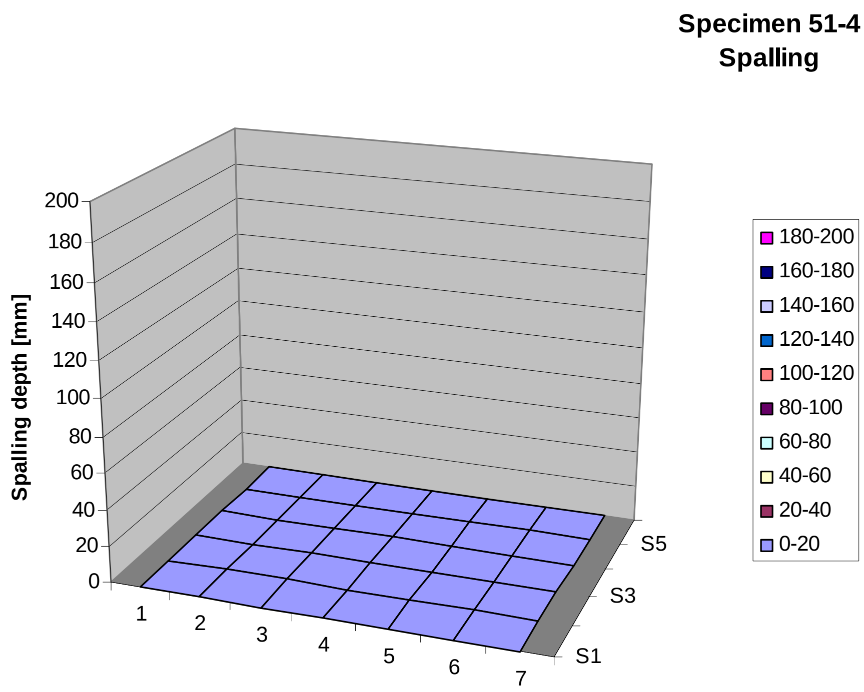


Figure A.656 Spalling measurements on specimen 51-4.

Table A.362 Observations made on specimen 51-4.

Time	Observation
0,00	Start of test
15,00	Water on top surface
25,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-08-21	
Specimen:	51-4	
Load level:	238	kN/bar
Weight loss:	3,6	kg

Figure A.657 Specimen 51-4 after test.

Concrete 52

Table A.363 Concrete admixture recipe 52.

Recipe	52
Water (kg/m^3)	220
CEM I 42,5N BV/LA/SR (kg/m^3)	550
Limestone filler, Limus 25 (kg/m^3)	0
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	8,00
Sikament 20HE 50 (% of cement weight)	1,45
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	3,0
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	570
T50 (s)	3
Air (%)	8
Compressive strength, 28 days (MPa)	58.0

Specimen 52-3

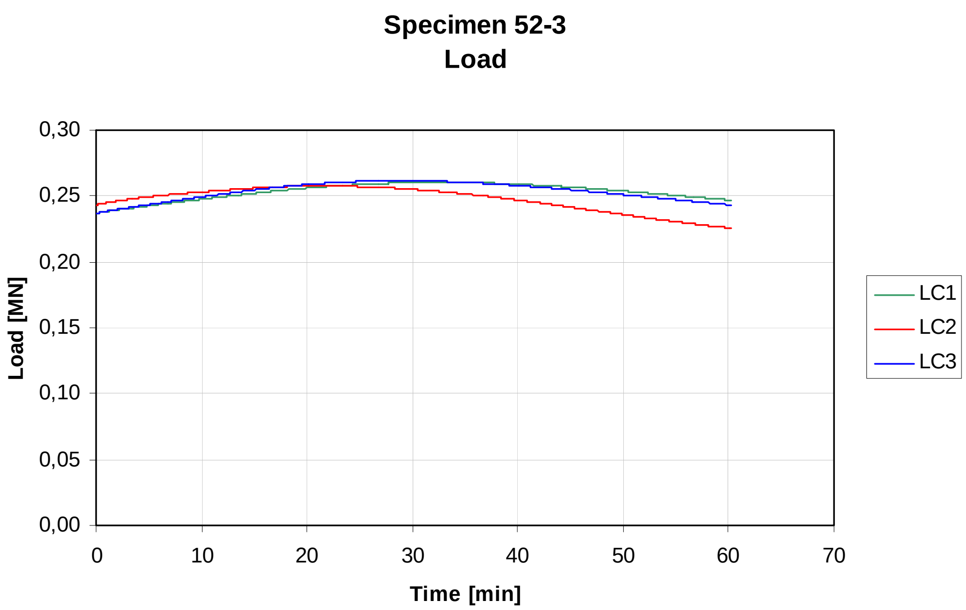


Figure A.658 Load measurements on specimen 52-3.

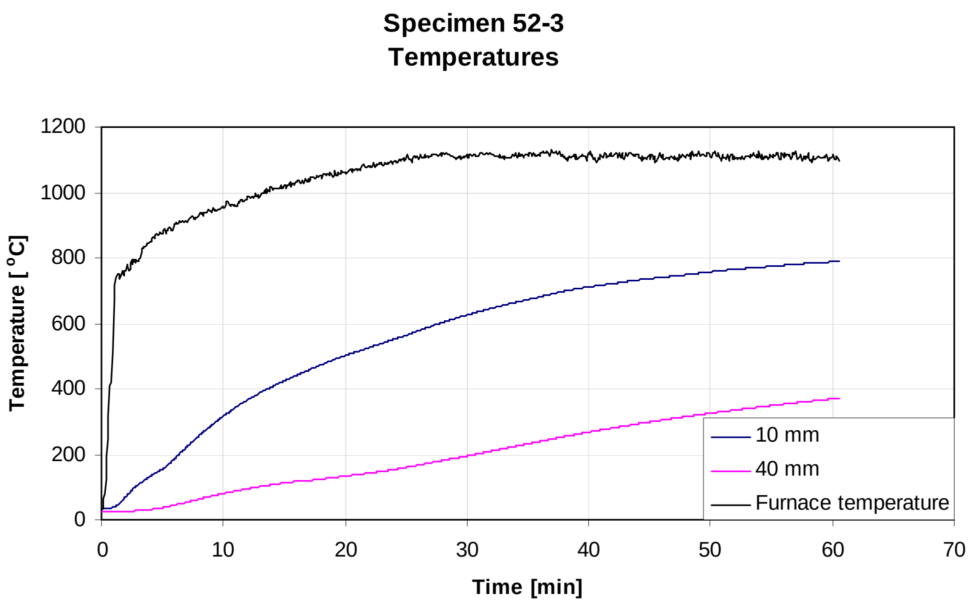


Figure A.659 Measured temperatures in furnace and in specimen 52-3.

Table A.364 Spalling measurements on specimen 52-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

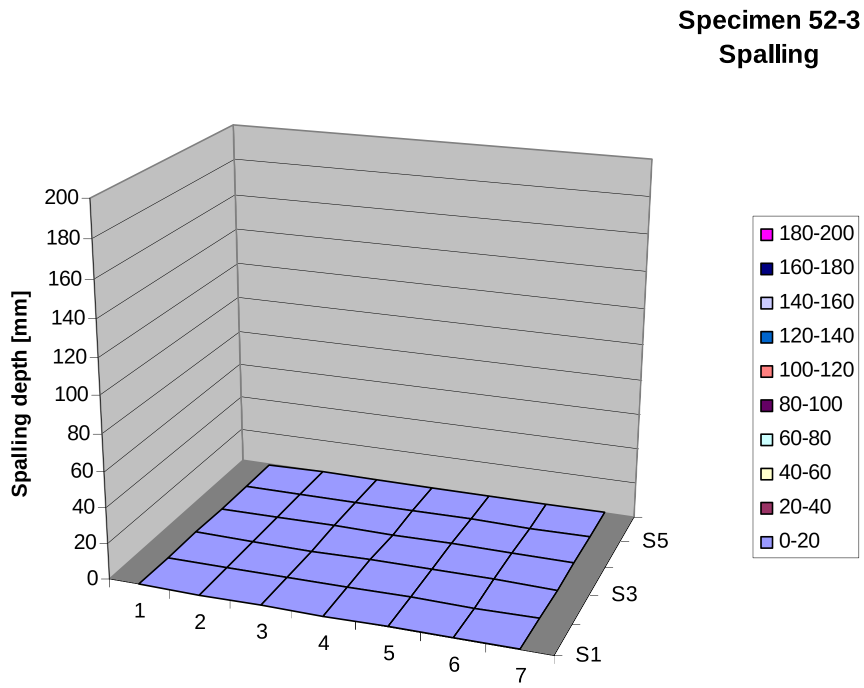


Figure A.660 Spalling measurements on specimen 52-3.

Table A.365 Observations made on specimen 52-3.

Time	Observation			
0,00	Start of test	Test date:	2007-08-21	
18,00	Water on top surface	Specimen:	52-3	
60,50	Test terminated	Load level:	239	kN/bar
		Weight loss:	-	kg

Figure A.661 Specimen 52-3 after test.

Specimen 52-4

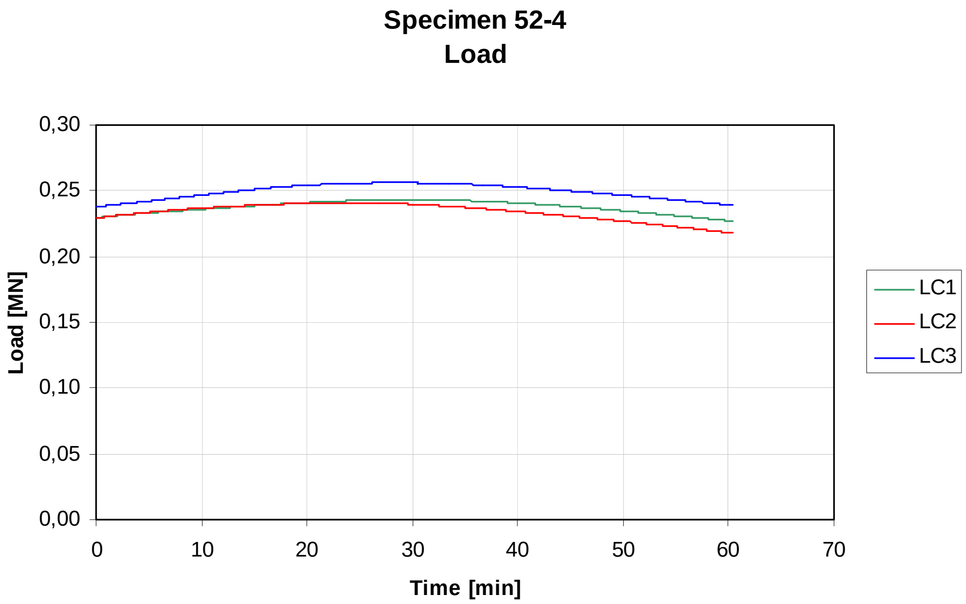


Figure A.662 Load measurements on specimen 52-4.

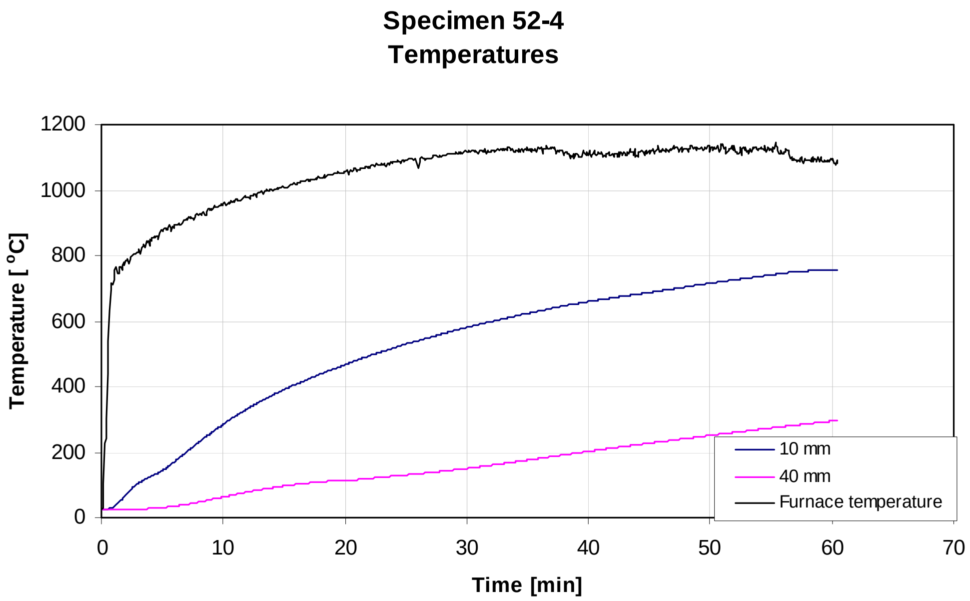


Figure A.663 Measured temperatures in furnace and in specimen 52-4.

Table A.366 Spalling measurements on specimen 52-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

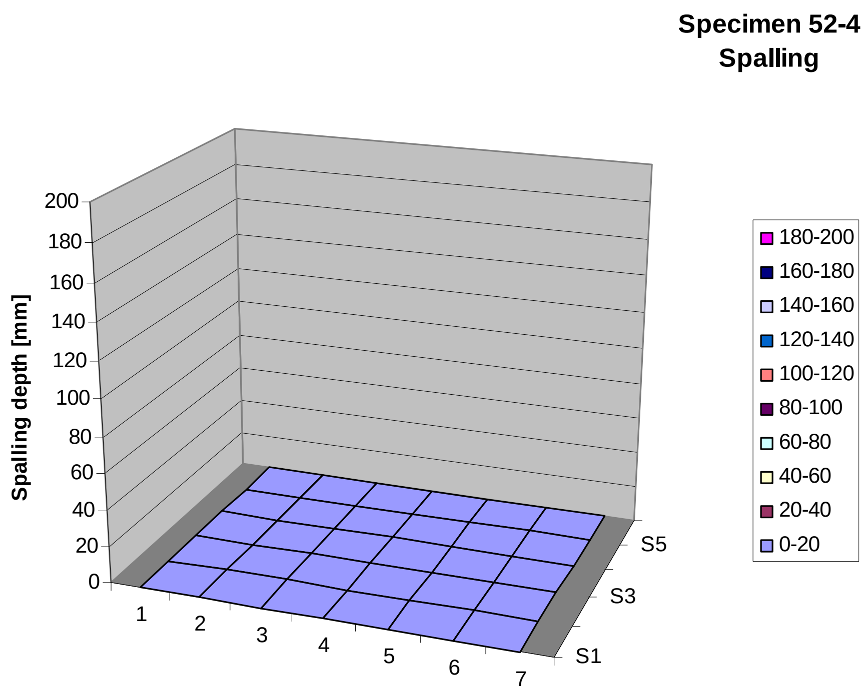


Figure A.664 Spalling measurements on specimen 52-4.

Table A.367 Observations made on specimen 52-4.

Time	Observation
0,00	Start of test
55,00	Water on top surface
60,50	Test terminated

Test date:	2007-08-22	
Specimen:	52-4	
Load level:	232	kN/bar
Weight loss:	2,5	kg

Figure A.665 Specimen 52-4 after test.

Concrete 53

Table A.368 Concrete admixture recipe 53.

Recipe	**53**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	140
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	7,0
Sikament 20HE 50 (% of cement weight)	1,67
Sika Aer-S (10%-ig)	4,0
Sika Aer-S (% of cement weight)	0,95
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	700
T50 (s)	3
Air (%)	12
Compressive strength, 28 days (MPa)	37.5

Specimen 53-1

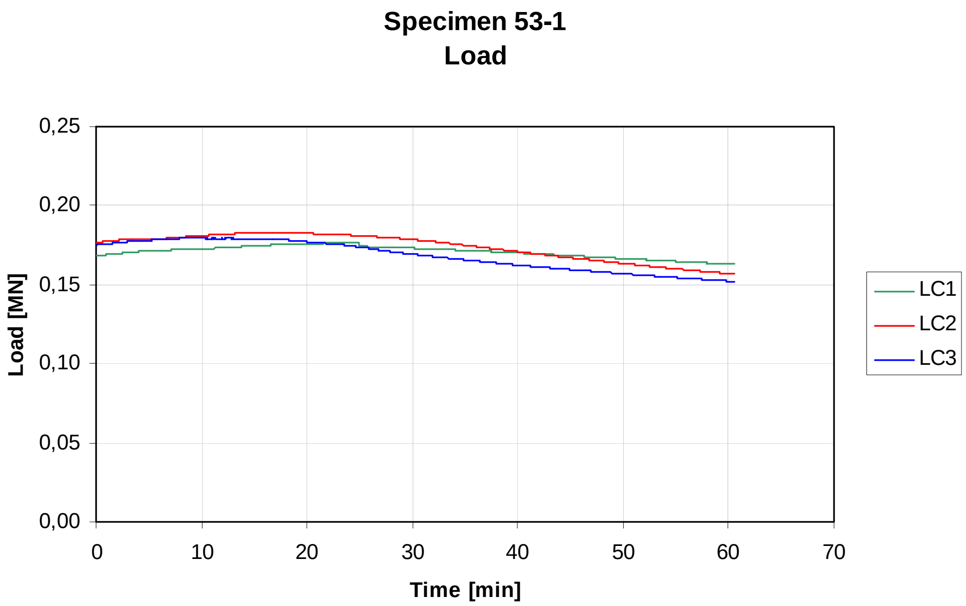


Figure A.666 Load measurements on specimen 53-1.

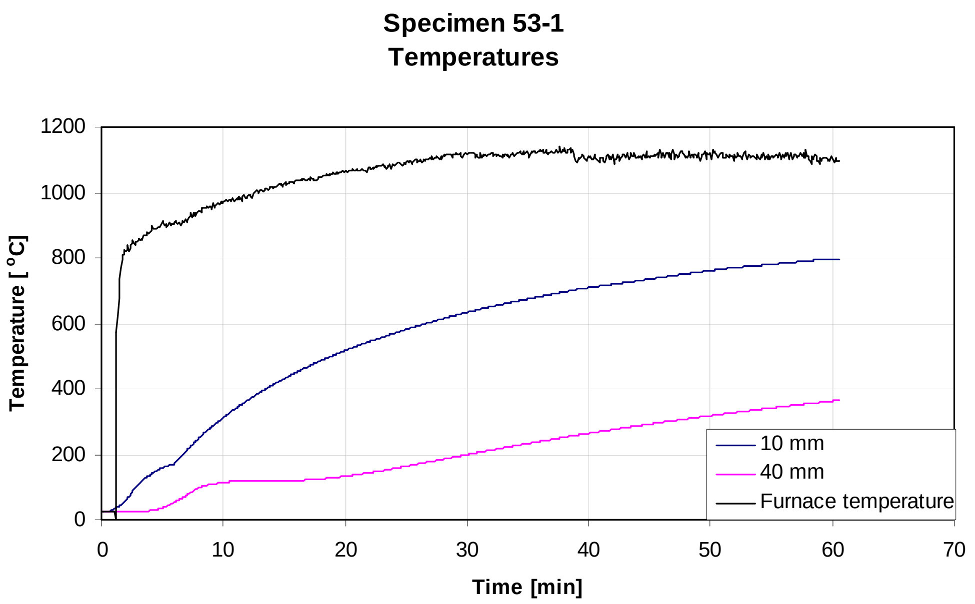


Figure A.667 Measured temperatures in furnace and in specimen 53-1.

Table A.369 Spalling measurements on specimen 53-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	4	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	4
Max measured	4

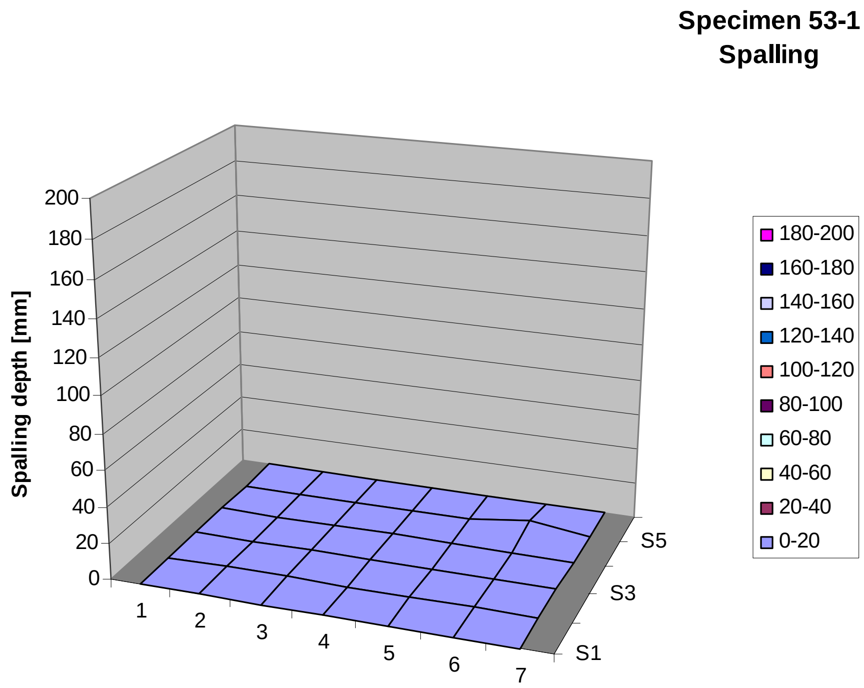


Figure A.668 Spalling measurements on specimen 53-1.

Table A.370 Observations made on specimen 53-1.

Time	Observation			
0,00	Start of test	Test date:	2007-08-23	
22,00	Water on top surface	Specimen:	53-1	
22,00	Cracks and water on sides	Load level:	173	kN/bar
60,50	Test terminated	Weight loss:	2,7	kg

Figure A.669 Specimen 53-1 after test.

Specimen 53-2

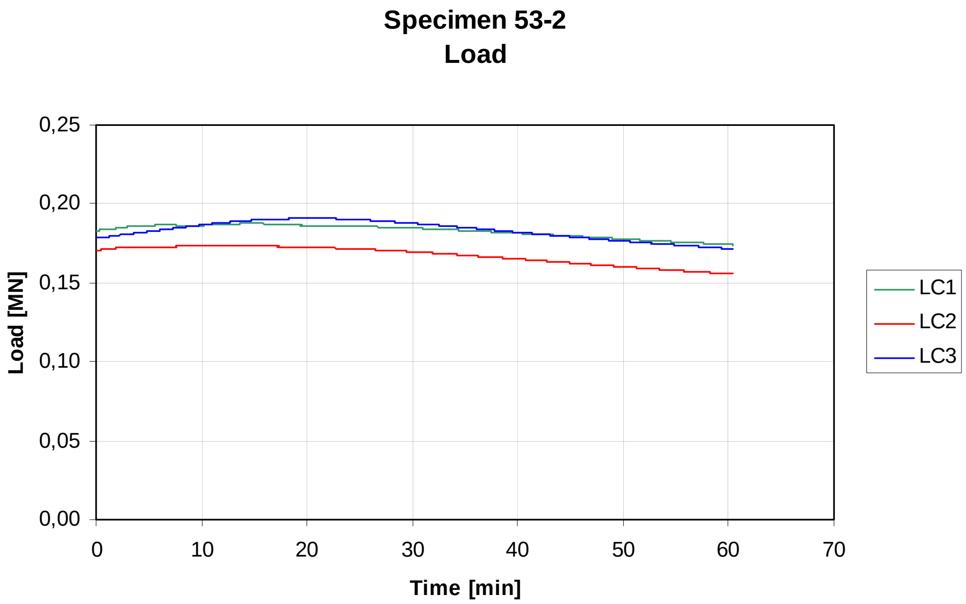


Figure A.670 Load measurements on specimen 53-2.

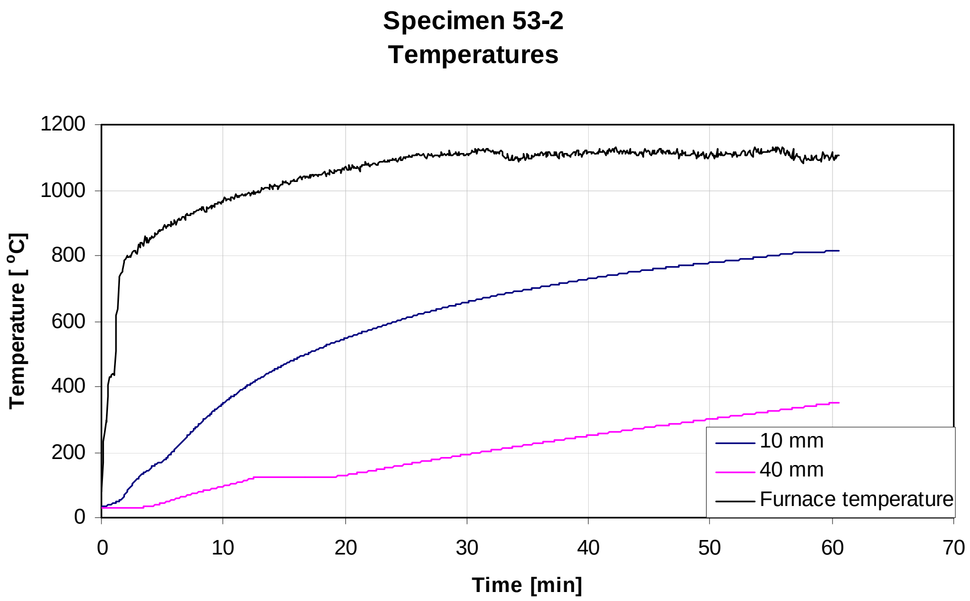


Figure A.671 Measured temperatures in furnace and in specimen 53-2.

Table A.371 Spalling measurements on specimen 53-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

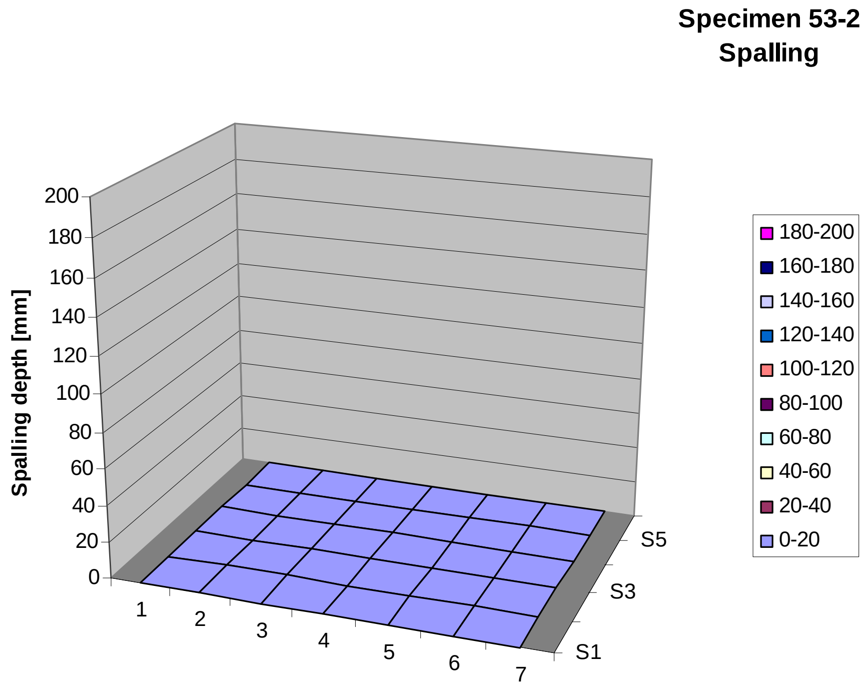


Figure A.672 Spalling measurements on specimen 53-2.

Table A.372 Observations made on specimen 53-2.

Time	Observation
0,00	Start of test
15,00	Water on top surface
60,50	Test terminated

Test date:	2007-08-23	
Specimen:	53-2	
Load level:	177	kN/bar
Weight loss:	2,2	kg

Figure A.673 Specimen 53-2 after test.

Concrete 54

Table A.373 Concrete admixture recipe 54.

Recipe	**54**
Water (kg/m^3)	168
CEM I 42,5N BV/LA/SR (kg/m^3)	420
Limestone filler, Limus 25 (kg/m^3)	140
Water-powder ratio, w/p	0,30
Water-cement ratio, w/c	0,40
Sikament 20HE 50 (20% torrhalt)	7,0
Sikament 20HE 50 (% of cement weight)	1,67
Sika Aer-S (10%-ig)	3,5
Sika Aer-S (% of cement weight)	0,84
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	1,0
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	640
T50 (s)	5
Air (%)	14
Compressive strength, 28 days (MPa)	34.0

Specimen 54-3

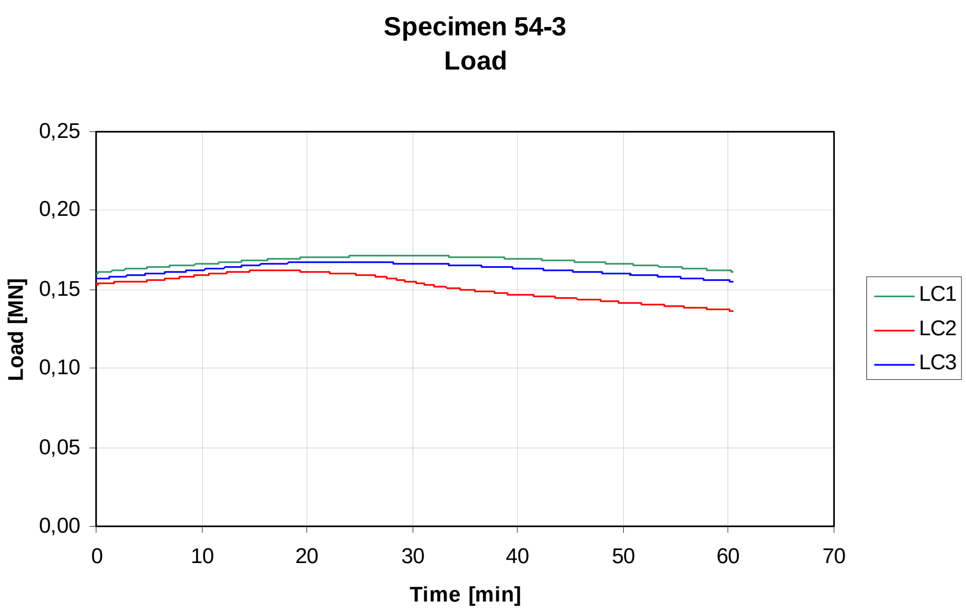


Figure A.674 Load measurements on specimen 54-3.

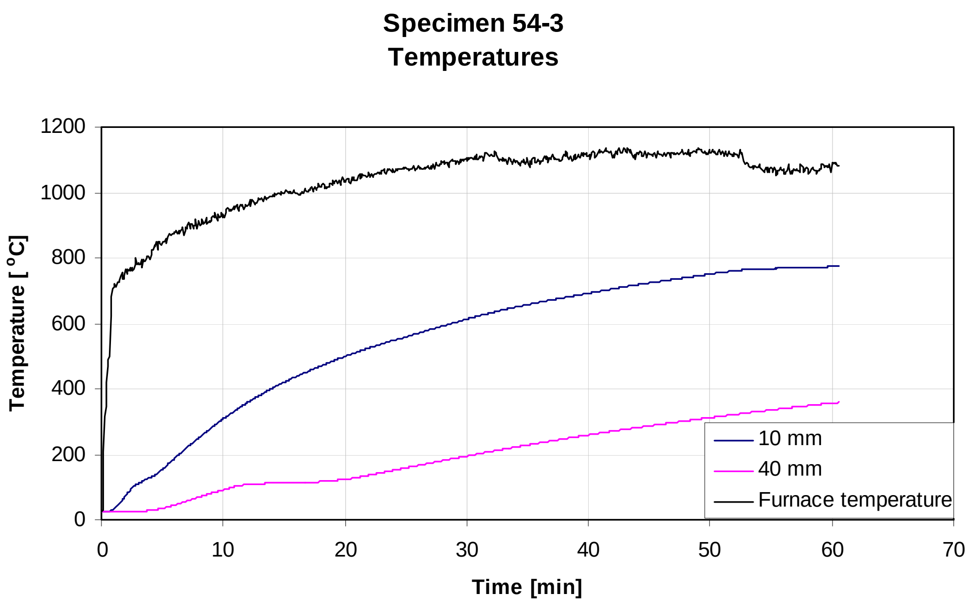


Figure A.675 Measured temperatures in furnace and in specimen 54-3.

Table A.374 Spalling measurements on specimen 54-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

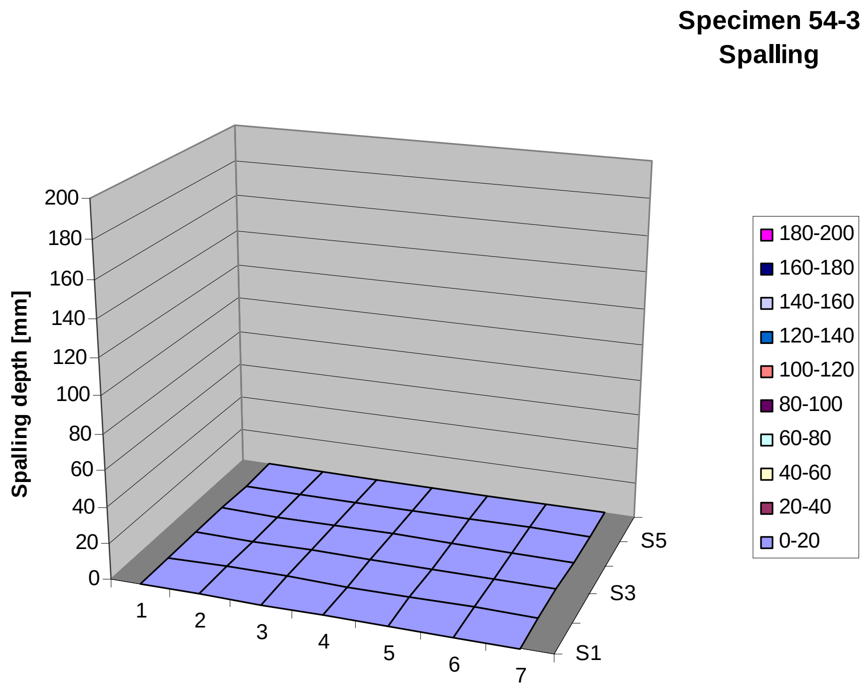


Figure A.676 Spalling measurements on specimen 54-3.

Table A.375 Observations made on specimen 54-3.

Time	Observation			
0,00	Start of test	Test date:	2007-08-24	
30,00	Water onsides and top surface	Specimen:	54-3	
60,50	Test terminated	Load level:	157	kN/bar
		Weight loss:	1,7	kg

Figure A.677 Specimen 54-3 after test.

Specimen 54-4

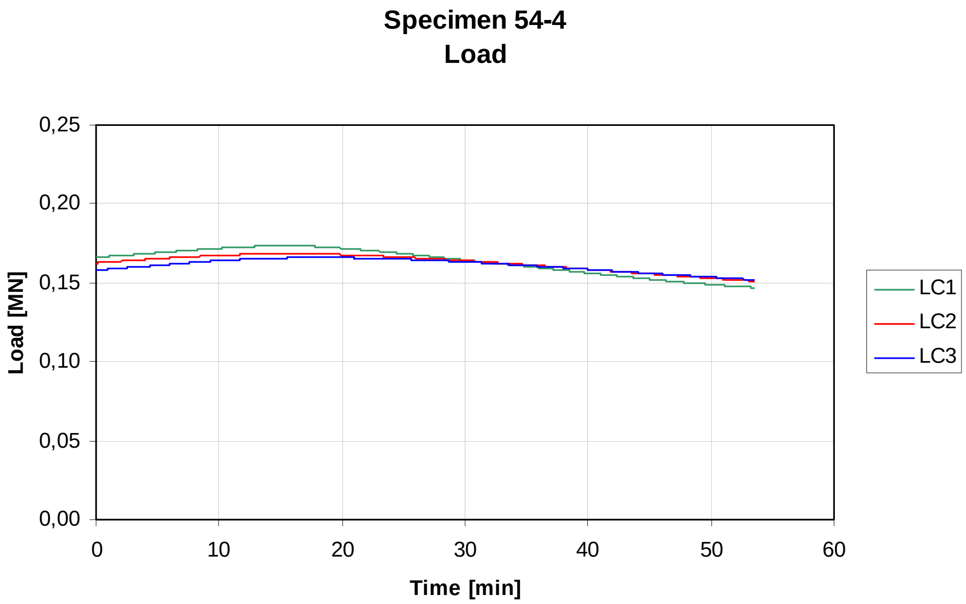


Figure A.678 Load measurements on specimen 54-4.

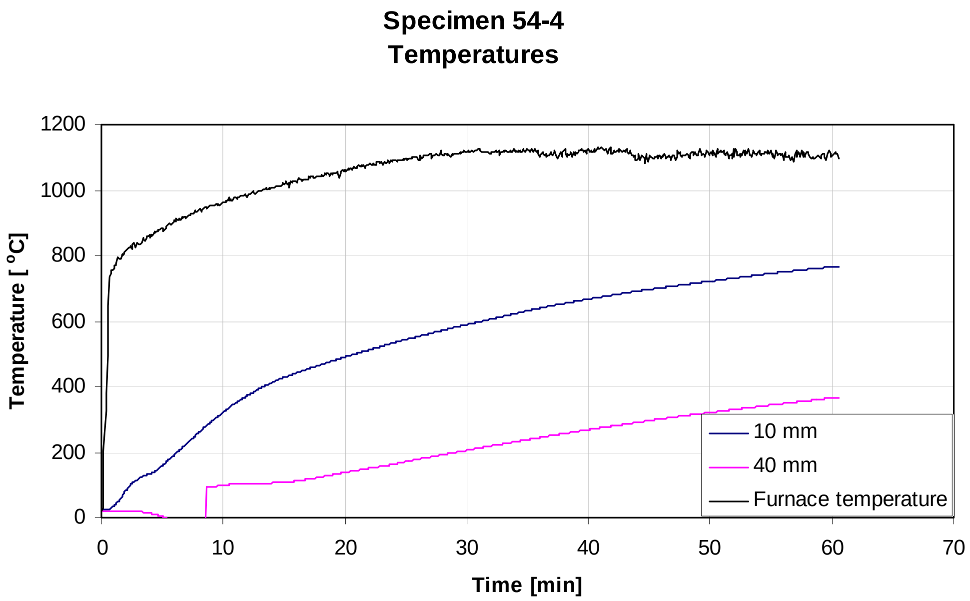


Figure A.679 Measured temperatures in furnace and in specimen 54-4.

Table A.376 Spalling measurements on specimen 54-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

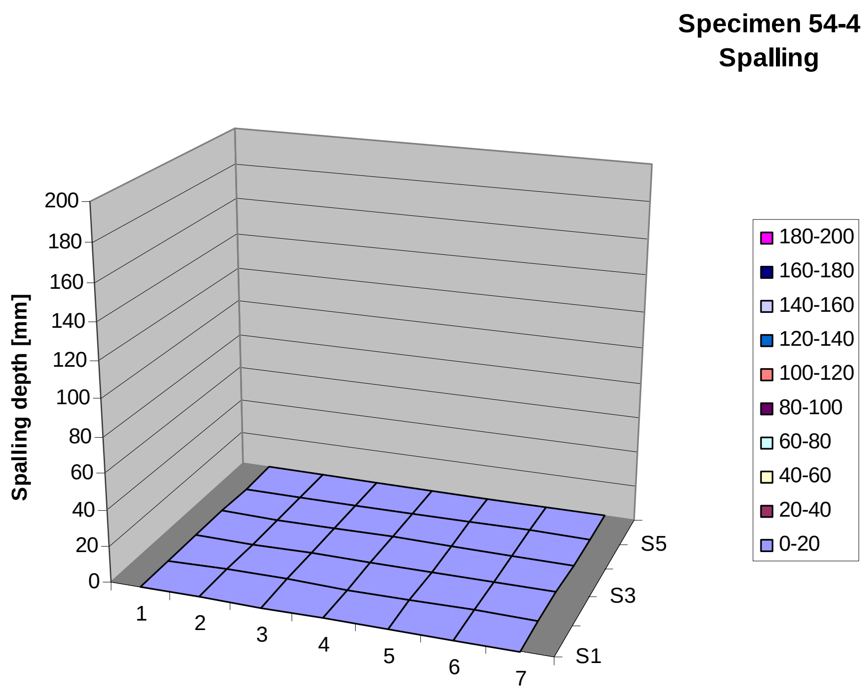


Figure A.680 Spalling measurements on specimen 54-4.

Table A.377 Observations made on specimen 54-4.

Time	Observation
0,00	Start of test
40,00	Water on sides
60,50	Test terminated

Test date:	2007-08-27
Specimen:	54-4
Load level:	162
Weight loss:	1,4

Figure A.681 Specimen 54-4 after test.

Concrete 55

Table A.378 Concrete admixture recipe 55.

Recipe	**55**
Water (kg/m^3)	224
CEM II 42,5R A-LL (kg/m^3)	430
Limestone filler, Limus 25 (kg/m^3)	124
Water-powder ratio, w/p	0,40
Water-cement ratio, w/c	0,52
Sikament 20HE 50 (20% torrhalt)	6,0
Sikament 20HE 50 (% of cement weight)	1,40
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	2,0
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	630
T50 (s)	2
Air (%)	3.5
Compressive strength, 28 days (MPa)	48.2

Specimen 55-1

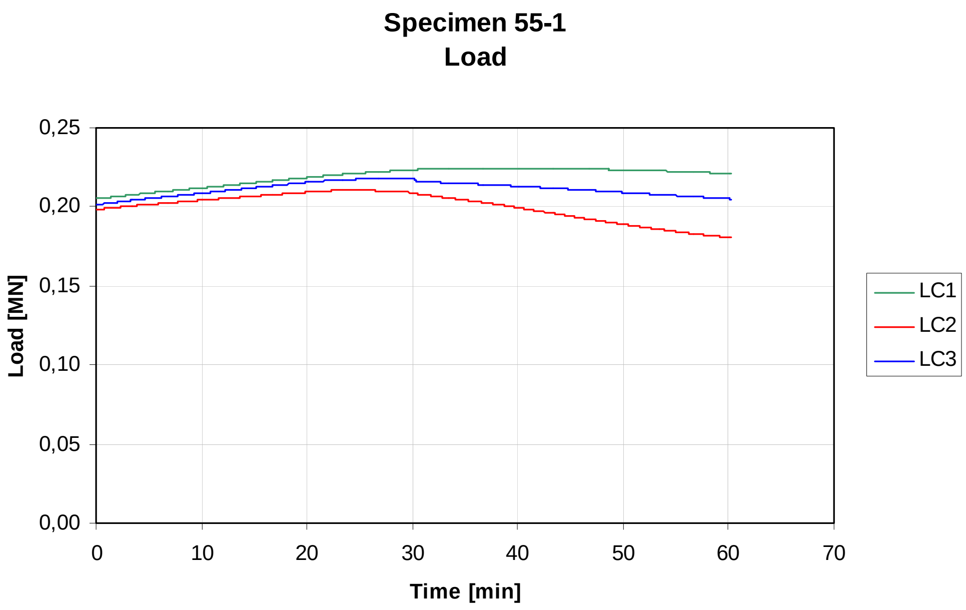


Figure A.682 Load measurements on specimen 55-1.

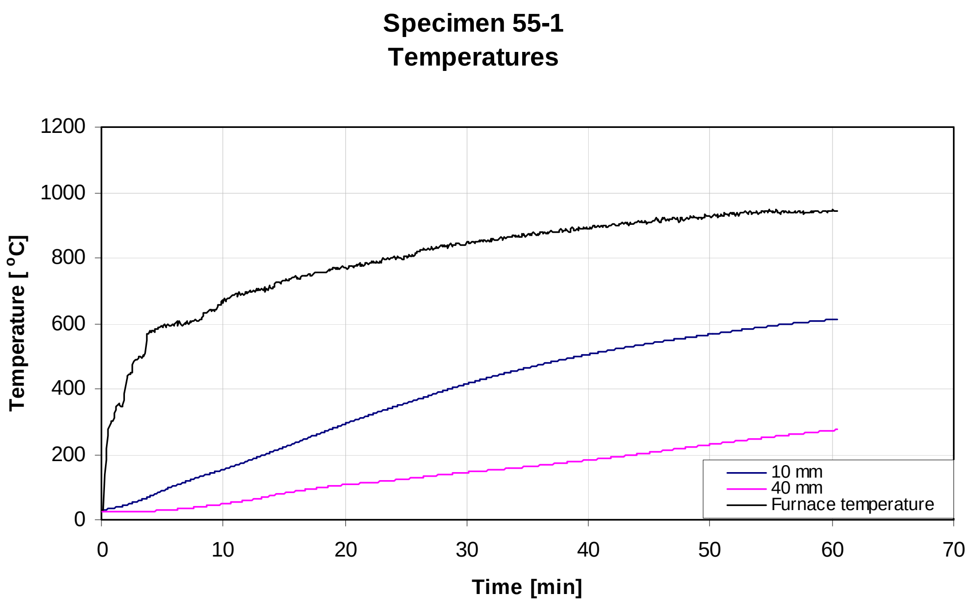


Figure A.683 Measured temperatures in furnace and in specimen 55-1.

Table A.379 Spalling measurements on specimen 55-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

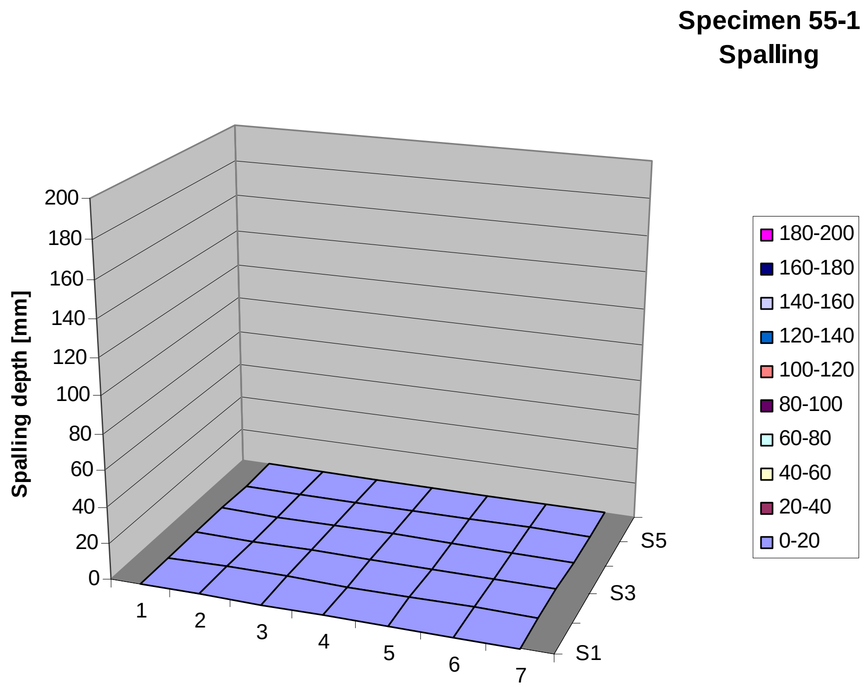


Figure A.684 Spalling measurements on specimen 55-1.

Table A.380 Observations made on specimen 55-1.

Time	Observation			
0,00	Start of test	Test date:	2007-08-27	
22,00	Water on sides and top surface	Specimen:	55-1	
60,50	Test terminated	Load level:	202	kN/bar
		Weight loss:	2,0	kg

Figure A.685 Specimen 55-1 after test.

Specimen 55-2

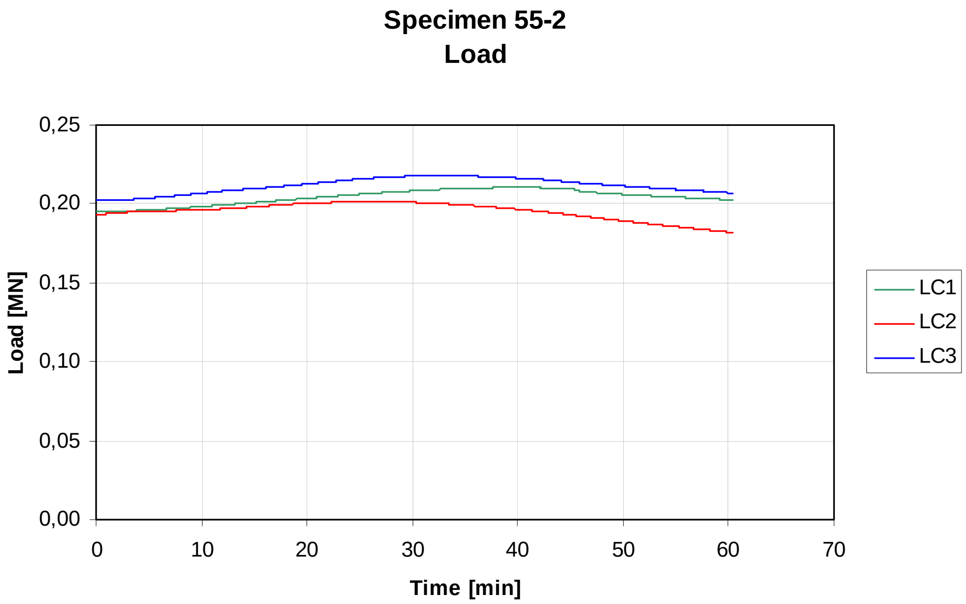


Figure A.686 Load measurements on specimen 55-2.

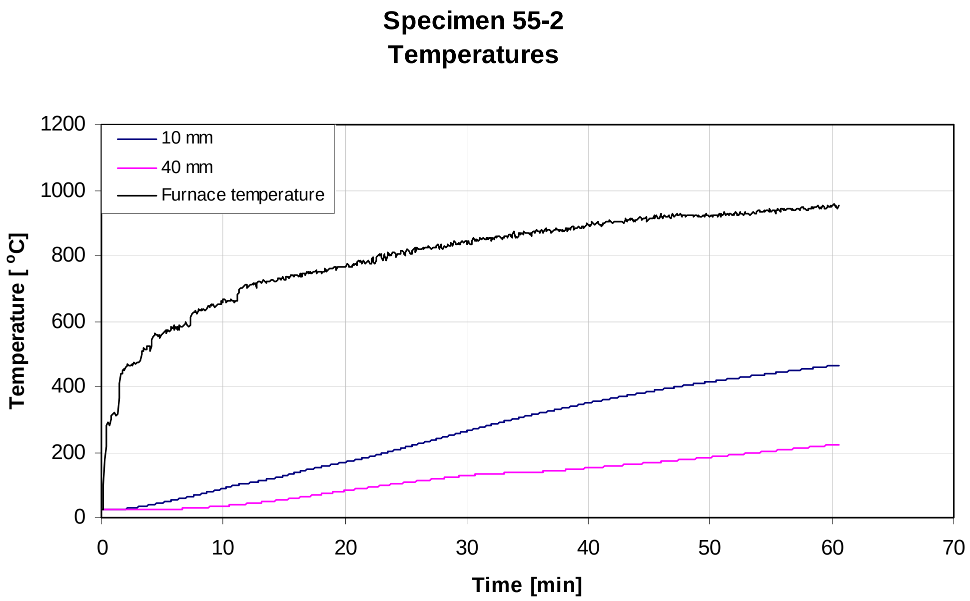


Figure A.687 Measured temperatures in furnace and in specimen 55-2.

Table A.381 Spalling measurements on specimen 55-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

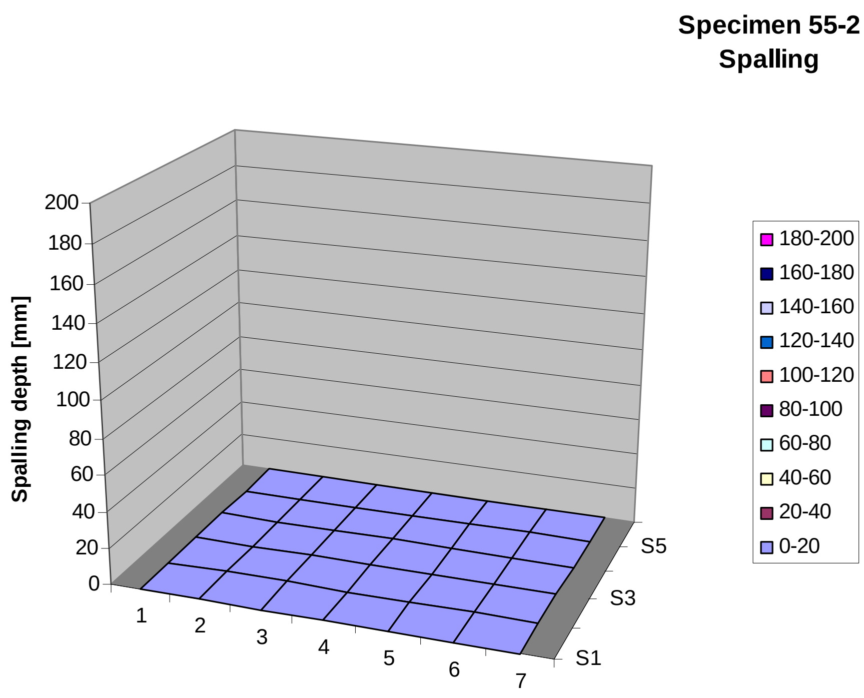


Figure A.688 Spalling measurements on specimen 55-2.

Table A.382 Observations made on specimen 55-2.

Time	Observation
0,00	Start of test
30,00	Water on sides and top surface
60,50	Test terminated

Test date:	2007-08-28	
Specimen:	55-2	
Load level:	197	kN/bar
Weight loss:	2,0	kg

Figure A.689 Specimen 55-2 after test.

Concrete 56

Table A.383 Concrete admixture recipe 56.

Recipe	**56**
Water (kg/m^3)	224
CEM II 42,5R A-LL (kg/m^3)	430
Limestone filler, Limus 25 (kg/m^3)	124
Water-powder ratio, w/p	0.40
Water-cement ratio, w/c	0.52
Sikament 20HE 50 (20% torrhalt)	4.9
Sikament 20HE 50 (% of cement weight)	1.14
Fiber, Sika Crackstop, ϕ=32 µm, l=6 mm (kg/m^3)	1.0
Gravel 0 – 8 mm (%)	56
Partly crushed 8 – 16 mm (%)	44
Slump flow (mm)	700
T50 (s)	2
Air (%)	2
Compressive strength, 28 days (MPa)	49.5

Specimen 56-3

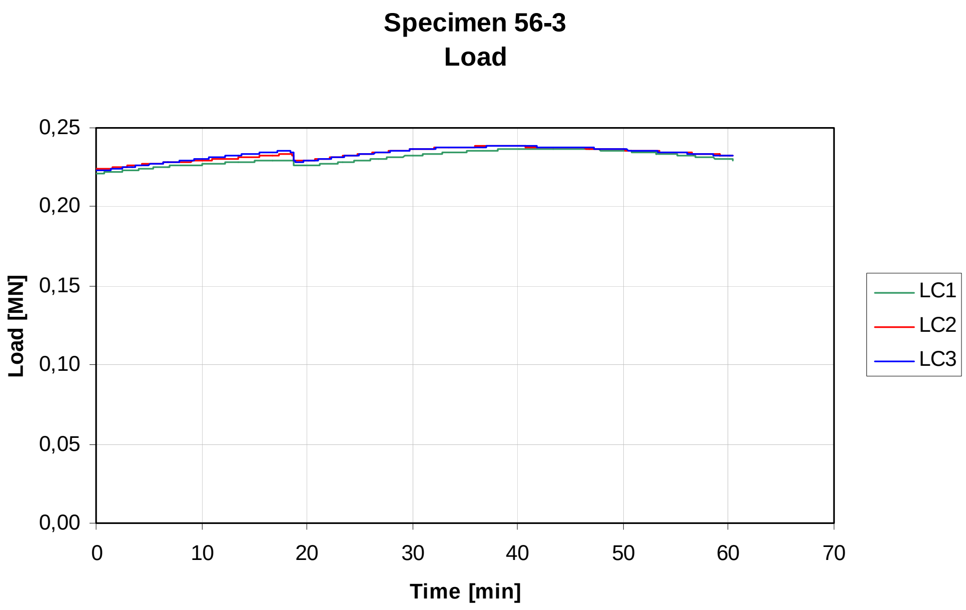


Figure A.690 Load measurements on specimen 56-3.

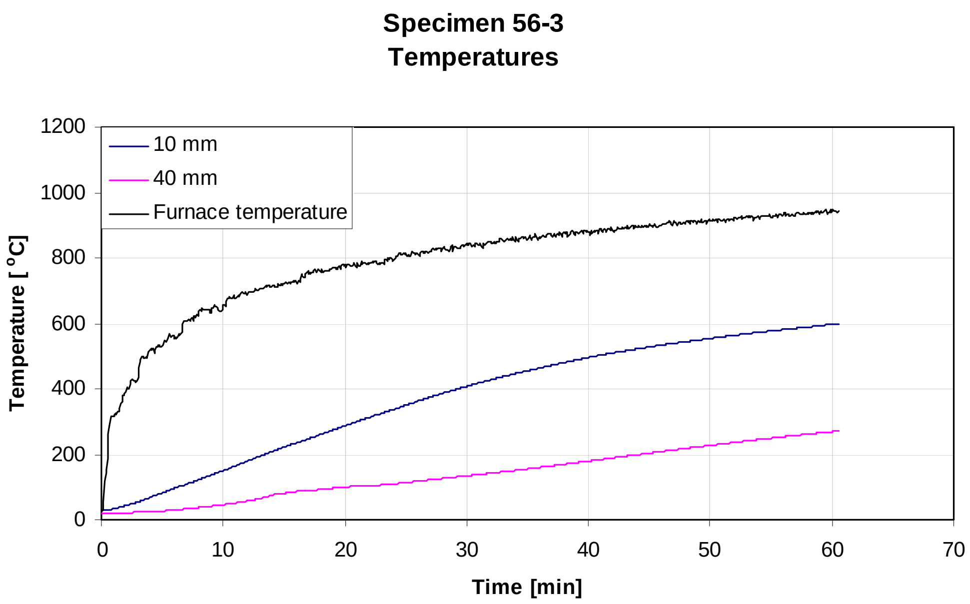


Figure A.691 Measured temperatures in furnace and in specimen 56-3.

Table A.384 Spalling measurements on specimen 56-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

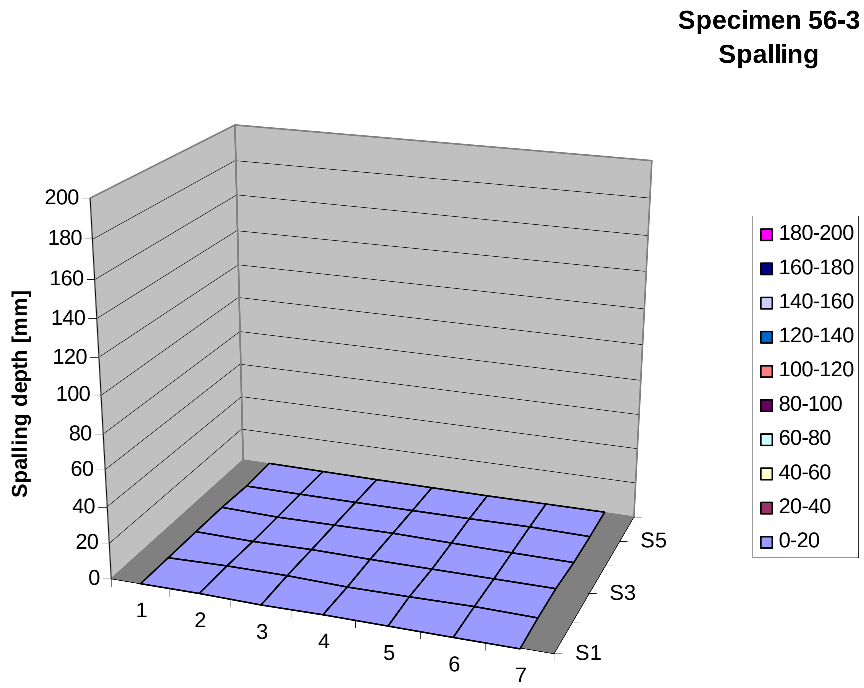


Figure A.692 Spalling measurements on specimen 56-3.

Table A.385 Observations made on specimen 56-3.

Time	Observation			
0,00	Start of test	Test date:	2007-08-28	
20,00	Horizontal cracks on sides	Specimen:	56-3	
45,00	Water from cracks	Load level:	222	kN/bar
60,50	Test terminated	Weight loss:	1,9	kg

Figure A.693 Specimen 56-3 after test.

Specimen 56-4

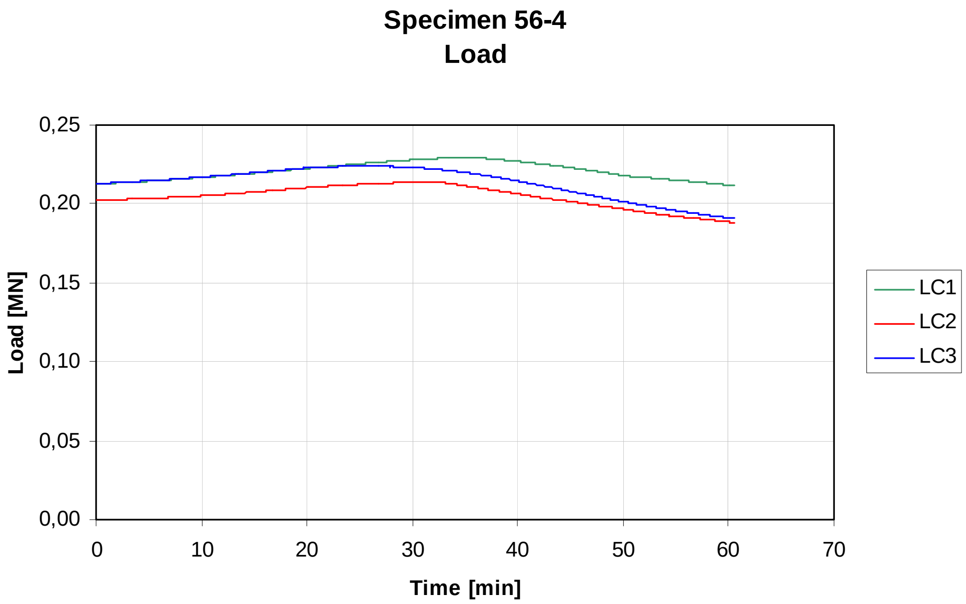


Figure A.694 Load measurements on specimen 56-4.

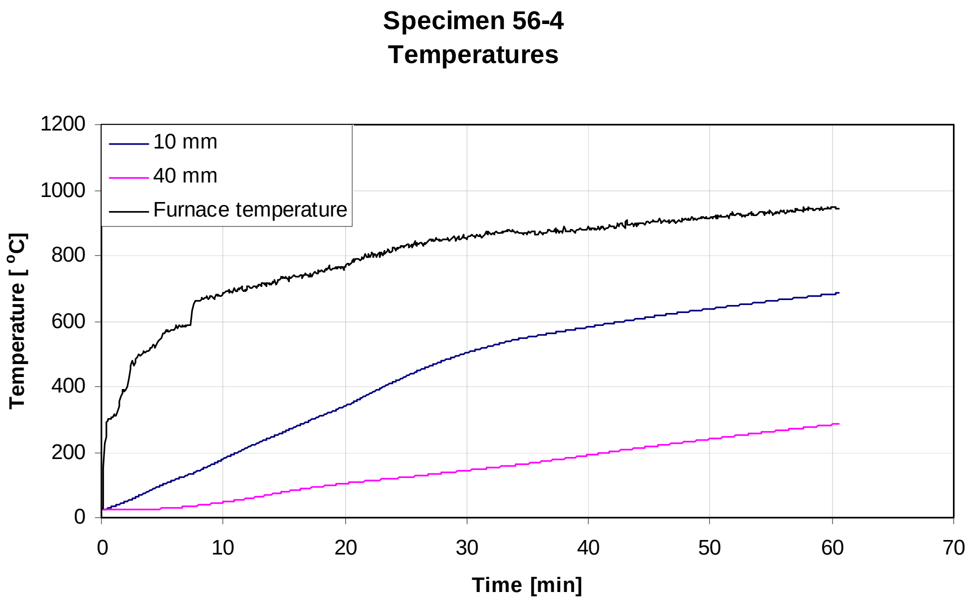


Figure A.695 Measured temperatures in furnace and in specimen 56-4.

Table A.386 Spalling measurements on specimen 56-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

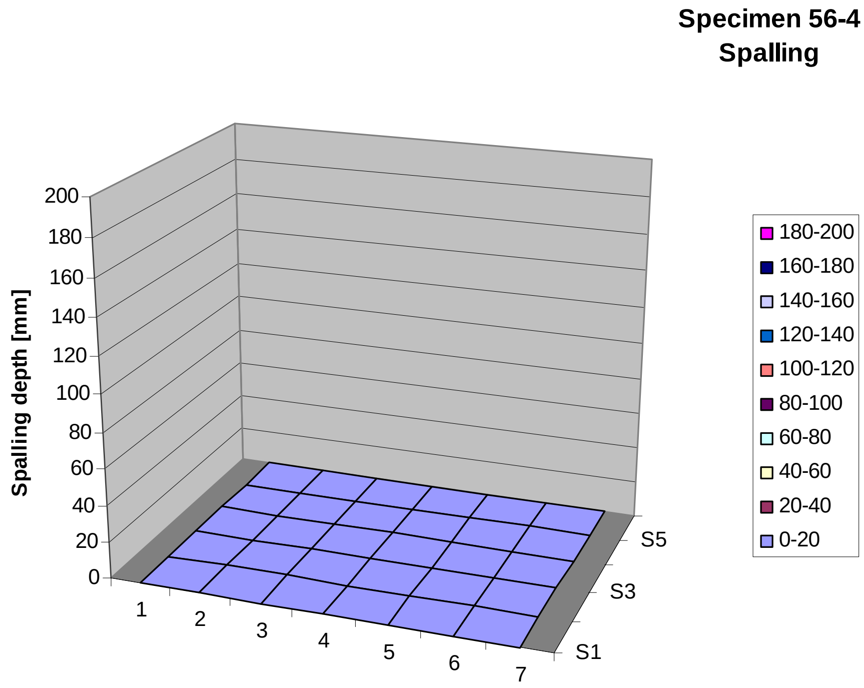


Figure A.696 Spalling measurements on specimen 56-4.

Table A.387 Observations made on specimen 56-4.

Time	Observation
0,00	Start of test
50,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-08-29	
Specimen:	56-4	
Load level:	209	kN/bar
Weight loss:	3,1	kg

Figure A.697 Specimen 56-4 after test.

Concrete 57

Table A.388 Concrete admixture recipe 57.

Recipe	**57**
Water (kg/m^3)	236
CEM II 42,5R A-LL (kg/m^3)	365
Limestone filler, Limus 25 (kg/m^3)	109
Water-powder ratio, w/p	0.50
Water-cement ratio, w/c	0.65
Sikament 20HE 50 (20% torrhalt)	5.2
Sikament 20HE 50 (% of cement weight)	1.42
Fiber, Sika Crackstop, ϕ=32 μm, l=6 mm (kg/m^3)	2.0
Gravel 0 – 8 mm (%)	63
Partly crushed 8 – 16 mm (%)	37
Slump flow (mm)	700
T50 (s)	1
Air (%)	3
Compressive strength, 28 days (MPa)	28.6

Specimen 57-1

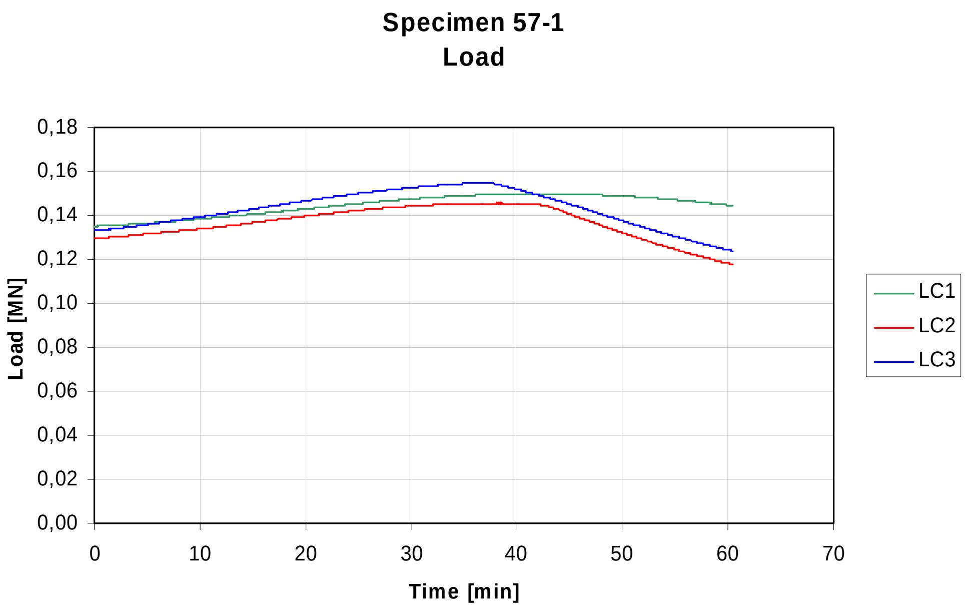


Figure A.698 Load measurements on specimen 57-1.

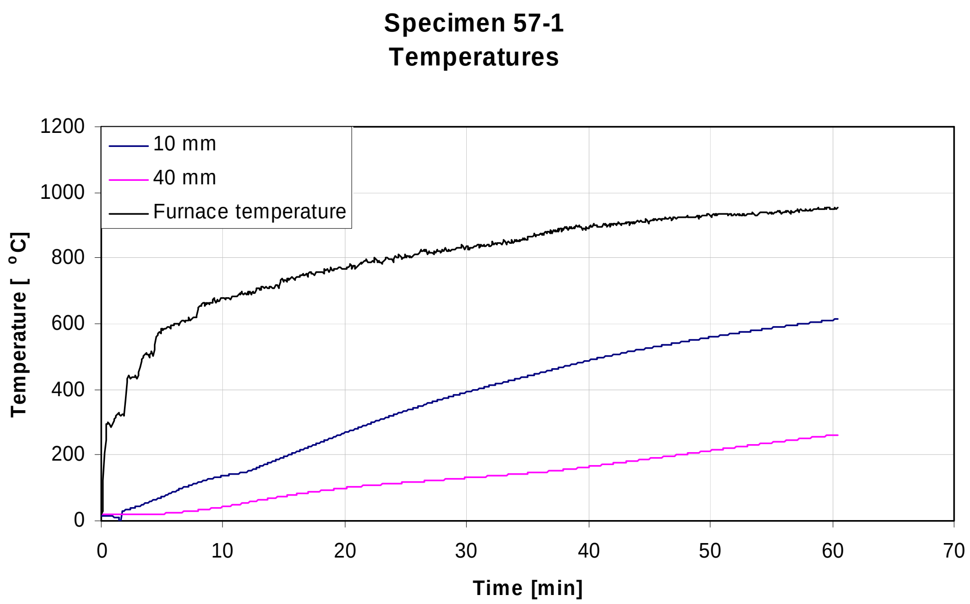


Figure A.699 Measured temperatures in furnace and in specimen 57-1.

Table A.389 Spalling measurements on specimen 57-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

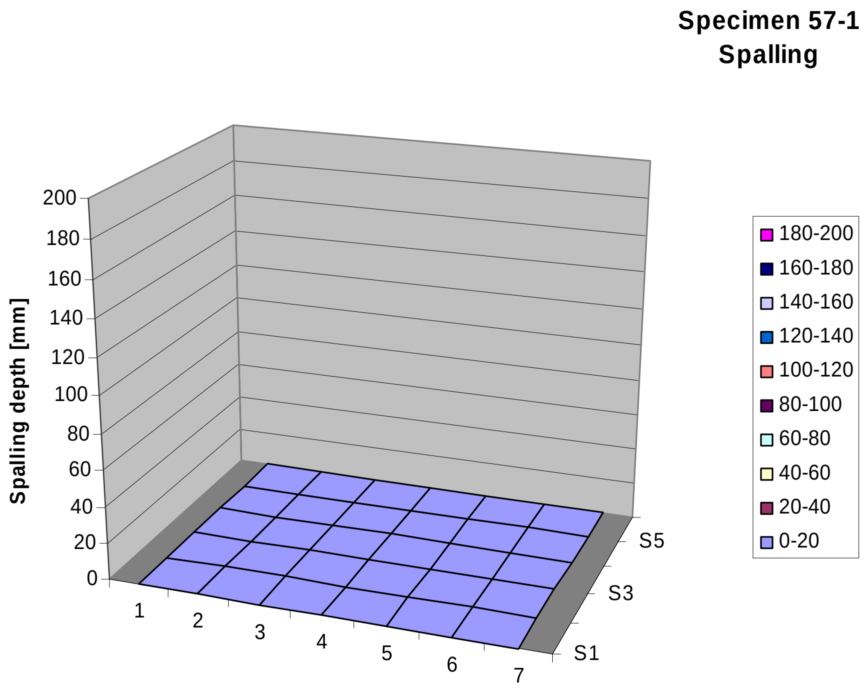


Figure A.700 Spalling measurements on specimen 57-1.

Table A.390 Observations made on specimen 57-1.

Time	Observation			
0,00	Start of test	Test date:	2007-10-30	
62,00	Test terminated	Specimen:	57-1	
		Load level:	133	kN/bar
		Weight loss:	2,1	kg

Figure A.701 Specimen 57-1 after test.

Specimen 57-2

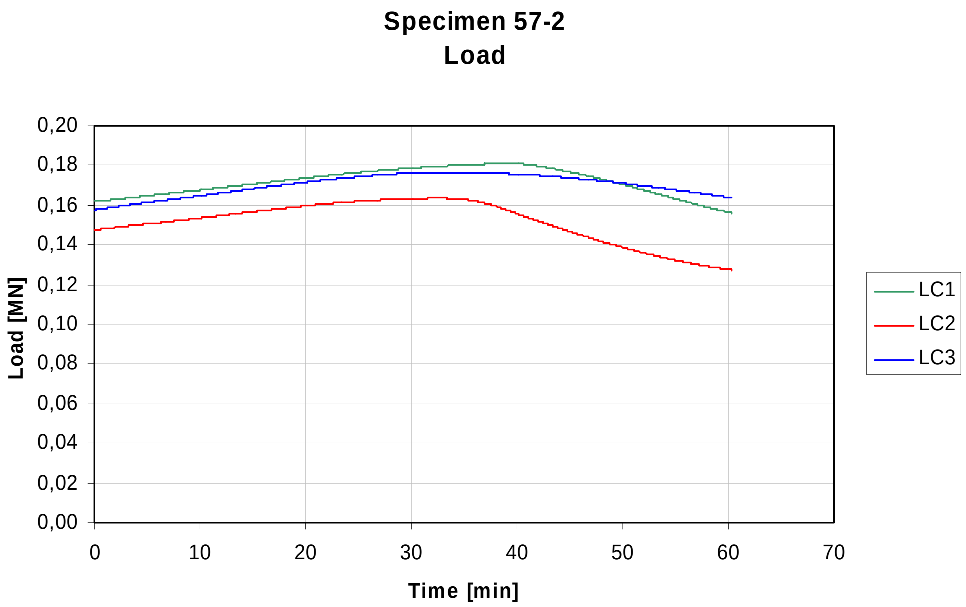


Figure A.702 Load measurements on specimen 57-2.

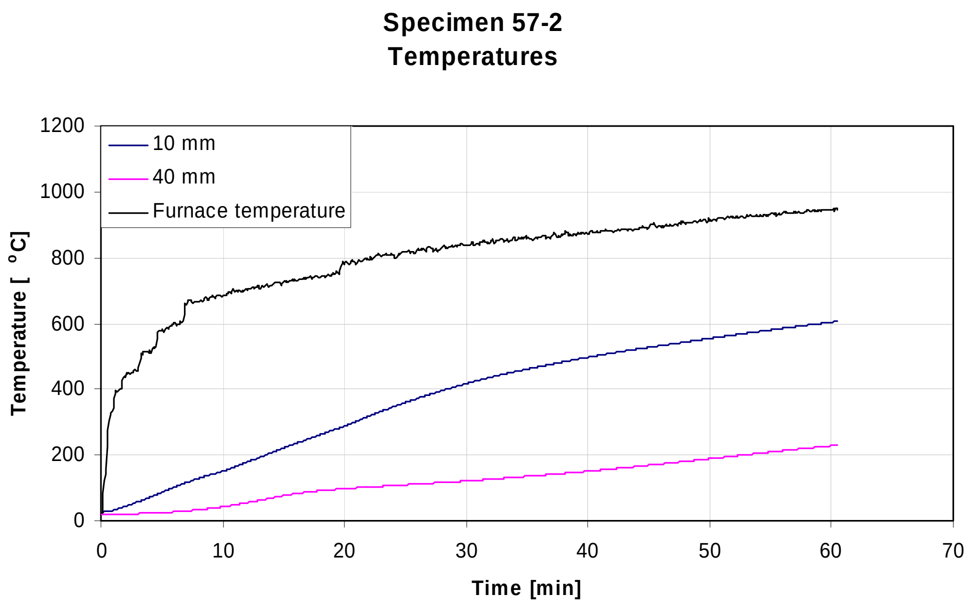


Figure A.703 Measured temperatures in furnace and in specimen 57-2.

Table A.391 Spalling measurements on specimen 57-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

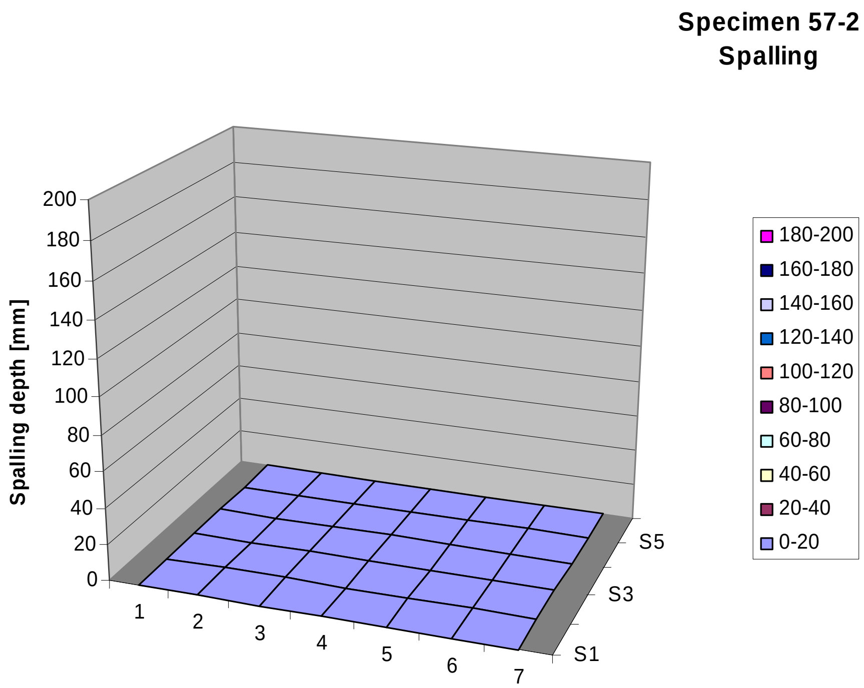


Figure A.704 Spalling measurements on specimen 57-2.

Table A.392 Observations made on specimen 57-2.

Time	Observation
0,00	Start of test
60,50	Test terminated

Test date:	2007-10-30	
Specimen:	57-2	
Load level:	156	kN/bar
Weight loss:	3,2	kg

Figure A.705 Specimen 57-2 after test.

Concrete 58

Table A.393 Concrete admixture recipe 58.

Recipe	**58**
Water (kg/m^3)	183
Cement, Norskt ANL (kg/m^3)	410
Silica (kg/m^3)	32
Water-powder ratio, w/p	0.41
Water-cement ratio, w/c	0.45
Sikament 20HE 50 (20% torrhalt)	6.0
Sikament 20HE 50 (% of cement weight)	1.46
Sika Aer-S (10%-ig)	0.60
Sika Aer-S (% of cement weight)	2.5
Gravel 0 – 8 mm (%)	58
Partly crushed 8 – 16 mm (%)	42
Slump flow (mm)	640
T50 (s)	2
Air (%)	10
Compressive strength, 28 days (MPa)	42.3

Specimen 58-1

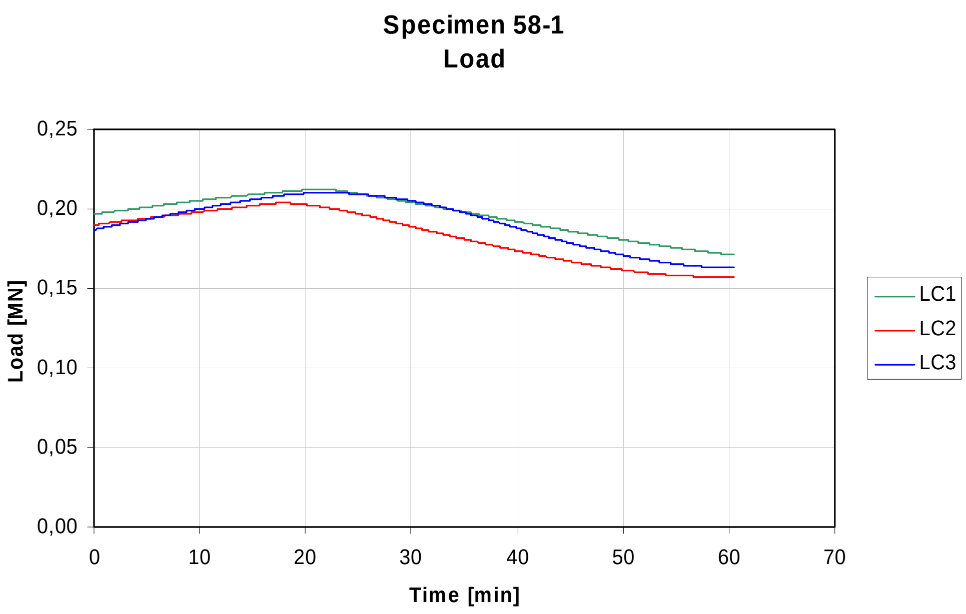


Figure A.706 Load measurements on specimen 58-1.

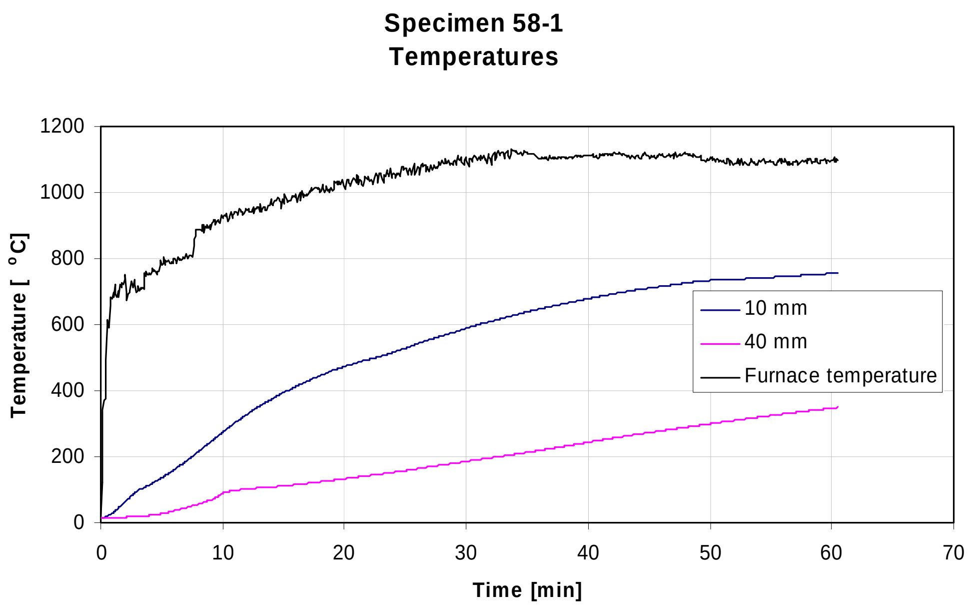


Figure A.707 Measured temperatures in furnace and in specimen 58-1.

Table A.394 Spalling measurements on specimen 58-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

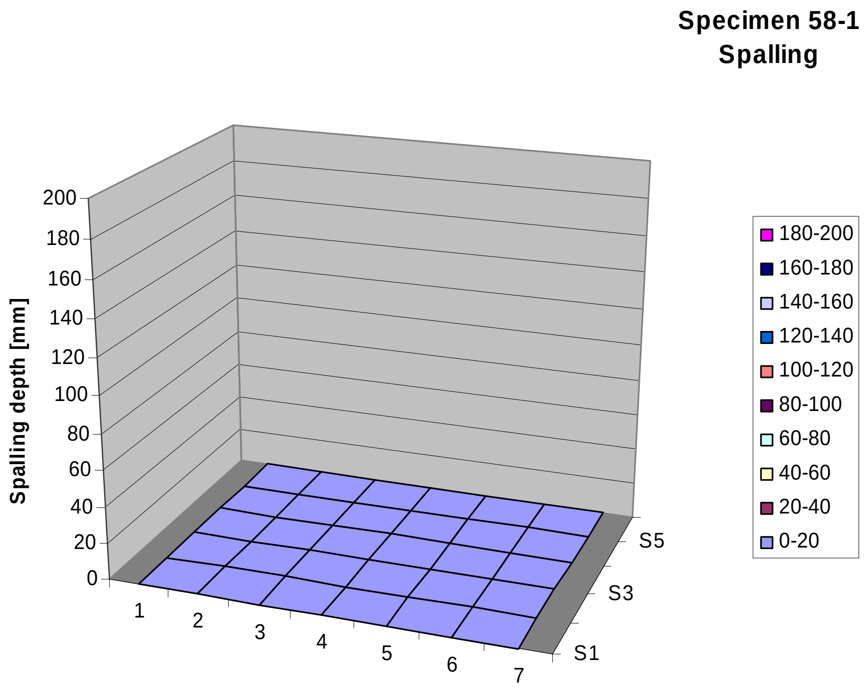


Figure A.708 Spalling measurements on specimen 58-1.

Table A.395 Observations made on specimen 58-1.

Time	Observation				
0,00	Start of test	Test date:	2007-10-31	
30,00	Cracks and water on sides	Specimen:	58-1	
60,50	Test terminated	Load level:	191	kN/bar
		Weight loss:	1,9	kg

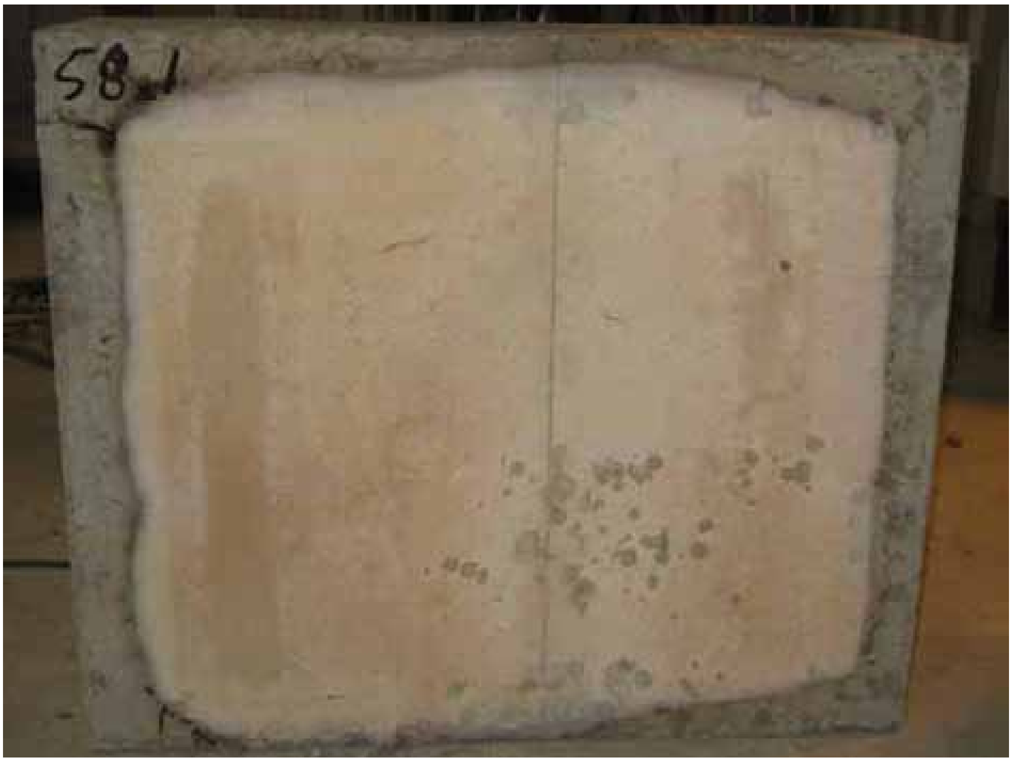


Figure A.709 Specimen 58-1 after test.

Specimen 58-2

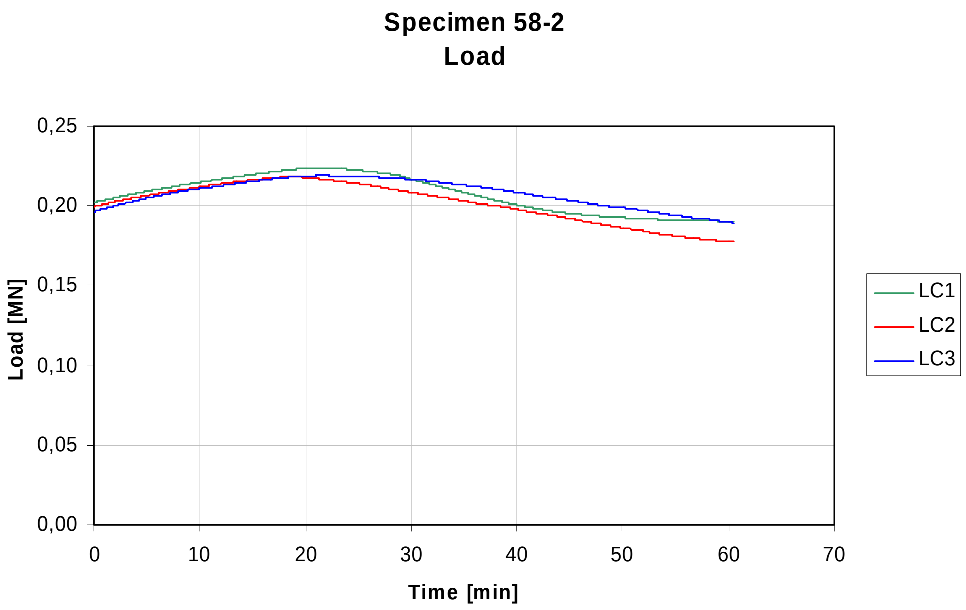


Figure A.710 Load measurements on specimen 58-2.

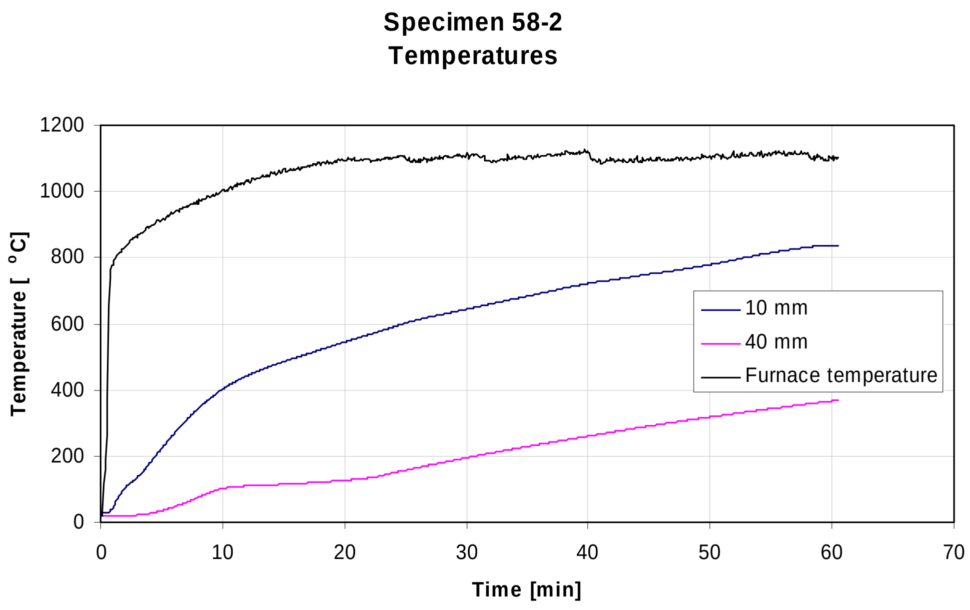


Figure A.711 Measured temperatures in furnace and in specimen 58-2.

Table A.396 Spalling measurements on specimen 58-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

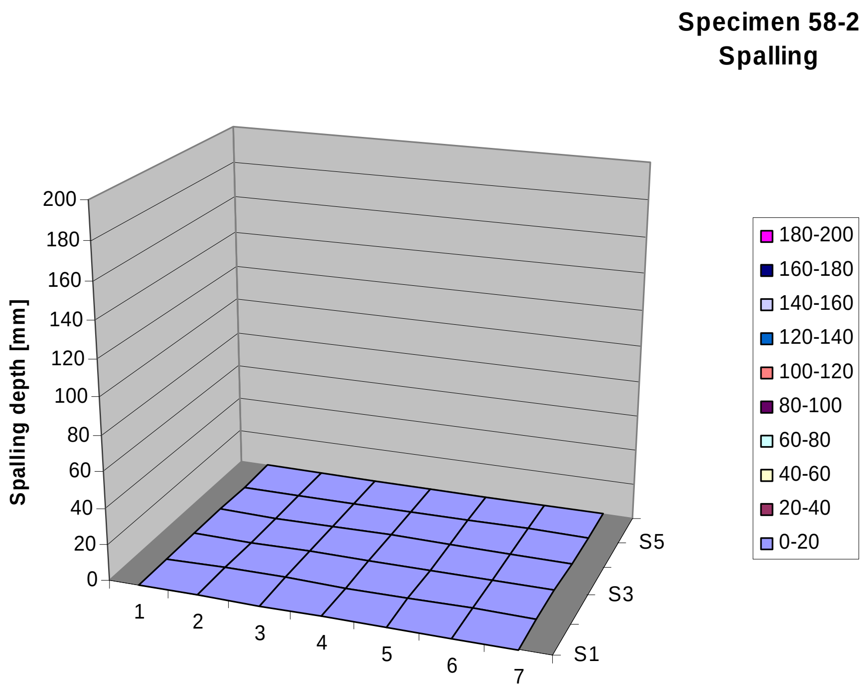


Figure A.712 Spalling measurements on specimen 58-2.

Table A.397 Observations made on specimen 58-2.

Time	Observation
0,00	Start of test
30,00	Cracks and water on sides
60,67	Test terminated

Test date:	2007-10-31	
Specimen:	58-2	
Load level:	199	kN/bar
Weight loss:	1,9	kg

Figure A.713 Specimen 58-2 after test.

Concrete 59

Table A.398 Concrete admixture recipe 59.

Recipe	59
Water (kg/m^3)	183
Cement, Norskt ANL (kg/m^3)	410
Silica (kg/m^3)	32
Water-powder ratio, w/p	0.41
Water-cement ratio, w/c	0.45
Sikament 20HE 50 (20% torrhalt)	7.0
Sikament 20HE 50 (% of cement weight)	1.71
Sika Aer-S (10%-ig)	0.50
Sika Aer-S (% of cement weight)	2.1
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	0.5
Gravel 0 – 8 mm (%)	58
Partly crushed 8 – 16 mm (%)	42
Slump flow (mm)	550
T50 (s)	3
Air (%)	12.5
Compressive strength, 28 days (MPa)	42.6

Specimen 59-1

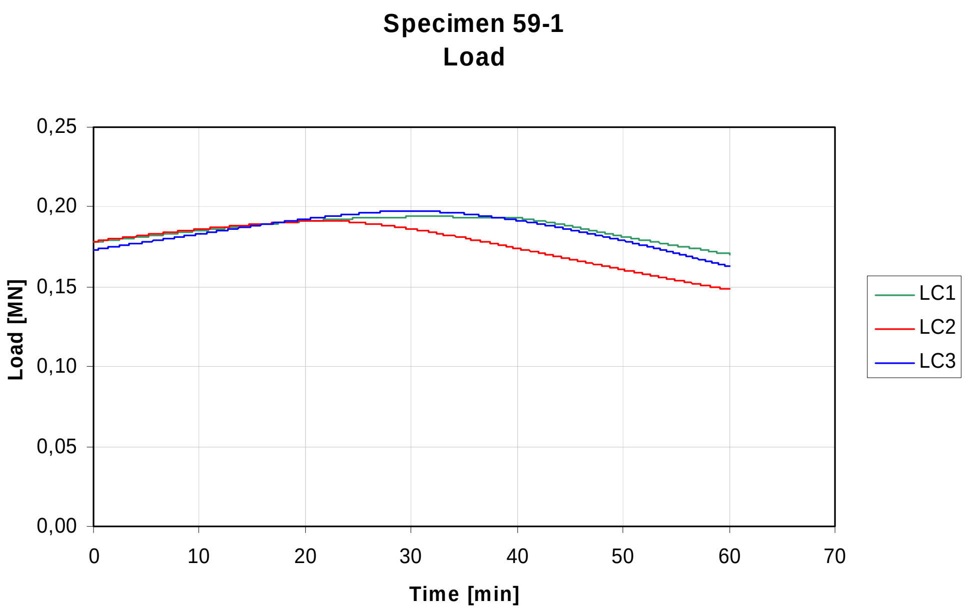


Figure A.714 Load measurements on specimen 59-1.

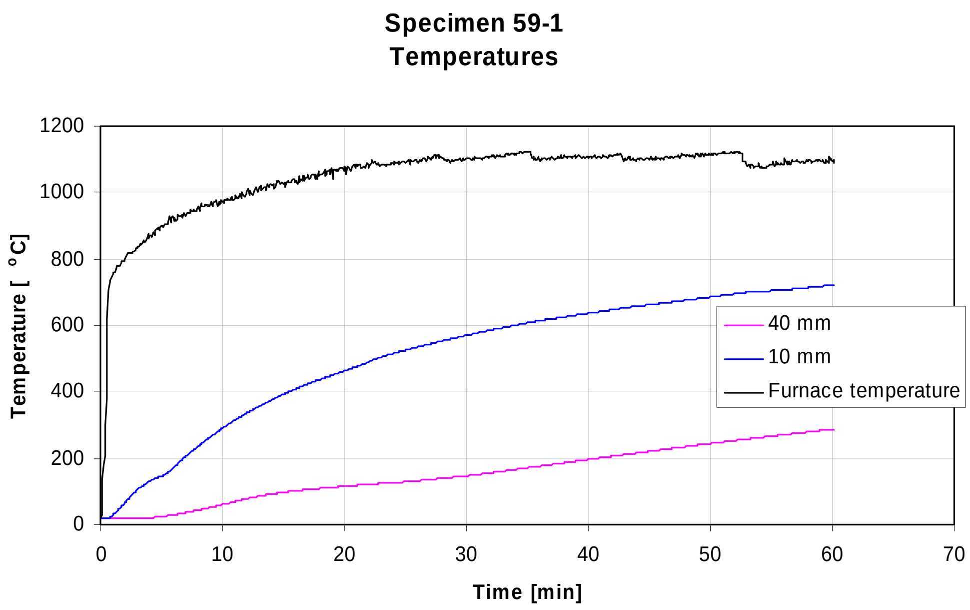


Figure A.715 Measured temperatures in furnace and in specimen 59-1.

Table A.399 Spalling measurements on specimen 59-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

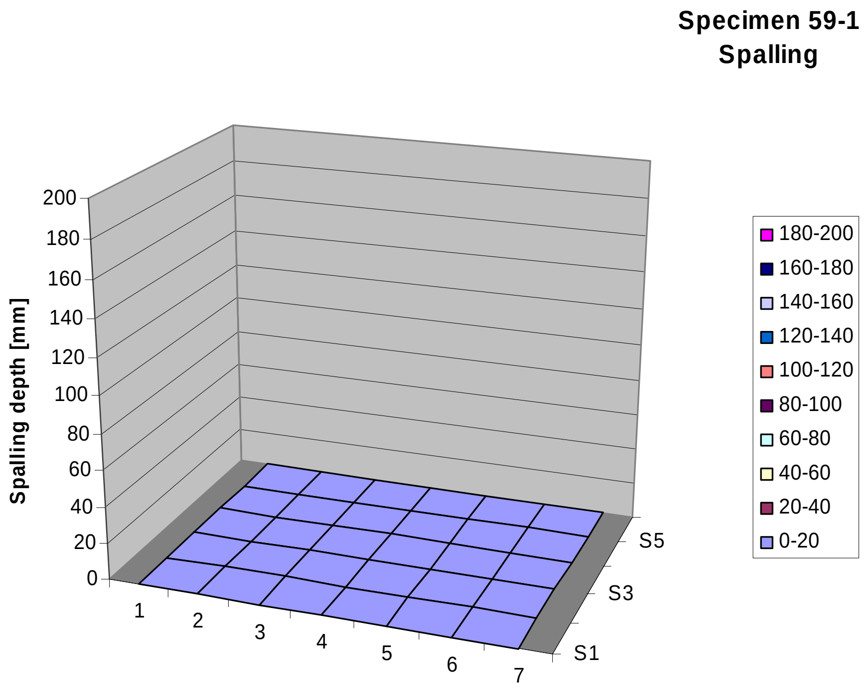


Figure A.716 Spalling measurements on specimen 59-1.

Table A.400 Observations made on specimen 59-1.

Time	Observation			
0,00	Start of test	Test date:	2007-11-01	
55,00	Small racks and water on sides	Specimen:	59-1	
60,67	Test terminated	Load level:	177	kN/bar
		Weight loss:	0,2	kg

Figure A.717 Specimen 59-1 after test.

Specimen 59-2

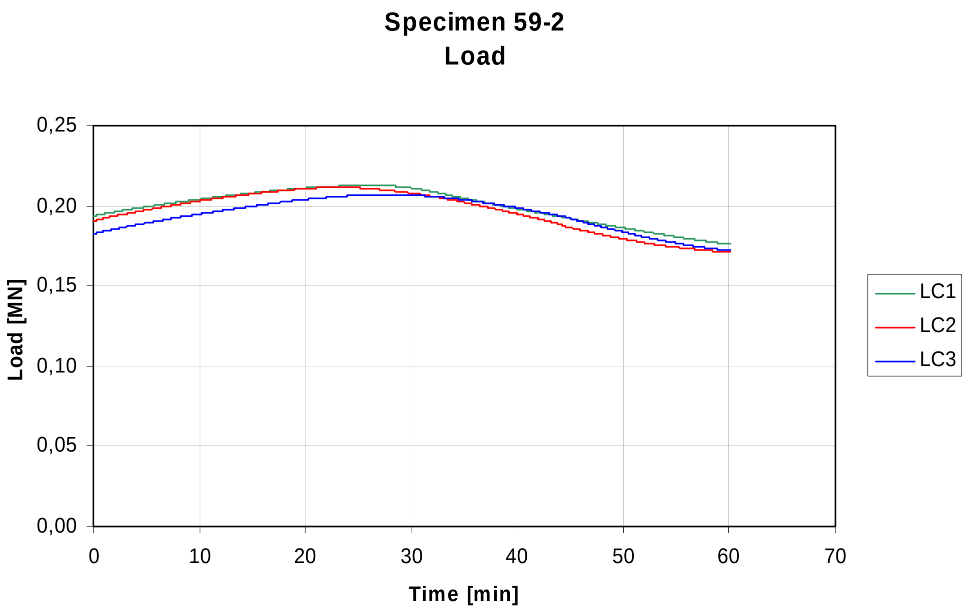


Figure A.718 Load measurements on specimen 59-2.

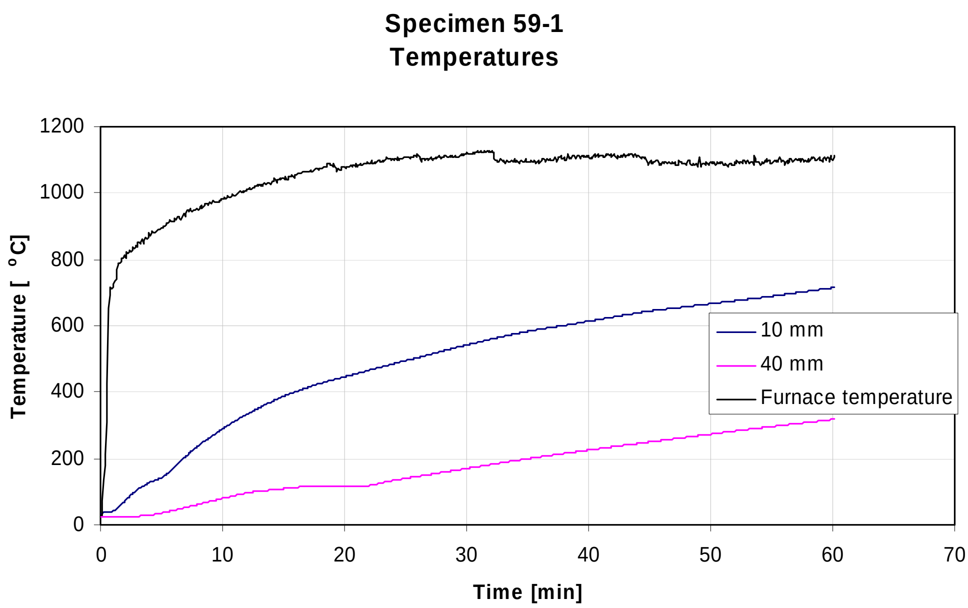


Figure A.719 Measured temperatures in furnace and in specimen 59-2.

Table A.401 Spalling measurements on specimen 59-2.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

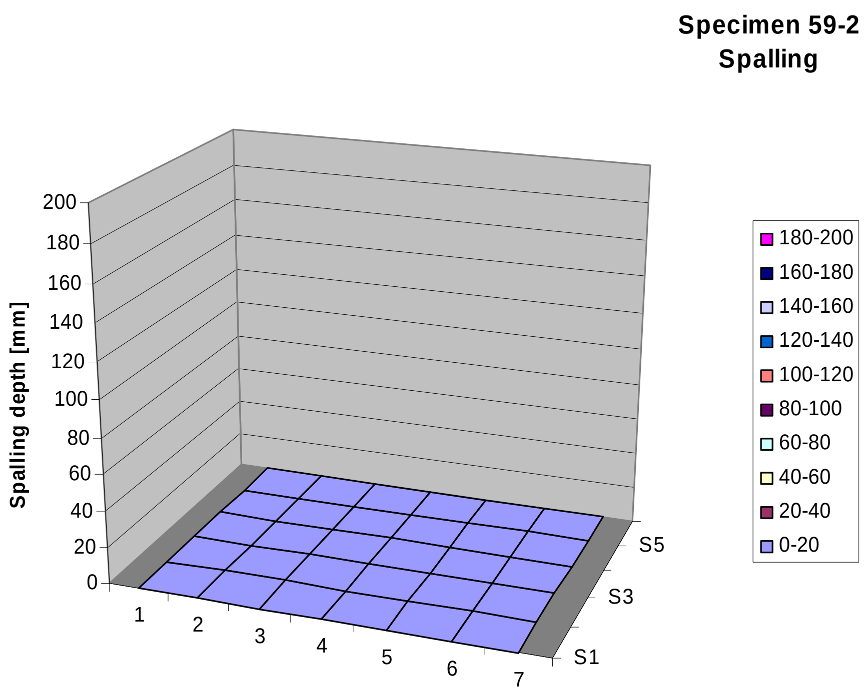


Figure A.720 Spalling measurements on specimen 59-2.

Table A.402 Observations made on specimen 59-2.

Time	Observation
0,00	Start of test
60,17	Test terminated

Test date:	2007-11-01	
Specimen:	59-2	
Load level:	189	kN/bar
Weight loss:	0,4	kg

Figure A.721 Specimen 59-2 after test.

Concrete 60

Table A.403 Concrete admixture recipe 60.

Recipe	**60**
Water (kg/m^3)	183
Cement, Norskt ANL (kg/m^3)	410
Silica (kg/m^3)	32
Water-powder ratio, w/p	0.41
Water-cement ratio, w/c	0.45
Sikament 20HE 50 (20% torrhalt)	7.0
Sikament 20HE 50 (% of cement weight)	1.71
Sika Aer-S (10%-ig)	0.40
Sika Aer-S (% of cement weight)	1.6
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	1.0
Gravel 0 – 8 mm (%)	58
Partly crushed 8 – 16 mm (%)	42
Slump flow (mm)	530
T50 (s)	4
Air (%)	12
Compressive strength, 28 days (MPa)	45.3

Specimen 60-3

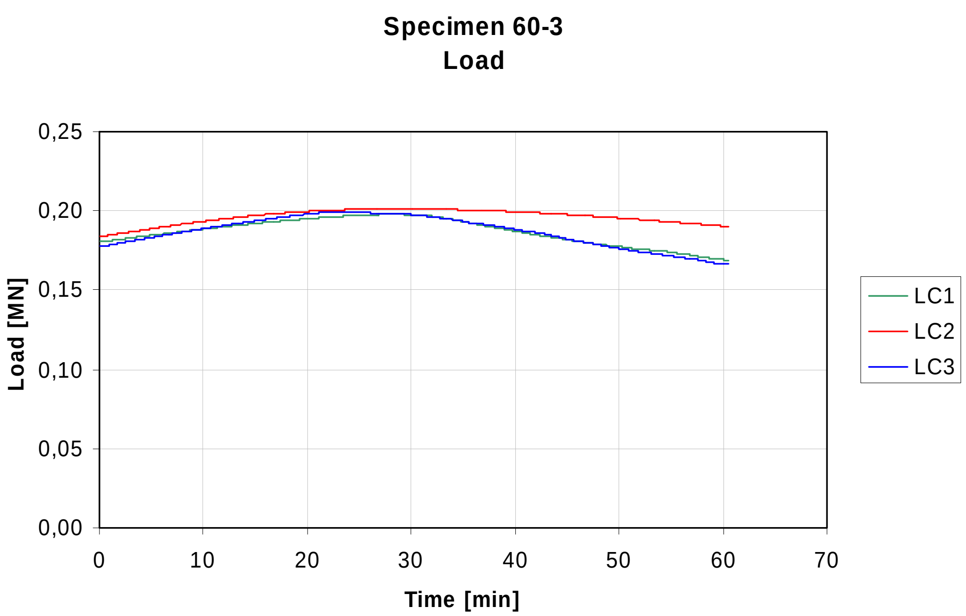


Figure A.722 Load measurements on specimen 60-3.

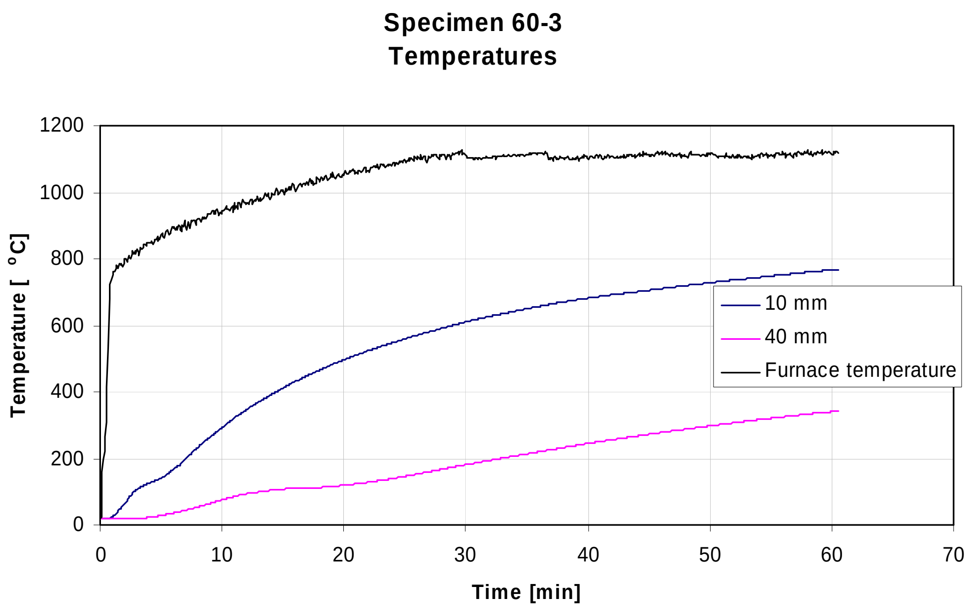


Figure A.723 Measured temperatures in furnace and in specimen 60-3.

Table A.404 Spalling measurements on specimen 60-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

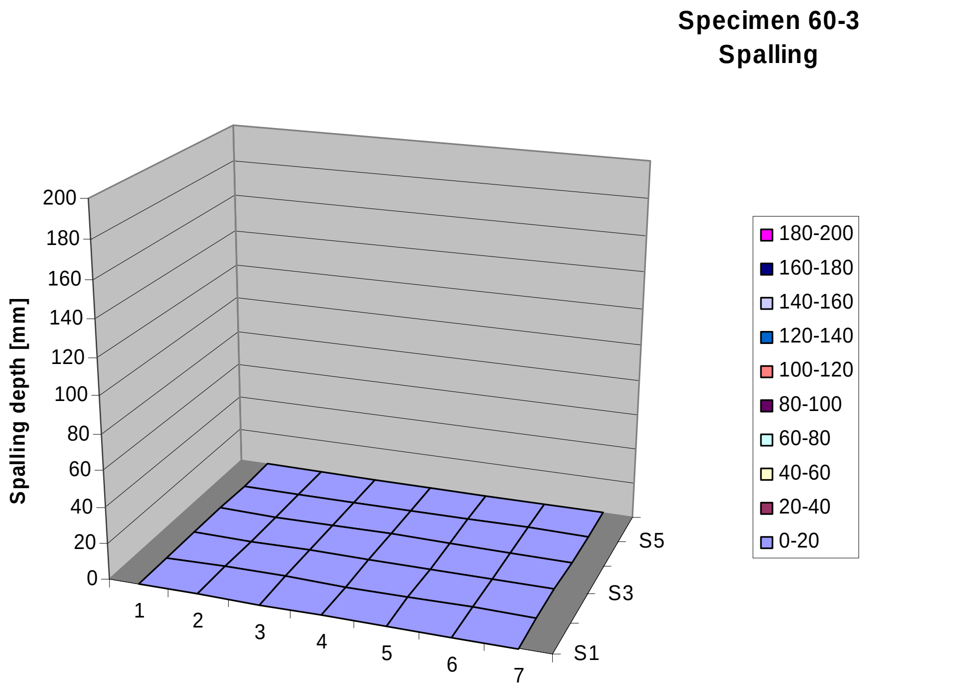


Figure A.724 Spalling measurements on specimen 60-3.

Table A.405 Observations made on specimen 60-3.

Time	Observation			
0,00	Start of test	Test date:	2007-11-06	
20,00	Water on top surface	Specimen:	60-3	
60,50	Test terminated	Load level:	181	kN/bar
		Weight loss:	0,9	kg

Figure A.725 Specimen 60-3 after test.

Specimen 60-4

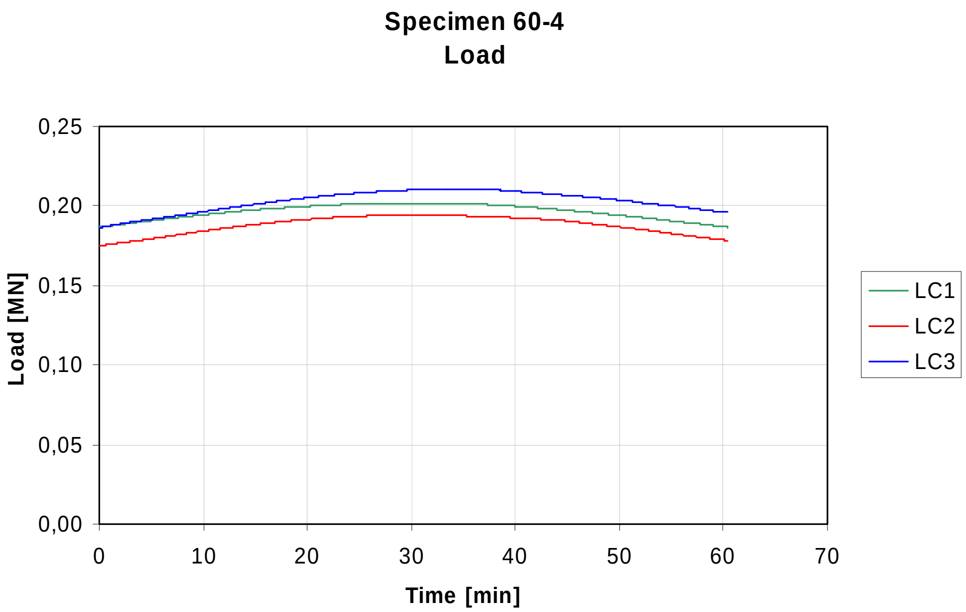


Figure A.726 Load measurements on specimen 60-4.

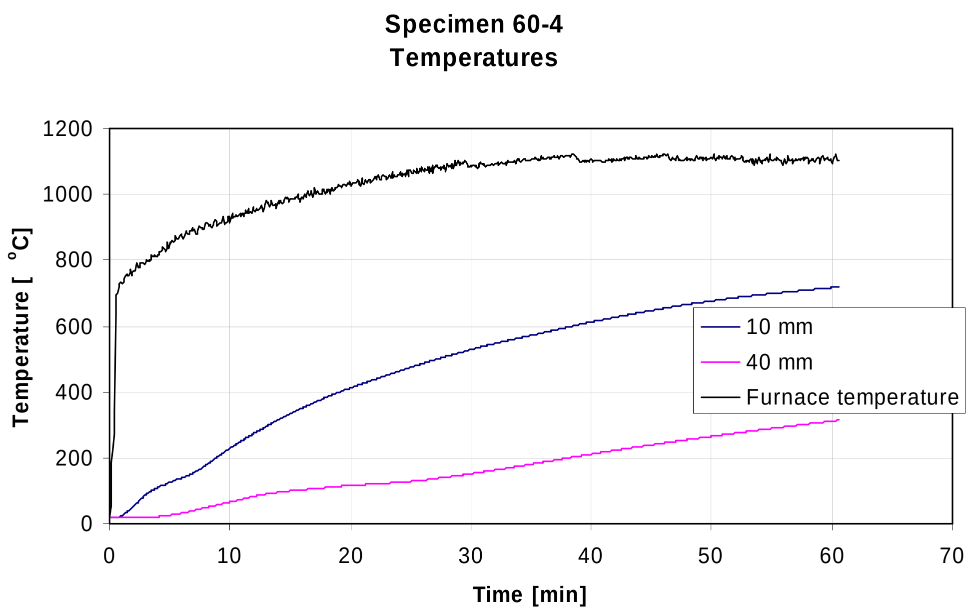


Figure A.727 Measured temperatures in furnace and in specimen 60-4.

Table A.406 Spalling measurements on specimen 60-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

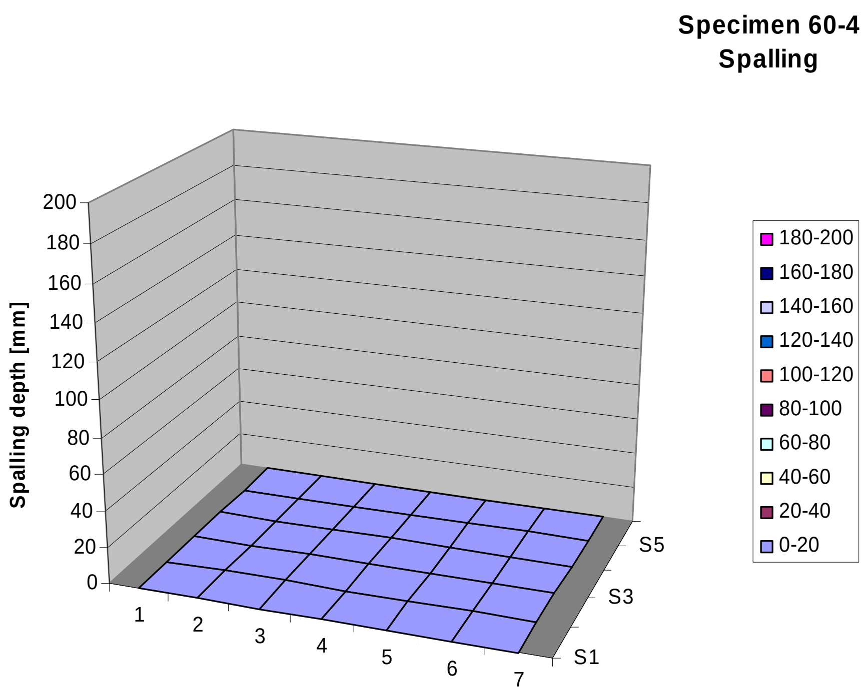


Figure A.728 Spalling measurements on specimen 60-4.

Table A.407 Observations made on specimen 60-4.

Time	Observation			
0,00	Start of test	Test date:	2007-11-09	
20,00	Water on top surface	Specimen:	60-4	
60,50	Test terminated	Load level:	183	kN/bar
		Weight loss:	1,5	kg

Figure A.729 Specimen 60-4 after test.

Concrete 61

Table A.408 Concrete admixture recipe 61.

Recipe	**61**
Water (kg/m^3)	183
Cement, Norskt ANL (kg/m^3)	410
Silica (kg/m^3)	32
Water-powder ratio, w/p	0.41
Water-cement ratio, w/c	0.45
Sikament 20HE 50 (20% torrhalt)	11.5
Sikament 20HE 50 (% of cement weight)	2.80
Sika Aer-S (10%-ig)	0.20
Sika Aer-S (% of cement weight)	0.8
Fiber, Sika Crackstop, ϕ=18 μm, l=6 mm (kg/m^3)	2.0
Gravel 0 – 8 mm (%)	58
Partly crushed 8 – 16 mm (%)	42
Slump flow (mm)	650
T50 (s)	2
Air (%)	12
Compressive strength, 28 days (MPa)	39.9

Specimen 61-3

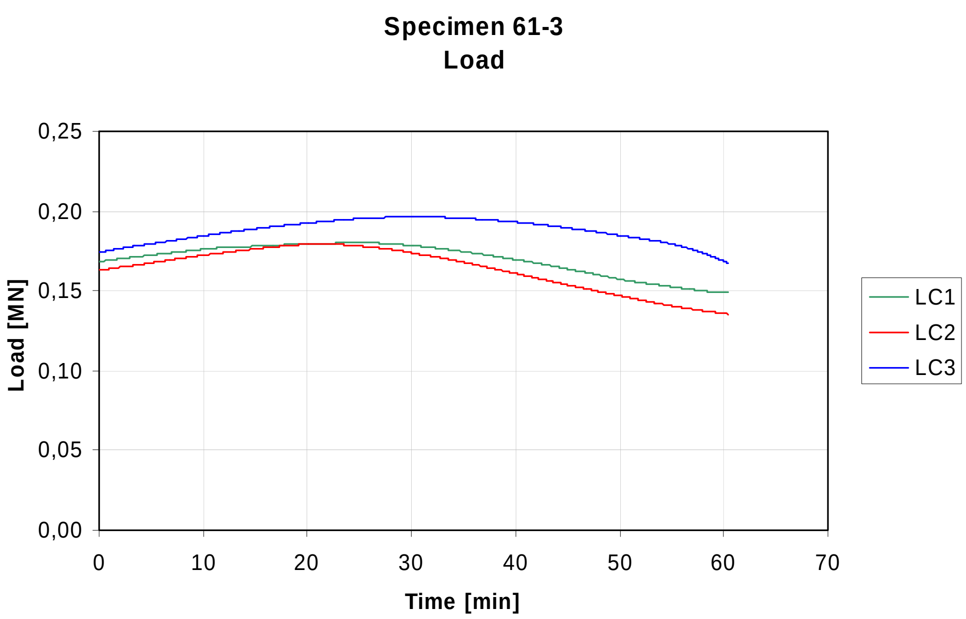


Figure A.730 Load measurements on specimen 61-3.

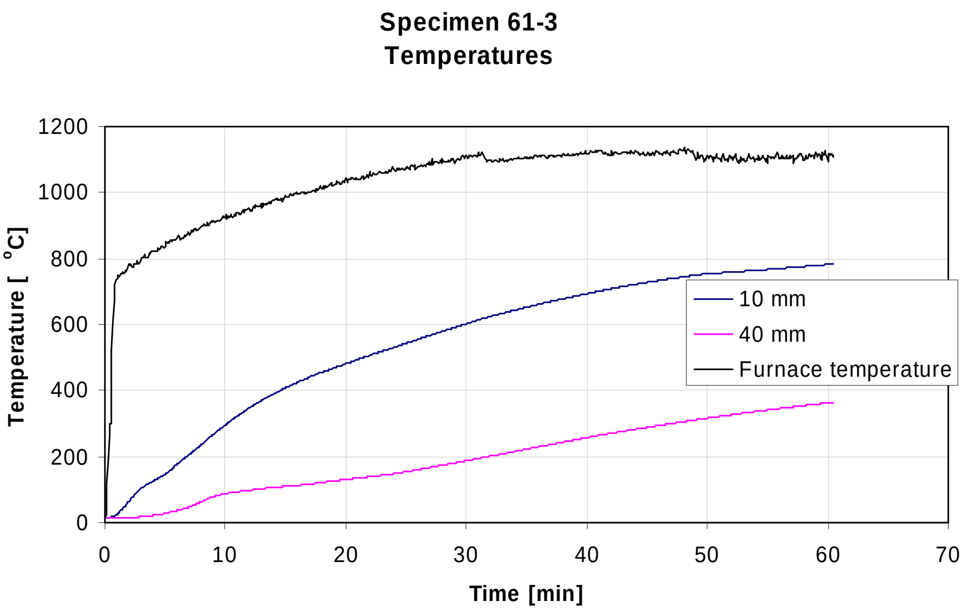


Figure A.731 Measured temperatures in furnace and in specimen 61-3.

Table A.409 Spalling measurements on specimen 61-3.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

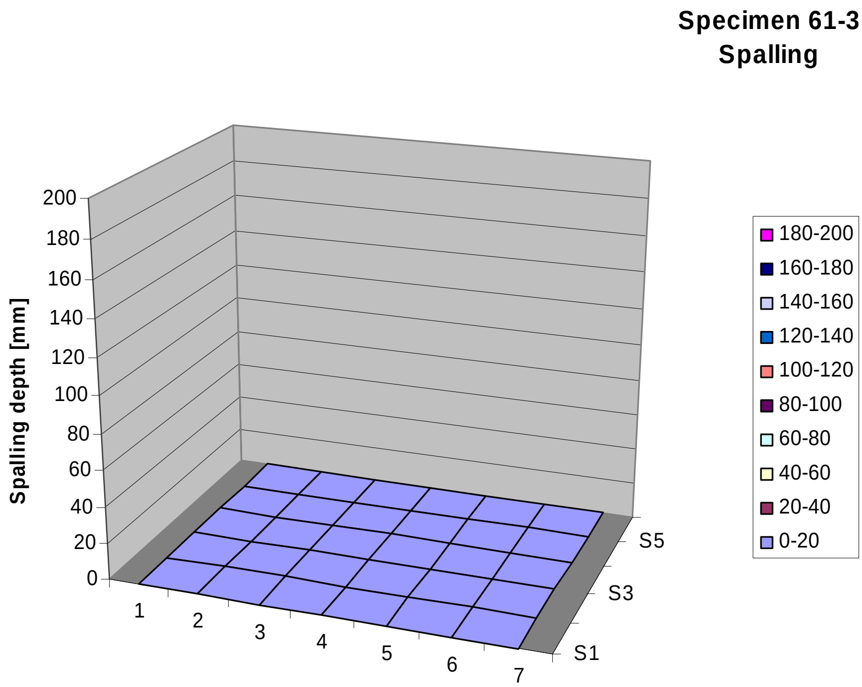


Figure A.732 Spalling measurements on specimen 61-3.

Table A.410 Observations made on specimen 61-3.

Time	Observation			
0,00	Start of test	Test date:	2007-11-15	
20,00	Water on top surface and sides	Specimen:	61-3	
60,00	Test terminated	Load level:	169	kN/bar
		Weight loss:	3,1	kg

Figure A.733 Specimen 61-3 after test.

Specimen 61-4

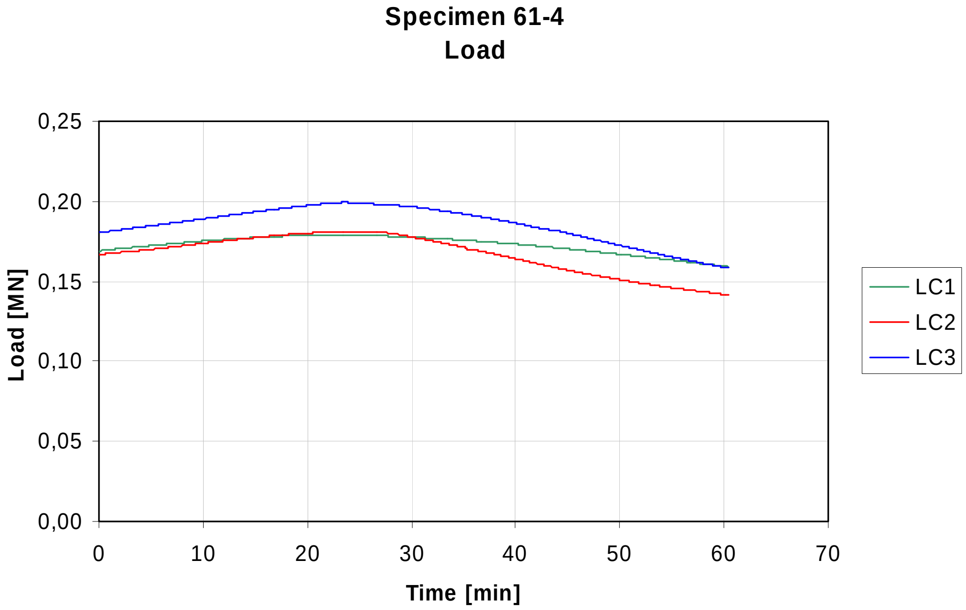


Figure A.734 Load measurements on specimen 61-4.

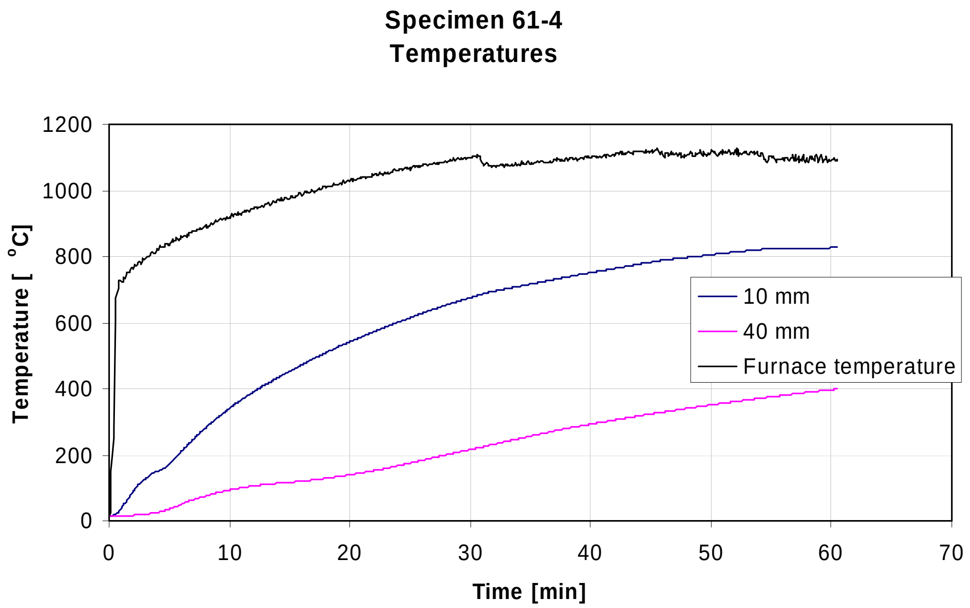


Figure A.735 Measured temperatures in furnace and in specimen 61-4.

Table A.411 Spalling measurements on specimen 61-4.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	0	0	0	0
400	0	0	0	0	0	0
500	0	0	0	0	0	0
600	0	0	0	0	0	0

Mean all	0
Mean inner	0
Max in diagram	0
Max measured	0

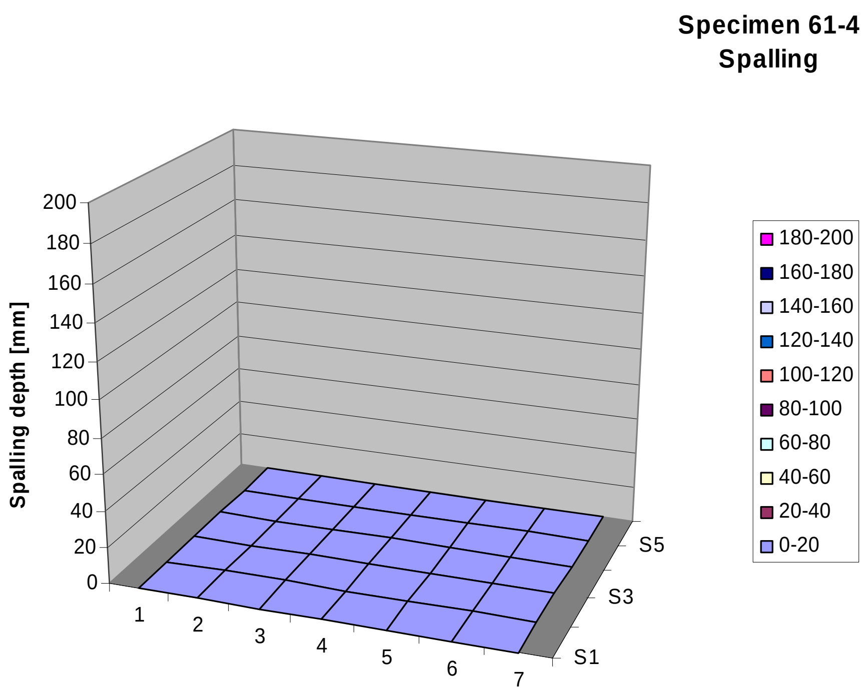


Figure A.736 Spalling measurements on specimen 61-4.

Table A.412 Observations made on specimen 61-4.

Time	Observation
0,00	Start of test
20,00	Water on sides
60,00	Test terminated

Test date:	2007-11-16	
Specimen:	61-4	
Load level:	172	kN/bar
Weight loss:	3,1	kg

Figure A.737 Specimen 61-4 after test.

Concrete 62

Table A.413 Concrete admixture recipe 62.

Recipe	**62**
Water (kg/m^3)	184
Cement, Norskt ANL (kg/m^3)	411
Silica (kg/m^3)	33
Water-powder ratio, w/p	0.41
Water-cement ratio, w/c	0.45
Sikament 20HE 50 (20% torrhalt)	6.0
Sikament 20HE 50 (% of cement weight)	1.46
Gravel 0 – 8 mm (%)	58
Partly crushed 8 – 16 mm (%)	42
Slump flow (mm)	670
T50 (s)	2
Air (%)	3.9
Compressive strength, 28 days (MPa)	73.4

Specimen 62-1

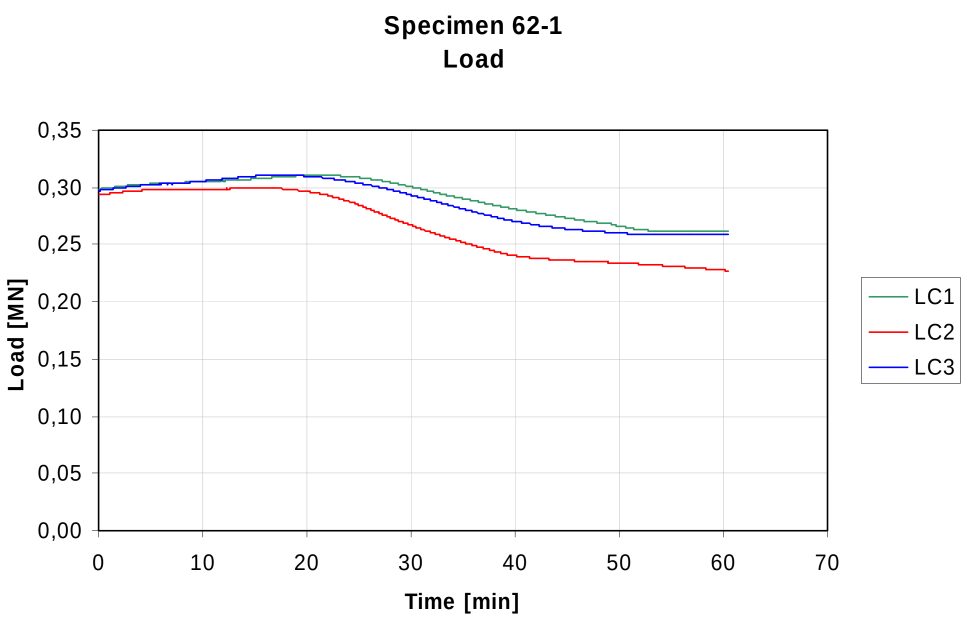


Figure A.738 Load measurements on specimen 62-1.

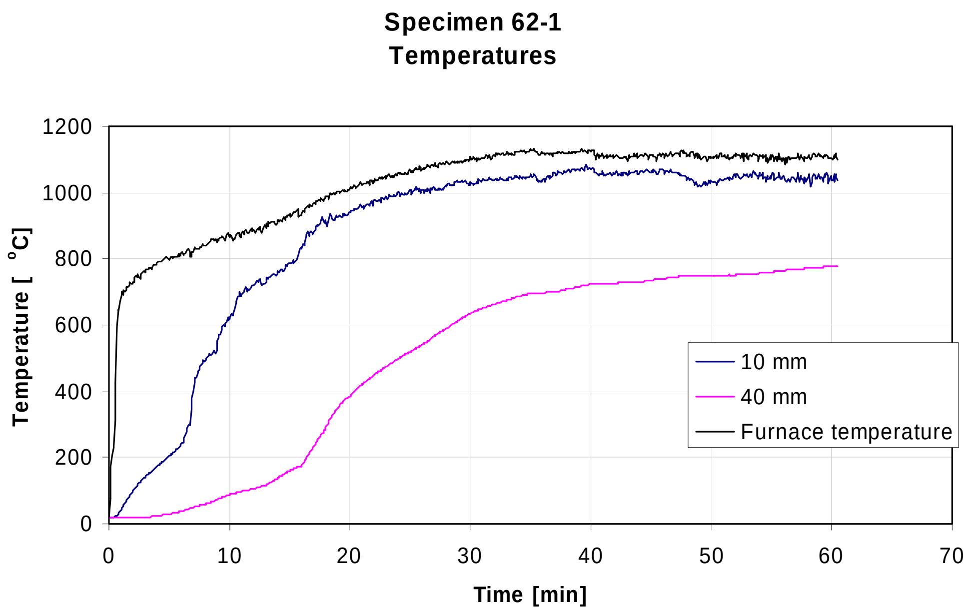


Figure A.739 Measured temperatures in furnace and in specimen 62-1.

Table A.414 Spalling measurements on specimen 62-1.

Position	0	100	200	300	400	500
0	0	0	0	0	0	0
100	0	7	31	23	20	1
200	0	23	35	25	22	1
300	0	24	40	23	21	2
400	0	26	40	18	17	3
500	0	12	18	14	6	0
600	0	0	0	0	0	0

Mean all	11
Mean inner	22
Max in diagram	40
Max measured	50

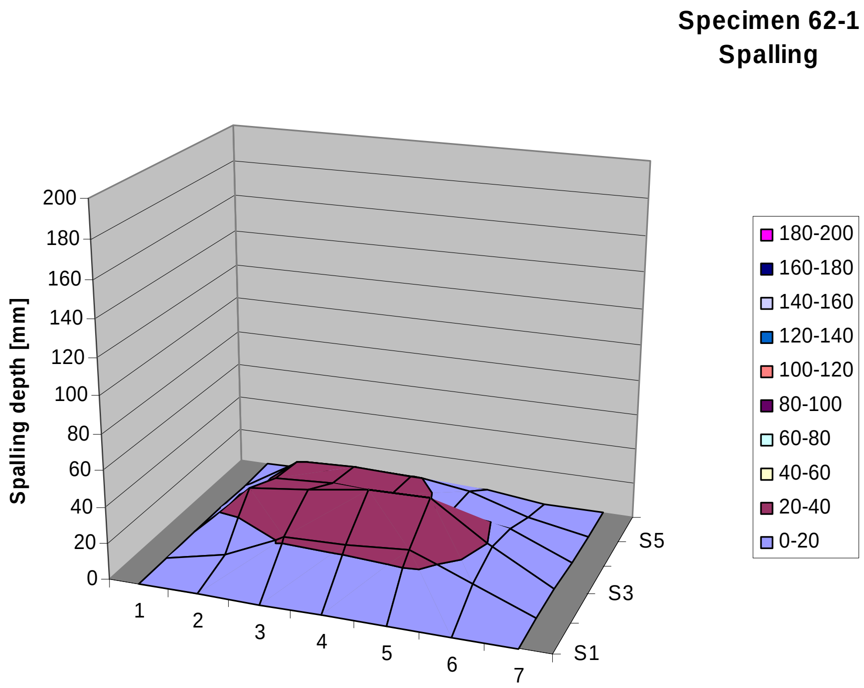


Figure A.740 Spalling measurements on specimen 62-1.

Table A.415 Observations made on specimen 62-1.

Time	Observation
0,00	Start of test
4,00	Small continuous explosions
5,00	The explosions grows louder
17,00	Spalling stopped
20,00	Cracks and water on sides
60,50	Test terminated

Test date:	2007-11-19	
Specimen:	62-1	
Load level:	297	kN/bar
Weight loss:	11,5	kg

Figure A.741 Specimen 62-1 after test.

Specimen 62-2

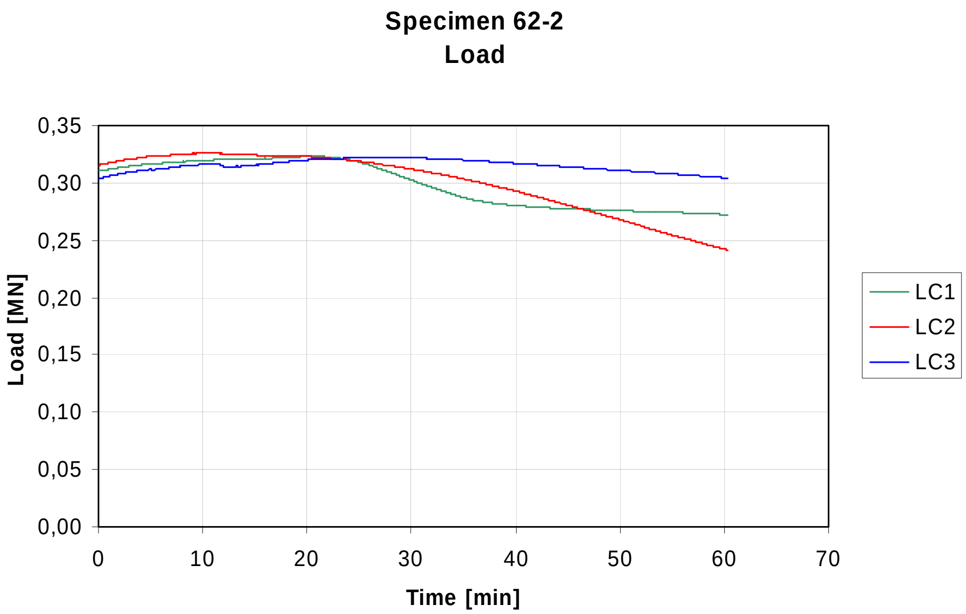


Figure A.742 Load measurements on specimen 62-2.

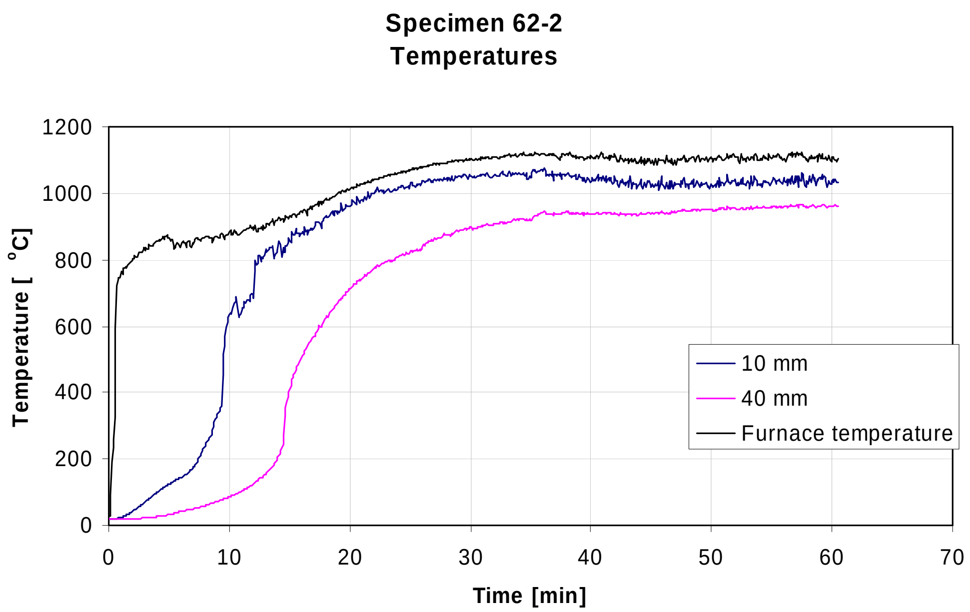


Figure A.743 Measured temperatures in furnace and in specimen 62-2.

Table A.416 Spalling measurements on specimen 62-2.

Position	0	100	200	300	400	500
0	0	0	2,3	2,7	0	0
100	0	25	45	44	12	0
200	0	40	59	43	16	1
300	2	3	51	40	15	0
400	0	25	42	31	11	2
500	0	10	26	23	6	0
600	0	0	0	0	0	0

Mean all	14
Mean inner	28
Max in diagram	59
Max measured	66

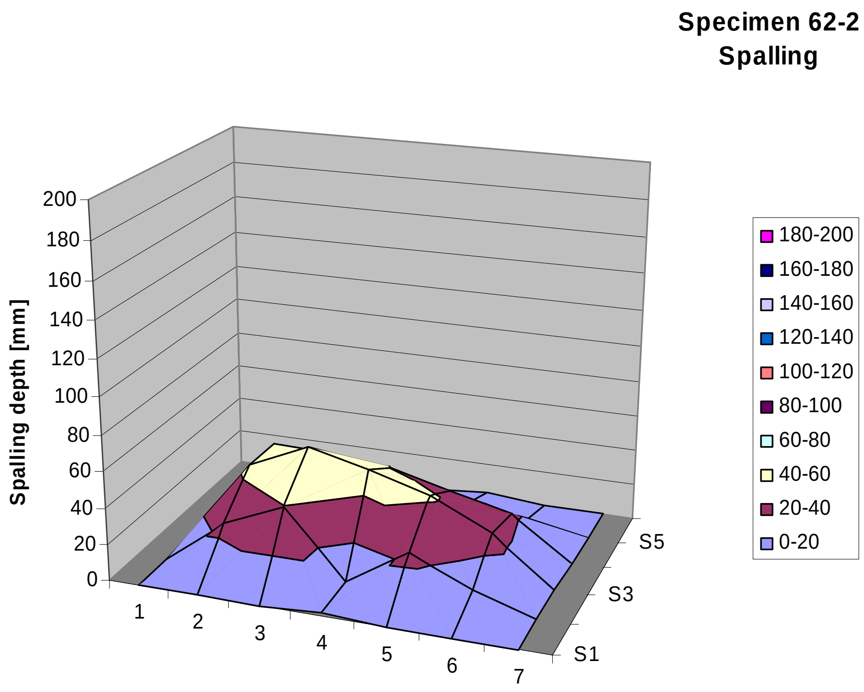


Figure A.744 Spalling measurements on specimen 62-2.

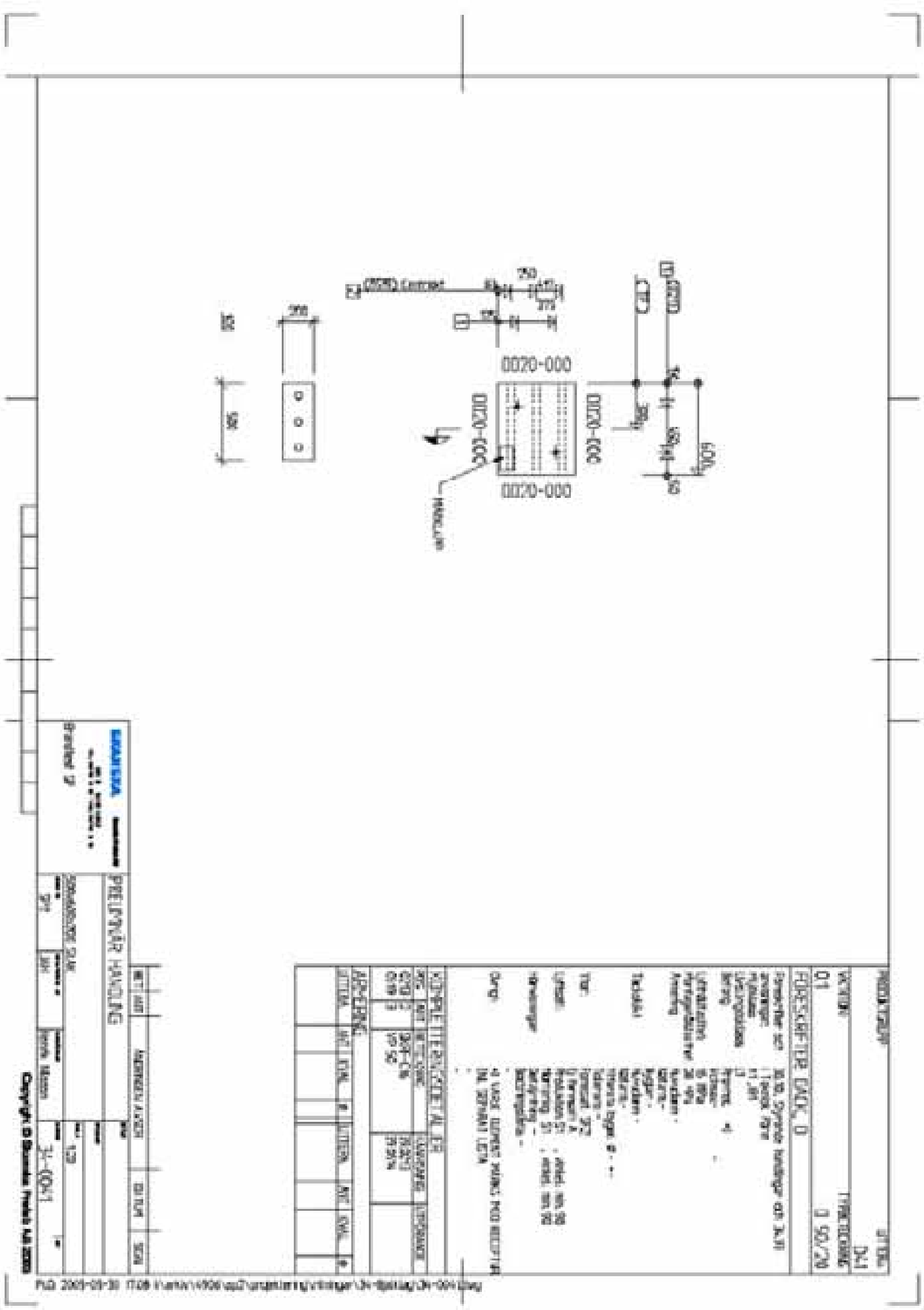
Table A.417 Observations made on specimen 62-2.

Time	Observation
0,00	Start of test
3,50	Small explosion
3,83	Small explosion
4,50	Two small explosions
5,33	Explosion
18,00	Spallin stops
24,00	Water on sides and on top surface
60,50	Test terminated

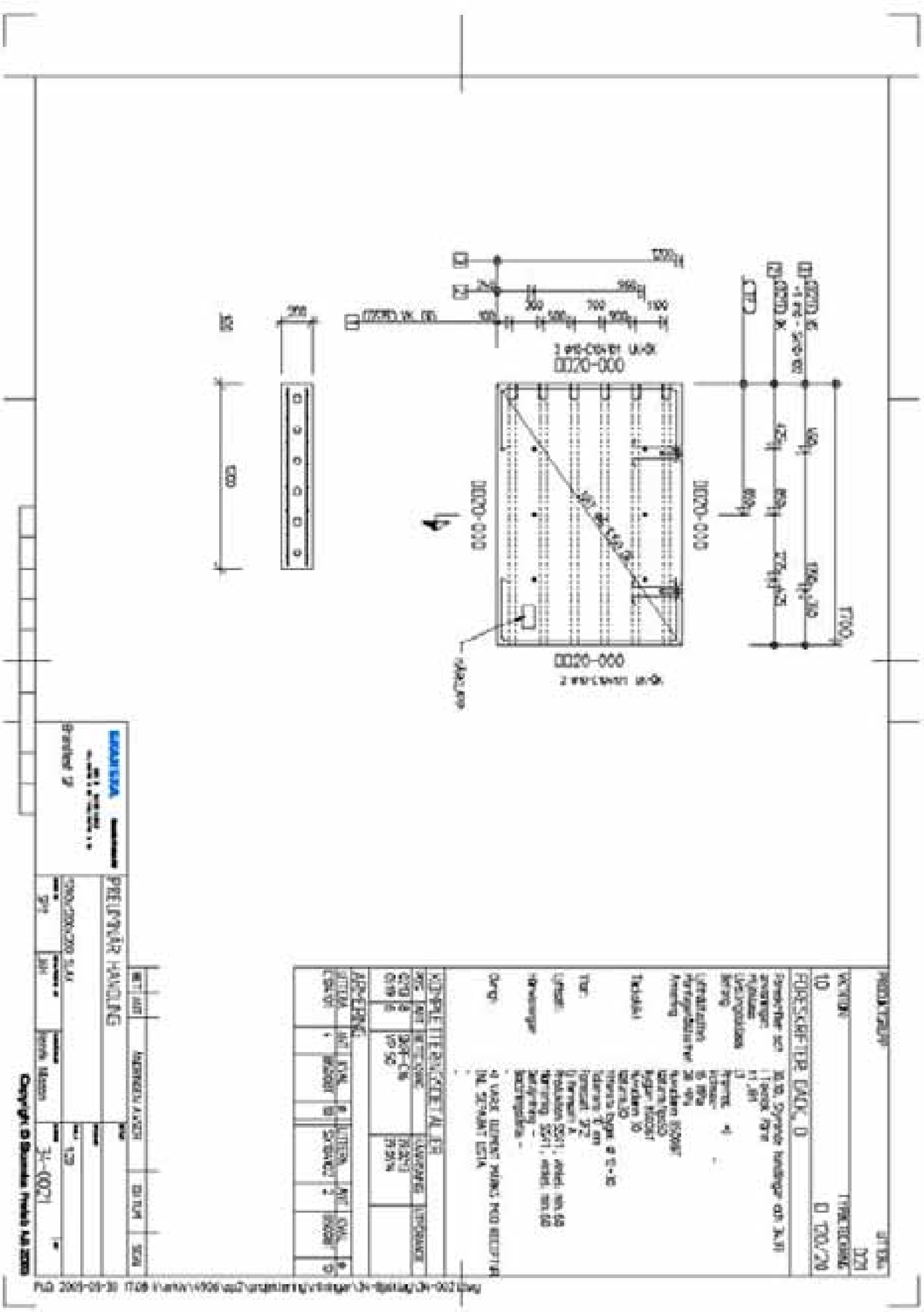
Test date:	2007-11-19	
Specimen:	62-2	
Load level:	310	kN/bar
Weight loss:	13,1	kg

Figure A.745 Specimen 62-2 after test.

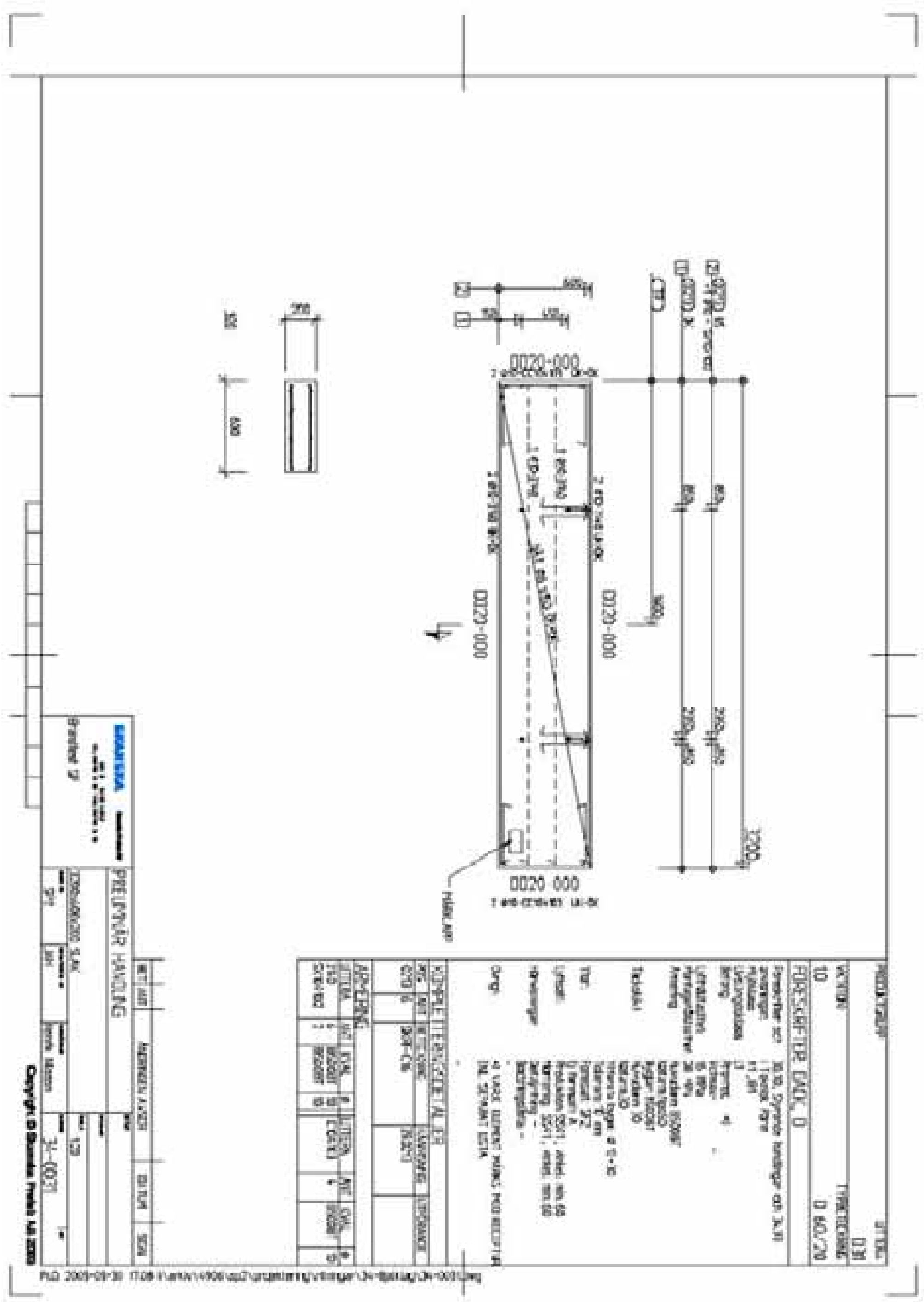
Appendix B – Small slab specimen



Appendix C – Large slab specimen



Appendix D – Beam specimen



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RAPPORT

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SBUF- projekt nr 11522 ”innovativ självkompakterande betong med goda brandspjälkningsegenskaper”. Rapport WP 4: ”Mikrostruktur- och beständighetsanalys”

Jan Trägårdh, Mariusz Kalinowski

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Sammmanfattning

Resultaten från CBIs undersökning inom SBUF-projektet ”SKB med goda brandspjälkningsegenskaper” indikerade att kloriddiffusionskonstanten och kapillärkoefficienten minskade med ökande flytmedelsdos/dispergeringseffekt och fibermängd i cementpastan. Undersökningen omfattade 12 olika anläggningsrecept med vct 0,40 men med tre olika v/p-tal och varierande PP-fiberhalter. Två olika typer av fiber användes: Ø=18µm,L=6mm och Ø=32µm,L=6mm. För att kunna jämföra proverna med varandra (olika fibertyper och mängder) anges fibermängden som en koncentration, dvs antalet fiber/betongvolym. Betongerna proportionerades och tillverkades av Sika i samarbete med Skanska. Två av betongrecepten fick en högre cementhalt och vattenhalt (recept 21 och 22 i tabell 1). Dessa prov uteslöts ur vissa resultatanalyser.

Kloriddiffusionskonstanten varierade ca 40 %, där de högre värdena var från referenser utan fibrer och en lägre flytmedelsdos medan de lägre värdena kring var från betonger med de högsta fiberkoncentrationerna och flytmedelsdoserna. Andra studerade parametrar var tex. v/p-tal, kapilläritet (kapillärkonstanten), karbonatiseringt, viskositet, lufthalt, frostmotstånd och tryckhållfasthet. Korrelationen mellan olika metoder för att mäta samma sak gjordes också. Resultatet blev att korrelationen mellan kloriddiffusionskoefficienten och kloridmigrationskoefficienten var acceptabel (0,67) liksom korrelationen mellan lufthalten i färskt och hårdnat tillstånd (0,73).

Övriga resultat indikerade att kapillärporstrukturen, dvs kapillärkofficienten som karaktäriserar finheten hos porsystemet, hade ett tydligt samband med dispergeringseffekten, som här indirekt representeras av flytdosen och PP-fiberhalten. Dispergeringseffekten påverkar i sin tur hydtratationsgraden och förmodligen kapillärporstrukturen. Det anses mindre troligt att PP-fiberna i sig har någon effekt på kloridinträngning, permeabiltet och vattenabsorptionsförmåga i kapillärporsystemet, vilket framförts i olika sammanhang [3], [13]. Fortsatt forskning på CBi kommer emellertid att försöka klargöra orsakssambamden.

Någon tydlig korrelation mellan v/p-tal och kapillärkofficient observerades inte. Ett samband man annars kan tänka sig är att ett minskat v/p-tal medför ett tätare kapillärporsystem, dvs en lägre koefficient [9], [14]. Undersökningen utesluter inte att så kan vara fallet, men resultaten stödjer inte detta.

De uppmätta max.- och min.- värdena i kapillärkoefficient för anläggningsbetongerna, lägst ca 0,35 och högst ca 0,65 kg/m^{2}x rot h, motsvarar erfarenhetsmässigt en ungefärlig skillnad i vct mellan 0,35 och 0,50 för en normalproportionerad SKB.

Kring PP-fibrerna bildades ett ca 2-3 mikrometer tjockt portlanditskikt som medförde att övergångszonen mellan fibrer och cementpasta blev tätare. Vid förhöjd temperatur, tex vid brandexponering, börjar portlanditstrukturen att brytas ner vid ca 370 °C och har fullständigt kollapsat vid ca 580 °C. När Portlanditen bryts ner bildas calciumoxid och vatten. Eftersom det vatten som bildas momentant övergår i ångfas, påverkas ångtrycket lokalt kring fibrerna. Möjligen kan det vara en bidragande faktor för sprickpropagering från fibrerna vid brand.

Salt-frostbeständigheten förbättrades markant med andelen fibrer i SKB (utan lufttillsats). Med fiberhalter mellan 1-2 kg/m^3 var frostbeständigheten mycket god efter 56 fryscykler. Orsaken till den förbättrade frostbeständigheten är den ökade lufthalten och det mer jämnt fördelade luftporsystemet som skapas av pp-fibrerna vid själva blandningen av betongen. Exempel på faktorer som gör att luftporsystemet får en tillräckligt god struktur för att klara kriteriet för salt-frostbeständighet är, konsistens, fiberhalt och framför allt att mantelytan på fiberna är bestrukna med ett dispergeringsmedel som också verkar som en luftporbildare. I projektet har kombinationen SKB och 6 mm långa pp-fiber varit tillräckligt för att skapa ett luftporsystem utan tillsättning av extra luftporbildare. Liknande resultat har tidigare rapporterats och uppmärksammats i USA [2].

Det finns en potential i att fibermängden och den förbättrade dispergeringseffekten som en ökad flytdos medför kan påverka beständighetsegenskaperna positivt hos självkompakterande anläggningsbetongbetonger. Det kan medföra ett mervärde i tex tunnelbyggen, där SKB med pp-fiber används för att förbättra brandspjälkningsegenskaperna.

1. Material och metodik

Tolv stycken självkompakterande anläggningsbetonger (CEM I) och sex stycken husbyggnadsbetonger (CEM II) provades och analyserades enligt schema i Fig. 3.
Materialrecepten ges i Fig. 2. och 3. Betonggjutningarna utfördes i Skanskas fabrik i Strängnäs tillsammans med personal från Sika.

1.1 Material
De 12 anläggningsbetongerna och 4 husbyggnadsbetongerna blev utvalda från en stor försöksmatris på ca 65 betongrecept för att motsvara ett representativt urval i syfte att prova beständighetsegenskaperna och tätheten i kapillärporsystemet samt mikrostrukturen. Husbyggnadsbetongerna provades enbart med avseende på täthet och mikrostruktur (tunnslip).
Resultaten från analys av mikrostruktur och täthet har som syfte att ge underlag för tolkningar av brandbeständighetsegenskaperna. Ett annat syfte var att verifiera hur traditionella beständighetsegenskaper (frostavskalning, karbonatiseringshastighet, kloriddiffussion/migration och vattenabsroption påverkades av PP-fiberinblandning.

Tabell 1 . Recept för SKB anläggngningsbetonger, vct 0,40 .

SKB-recept	1 REF.	2	3a	4	6 REF.	11	13	16	18 REF.	19	(21*)	(22*)
w/c-ratio	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
w/p-ratio	0.25	0.25	0.25	0.25	0.30	0.30	0.30	0.30	0.40	0.40	0.40	0.40
PP-fiber (kg/m^3) Ø=18µm,L=6mm	_	0.50	1.50	_	_	_	1.0	1.0 L=12 mm	_	0.50	_	_
PP-fiber (kg/m^3) Ø=32µm,L=6mm	_	_	_	1.0	_	2.0	_	_	_	_	1.35	3.0
Fiberyta/betongvol. (m^2/m^3)	0	122	366	43,7	0	87,4	244	244	0	122	59	131,2
Pastavolym (l) (Cem.+filler+H_2O)	396,8	396,8	396,8	396,8	355,5	361,7	355,5	355,5	303,8	303,8	397,4	397,4
CEM I (kg/m^3)	420	420	420	420	420	430	420	420	420	420	550	550
Kalk filler (kg/m^3) (Limus 25)	252	252	252	252	140	143	140	140	-	-	-	-

Flytdos, Sikament 20HE50,20% torrv. (% cem.vikt)	1,67	1,67	2,86	2,38	1,50	2,21	1,90	2,14	0	1,55	0,91	1,45
Tryckhållf. (MPa)	59,6	67,6	69,6	77,3	67,1	68,4	55,3	72,6	66,9	66,4	61,5	58,0
A (kap.koeff. kg/m2xrot tim)	0,513	0,439	0,358	0,392	0,522	0,391	0,468	0,374	0,452	0,475	0,670	0,613
Flytsättmått (mm)	735	680	630	660	750	600	630	580	610	600	680	570
T 50 (s)	5	6	7	7	4	6	6	7	7	5	3	3
Kommentar från Skanska	Bra	Bra	Bra, men seg	Bra, men seg	Bra, men segade fort	Bra	Bra, men ngt seg	Trög	Slaskig, blöt, gräns-fall	Bra	Bra	Bra
Ballast, 0-8 (%)	56	56	56	56	56	56	56	56	63	63	63	63
Luft, färsk (%)	1,6	2,3	3,2	1,8	2,3	3,3	3,5	2,9	2,7	4,7	4,5	8,0
Luft, hårdnad (%)	4,9	4,5	5,1	5,6	3,8	5,0	5,2	4,2	6,0	5,7	6,5	8,1

*Förhöjd cementhalt.

De tolv anläggningsbetongernas ingående delmaterial ges i Tabell 1. och valdes med utgångspunkten att vct och cementhalt förblev konstanta liksom andelen 0-8 mm ballastmaterial. Vid gjutningen gjordes emellertid avsteg med avseende på cementhalten i recept 21 och 22 (se nedan). Detta medförde att dessa två recept togs bort i tolkningarna av resultaten från flera mätningar eftersom cementhalten är en parameter som måste hållas konstant om resultaten skall kunna utvärderas. Ballastandelen 0-8 mm ökades också något i recept 18, 19, 21, och 22 för att kompensera borttagandet av kalkfiller i dessa recept.

Grunderna i receptvariationen är således följande: olika kalkfillerhalter (v/p-tal) och polypropylenfiberhalter (PP-fibrer, fiberkoncentration/cementpastavolym) vid konstant vct och cementhalt. Tanken bakom detta är att tätheten i kapillärporsystemet påverkas av kalkfillerhalten (v/p-talet) samt vct och därmed påverkas också ångdiffusiviteten vid brand.

Tabell 2. Recept för husbyggnadsbetonger, vct 0,65.

SCC-formula	39 REF.	40	41a1	42
w/c-ratio	0.65	0.65	0.65	0.65
w/p-ratio	0.50	0.50	0.50	0.50
PP-fiber (kg/m^3) Ø=18µm,L=6mm	–	0.5	1.0	–
PP-fiber (kg/m^3) Ø=32µm,L=12mm	–	–	–	1.0
Stabilizer, Sika (% av cem.vikt)	1,13	-	-	-
Sikament 20HE50 (% av cem.vikt)	1,27	1,36	1,44	1,42
T 50 (s)	<1	2	2	1-2
Flytsättmått (mm)	650	650	700	670
Kommentar	bra	bra	Tendens till separation	Tendens till separation
CEM II A-LL (kg/m^3)	355	355	355	355
Lime filler (kg/m^3)	105	105	105	105
Luft, färsk (%)	2,1	1,9	1,6	1,7
Luft, hårdnad (%)	4,4	4,6	3,2	3,8
Pastavolym (C+H_2O)	346,5	346,5	346,5	346,5
Vattenhalt (kg)	115,7	115,7	115,7	115,7
Pastavolym (C+H_2O+kalk)	385,4	385,4	385,4	385,4
Fiberyta/betongvol. (m^2/m^3)	0	122	244	68,63

1.2 Metodik

De metoder som utvaldes för att mäta olika egenskaper var följande:

1) Chloridediffusion - NT Build 443 - concrete surfaces exposed to 2.8 M NaCl solution for 35 days. The chloride analysis with ion-selective electrode and Ca-titration.

2) Chloride migration - NT Build 492 - a non-steady-state test of migration of chloride under influence of an external electrical field.

3) Capillary suction - DIN 52617 - conventional method from which the coefficient of capillarity and capillary porosity were calculated.

4) Microstructure analysis - scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS) and backscattered electron detector (BSE). Thin section analysis with polarising light microscope.

5) The salt-frost test - SS-EN 13 72 44 - concrete surfaces were exposed to 3 % NaCl solution and temperature variation between +20 and -18 °C during 56 freeze-thaw cycles.

6) Air-void structure - measured with an image analyser on plain-polished samples (150x150 mm). The analysis includes air voids with diameters between 0.1 and 4 mm.

7) Carbonation test according to AFPC-AFREM (1997) test protocol (Essai de carbonatation acceleree). **Deviation:** drying for at least 6 months in RH ca 50 % instead of oven drying for 48 hours at 40 degrees Celsius.

Tabell 3. Provningsschema.

	Mix nr	gjutn nr	Tunn-slip	SEM	Kapillär-sugning	Luftpor-analys	Frost-resistens	kloriddiff. + kloridmigr.	Karbonat-isering
CEM I	6	39			x	x	x	x	Provas 08-02
	13	38		x	x	x	x	x	provas
	11	33		x	x	x	x	x	provas
	21	51			x	x	x	x	provas
	22	52			x	x	x	x	provas
	1	~~20~~ 34	x		x	x	x	x	provas
	2	~~21~~ 35		x	x	x	x	x	provas
	3a	~~22~~ 36	x		x	x	x	x	provas
	4	~~24~~ 37		x	x	x	x	x	provas
	18	45			x	x	x	x	provas
	19	44			x	x	x	x	provas
	16	47			x	x	x	x	provas
CEM II	39	10	2805		x	x			
	40	11	2806		x	x			
	41a1	18	2808		x	x			
	42	14	2807		x	x			

2. Mikrostruktur, kapillär porositet

Mikrostrukturanalys av de testade betongerna utfördes på CBI med hjälp av svepelektronmikroskop (SEM) utrustat med bakåtspridda elektrondetektor (BSE) och energidispersiv röntgenspektroskop (EDS). PP-fibernas dispergering i cementmatrisen undersöktes med stereomikroskop. Detta gjordes genom att proven spräcktes och fibrerna drogs isär från en brottyta som undersöktes under mikroskopet. Resultatet var att fibrerna var väl spridda över hela brottytan och inga ”knippen” med odispergerade pp-fiber kunde observeras. I Fig. 1 nedan framgår det huvudsakliga observationen som gjordes i SEM och tunnslip med avseende på mikrostrukturen.
Innanför den streckade linjen i Fig. 1 syns en massiv bildning av portlanditkristaller mot gränsen till PP-fibern (heldragen linje). Kristallbildningen förekom allmänt kring alla fiber, i större eller mindre utsträckning. Tjockleken av skiktet är generellt ca 3 µm men kan uppgå till 10 µm. Portlanditbildningen kring fibrerna medförde också en förtätning av övergångszonen mellan fiber och cementpasta. Vid förhöjd temperatur, tex brandexponering, så börjar portlanditstrukturen att brytas ner vid ca 370 °C och har fullständigt kollapsat vid ca 580 °C. När Portlanditen kollapsar bildas calsiumoxid och vatten enligt följande:

$Ca(OH)_2$ + T (370 °C) → $CaO + H_2O$ (g)

Eftersom det vatten som bildas momentant övergår i ångfas kan detta påverka ångtrycket i betongen vid brandexponering, dvs ett lokalt förhöjt ångtryck kring fibrerna.

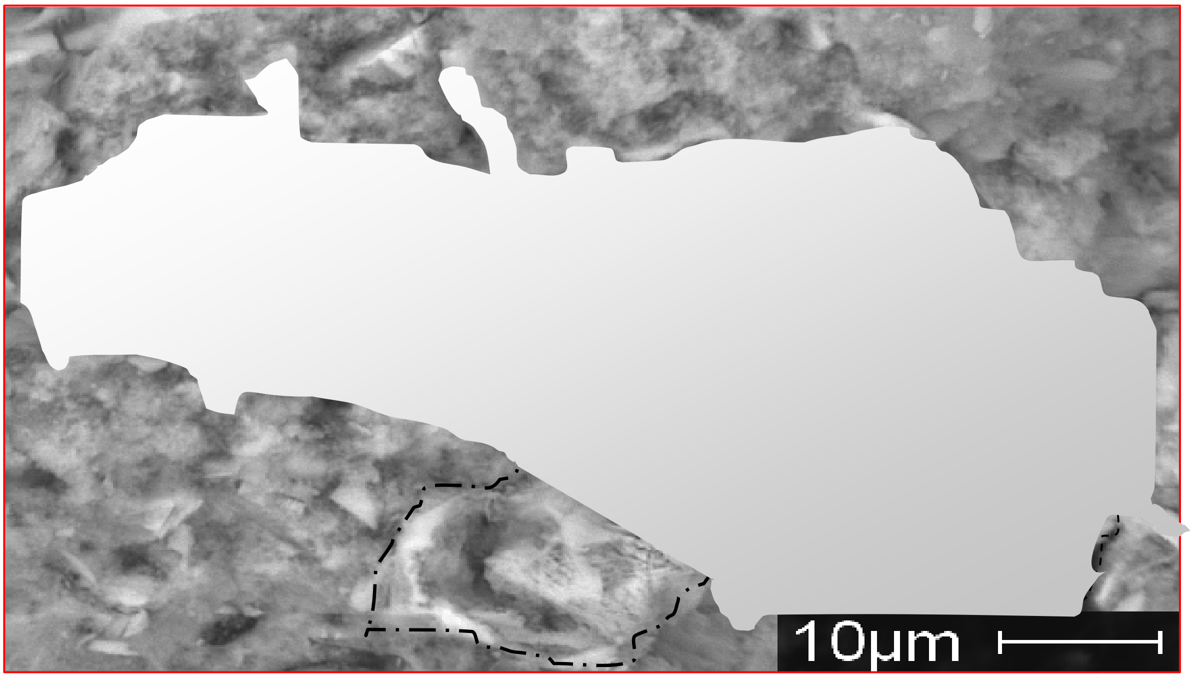


Fig. 1. Svepelektronbild som visar tillväxten av tavelformade portlanditkristaller i övergångszonen kring PP-fiber (streckat område). Kristallbildningen medför en tätare övergångszon.

Den totala porositeten varierade mycket lite mellan anläggningsbetongerna med vct 0,40, se Fig. 2 nedan. Porositeten ligger konstant på ca 10 vol. %. Den mättes med hjälp av vattenabsorption till en viss tid (knickpunkten) då mättnad av kapillärporsystemet inträffar. För att få med alla porerna som kan ha en betydelse för transportegenskaperna förlängdes emellertid vattenabsorptionen till konstant viktförändring inträffade (horisontell nivå i vattenabsorptionkurvan). Detta inträffade ungefär efter 6 veckor.

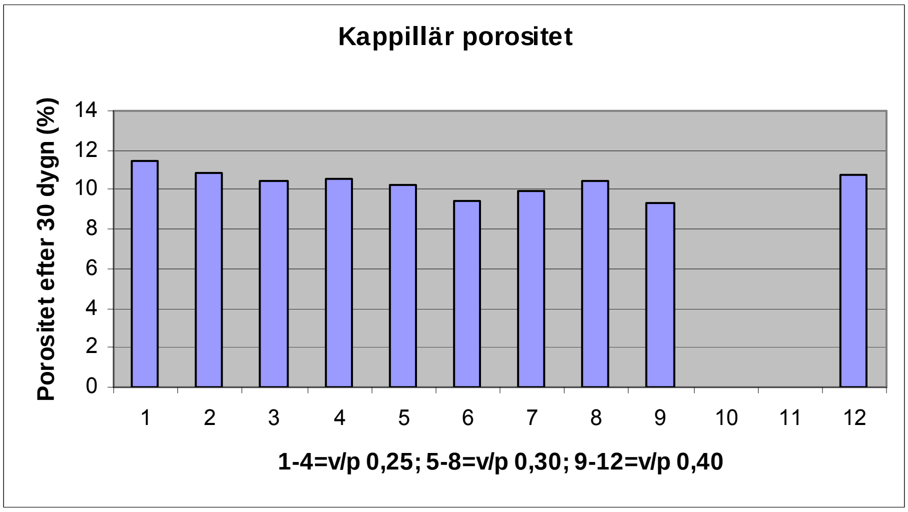


Fig. 2. Kapillärporositen för 10 av 12 anläggningsbetonger med vct=0,40. De två betonger som undantagits hade en avvikande cementhalt.

Kapillärkoefficienten (A) mättes för samtliga betonger, se Fig. 3 nedan. Kapillärkoefficienten är ett relativt mått på finheten/tätheten i kapillärporsystemet. Eftersom vct är ett indirekt mått på samma sak kan man tänka sig att en god korrelation skulle uppstå mellan vct och kapillärkoefficienten. Så var emellertid inte fallet och koefficienten varierade mellan 0,35 och 0,67 för vct 0,40 (se Fig. 3). Som jämförelse kan sägas att erfarenhetsmässigt brukar traditionella betonger med ett vct på 0,40 motsvara ca 0,35-0,40 i kapillärkoefficient (Kg/m^2 x $\sqrt{t}$) och vct 0,50 en koefficient på ca 0,50-0,55. Moderna betonger och material (flyttillsatsmedel, självkompakterande betong, filler etc.) påverkar emellertid kapillärporstrukturen och därmed betongens beständighetsegenskaper i mycket hög grad, till och med i högre grad än ett valt vct för ett speciellt betongrecept. Med andra ord är ett vct utifrån ett recept inte samma som den faktiska vct-ekvivalenten i den hårdnade betongen, om man utgår från att vct är ett mått på tätheten i kapillärporsystemet.

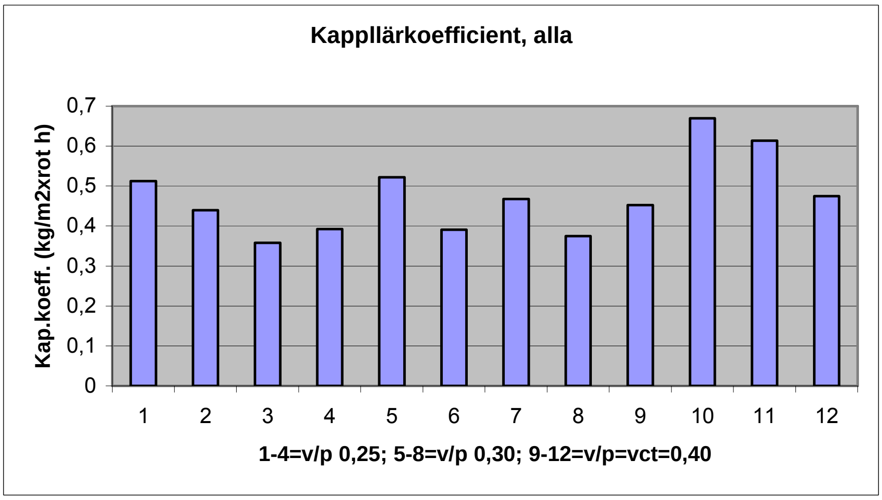


Fig. 3. Kapillärkoefficienten för alla prov med vct 0,40. Koefficienten varierade mellan 0,35 till 0,67. Betongerna 10 och 11 hade avvikande (högre) cementhalt, se Tabell 1.

I Fig. 4 nedan visas sambandet mellan tryckhållfasthet och kapillärkoefficient för betongerna med vct 0,40. Teoretiskt borde ett tydligt samband finnas, men sambandet i Fig. 4 är svagt. Detta kan bero på olika faktorer där den mest sannolika är skillnader i luftporhalten. Mängden PP-fiber har en betydande inverka på luftporhalten som i sin tur påverkar tryckhållfastheten i olika grad.

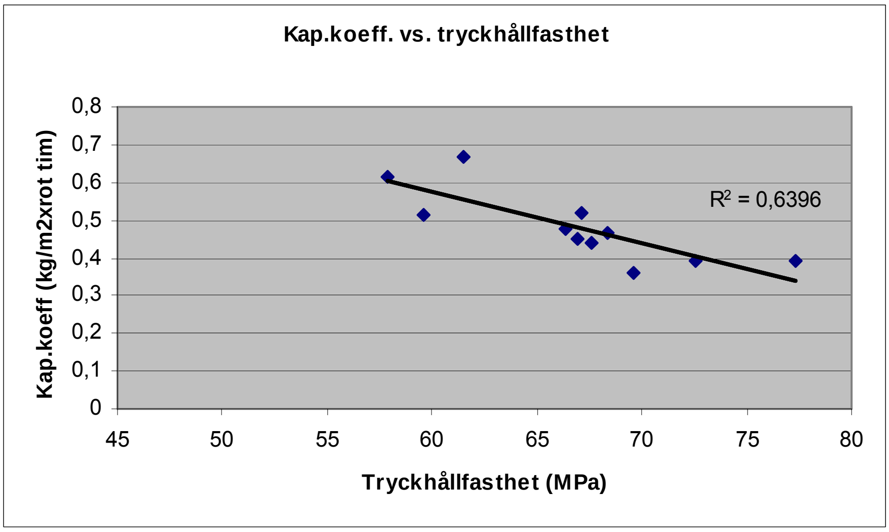


Fig. 4. Kapillärkoefficienten som funktion av tryckhållfastheten. Tryckhållfastheten varierade mellan 55 och 77 MPa för betongerna med vct 0,40.

Fig 5 nedan visar, något överraskande, att v/p-talet hade liten eller ingen inverkan på tätheten uttryckt som kapillärkoefficienten. I litteraturen finns rapporterat att en ökande fillerhalt ofta medför ett tätare kapillärporsystem, den s.k fillereffekten. Resultatet kan emellertid bero på att betongerna med kalkfiller inte nådde sin optimala dispergeringsgrad med använd flytdos.

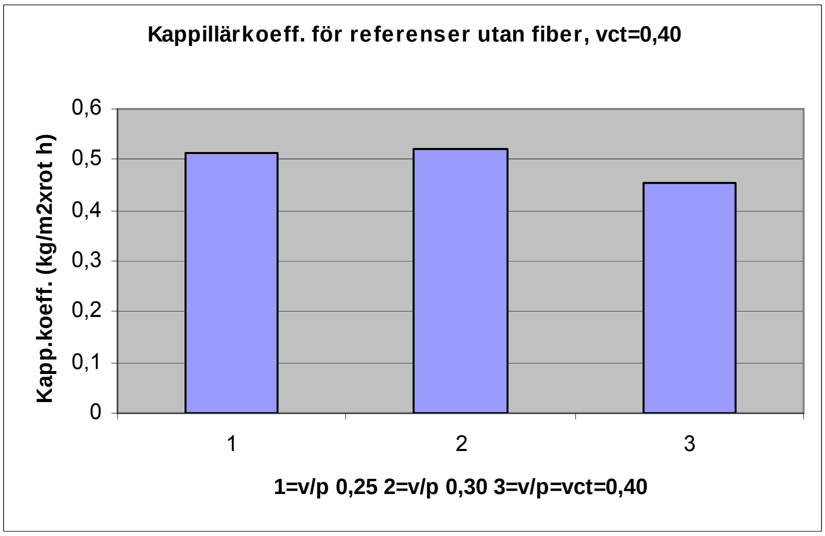


Fig.5. Kapillärkoefficientens variation med kalkfillerhalten (v/p-talet) för vct 0,40 och samma cementhalt. V/p-talet tycks medföra en liten effekt på tätheten förutsatt att finpartikelfasen var väldispergerad i alla tre betongerna.

Dispergeringsgradens inverkan på kapillärporsystemet

Det starkaste sambandet i studien observerades mellan kapillärkoefficienten och dispergeringseffekten uttryckt som halten flyttillsatsmedel (flytdos i % av cementvikten). Det generella sambandet framgår av Fig. 6 nedan. Så länge som inte separation inträffar så medför en ökande flytdos att finpartikelsystemet dispergerar effektivare. Detta medför i sin tur att tex cementkorn och fillerpartiklar hålls isär i större utsträckning, vilket underlättar tex cementets hydratisering och fillermaterialets utfyllnad i cementpastan. Denna effekt påverkar sannolikt kapillärporsystemets struktur i stor utsträckning.

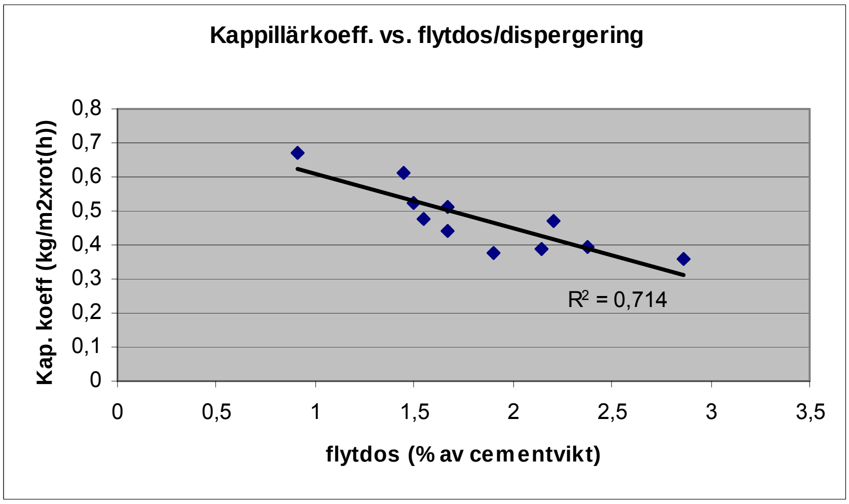


Fig. 6. Kapillärkoefficienten som funktion av dispergeringseffekten (flytdosen) för alla betongerna med vct 0,40.

Som framgår av Tabell 1 består försökserien för anläggningsbetongerna (vct 0,40) av tre stycken kategorier med tre olika vatten/pulvertal, 0,25, 0,30 och 0,40. Inom dessa kategorier har PP-fiberhalten och flytdosen varierats. I serien med v/p-talet 0,40 finns ingen kalkfillertillsats, dvs v/p-talet = vct. I Fig. 7 nedan visas kapillärkoefficienten mot flytdosen för de två serier som hade kalkfiller. Diagrammet visar att en ökad halt av fiber och/eller filler, som medför ett ökat krav på flytdos för att bibehålla en väldispergerad massa, påverkar kapillärporstrukturen till en viss gräns där massan inte kan dispergeras mer.

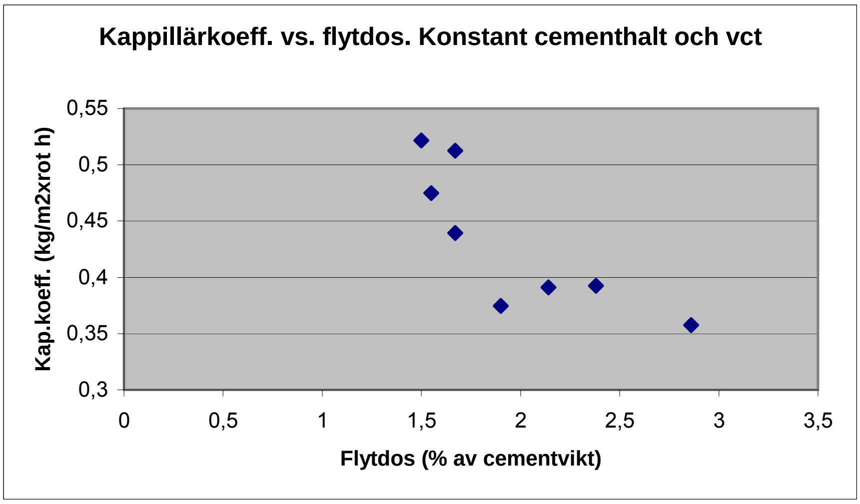


Fig. 7. Kapillärkoefficientens förhållande till dispergeringseffekten (flytdosen). Betonger med vct 0,40 och v/p-tal 0,25 resp. 0,30 (se tabell 1).

Fig. 8 nedan visar att betongerna med v/p-talet 0,25 ur diagrammet i Fig. 7 får en tätare kapillärporstruktur med en ständigt ökad flytdos. Detta tolkas som att den fulla dispergeringseffekten inte har nåtts och att en ökad dispergeringsgrad medför ett tätare och finare kapillärporsystem.

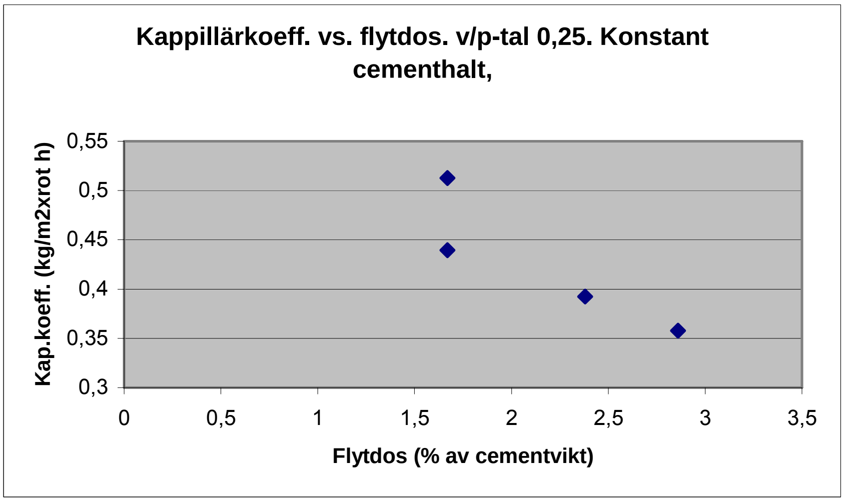


Fig. 8. Kapillärporkoefficienten som funktion av dispergeringseffekten (flytdosen). Betonger med vct =0,40 och v/p-tal 0,25

Diagrammet i Fig. 9 visar ett annat förhållande än det i Fig. 8. Optimal dispergeringseffekt uppnås innan en flytdos på ca 2 % av cementvikten nås och överskrids därefter med separation som följd.

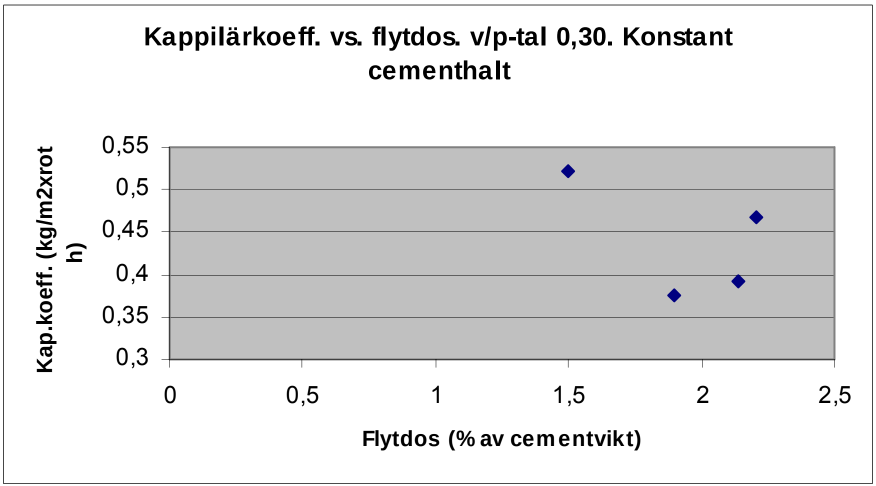


Fig. 9. Kapillärkoefficientens som funktion av dispergeringseffekten (flytdosen). Betonger med vct=0,40 och v/p-tal 0,30.

Diagrammet i Fig. 10 nedan visar samma sak som Fig. 7, 8 och 9 men med fiberkoncentrationen istället för dispergeringseffekten (flytdosen) mot kapillärkoefficienten.
Diagrammet i Fig. 11 visar samma sak som Fig. 10 för betongerna med vct 0,65. Det höga vatten-cementtalet hos dessa betonger i kombination med tillräcklig och konstant flytdos, medförde att optimal dispergeringseffekt uppnåddes. Detta medförde i sin tur att ingen skillnad noterades hos kapillärporstrukturen.

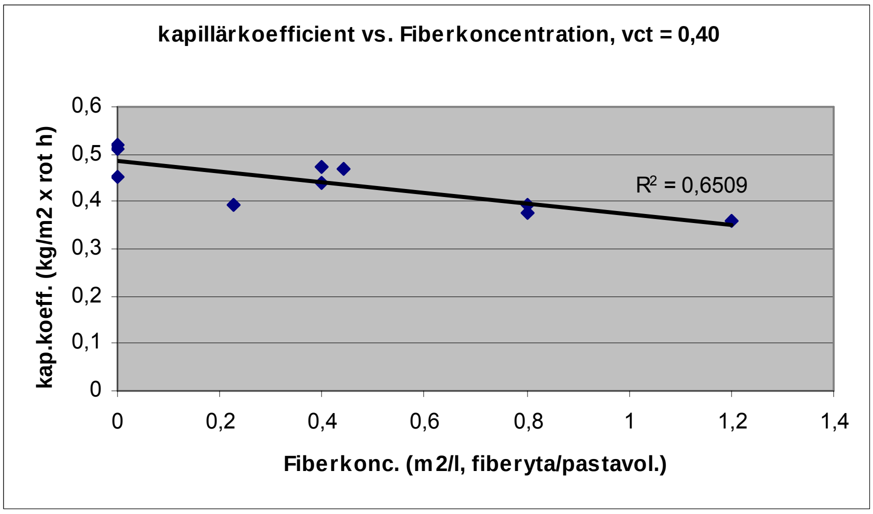


Fig. 10. Kapillärkoefficientens variation med fiberkoncentrationen. Ökande flytdos med ökande fiberkoncentration för bibehållen dispergeringsgrad.

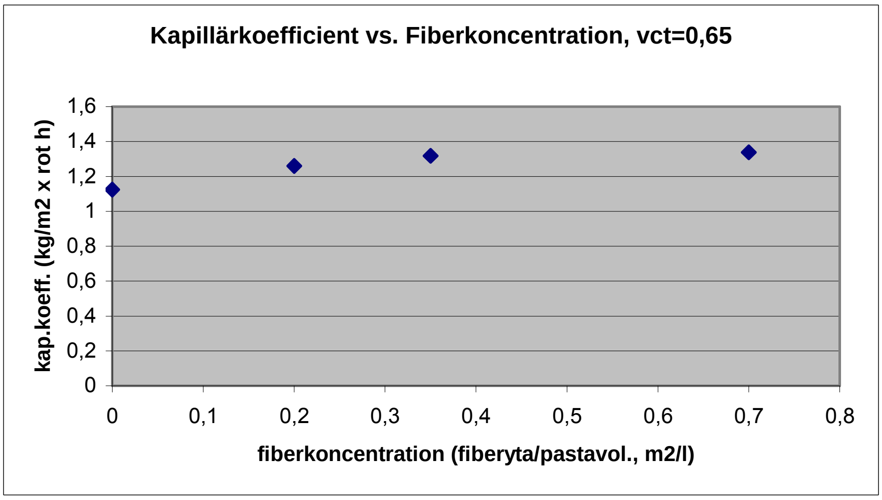


Fig. 11. Kapillärkoefficientens variation med fiberkoncentrationen för husbyggnadsbetong med vct 0,65. Flytdosen var konstant (1,27-1,42 % av cementvikten). Proverna med fiber visar ingen signifikant skillnad i kapillärkoeficient jmf. med provet utan fiber.

3. Kloriddiffussion och migration

Kloriddiffusionskoefficienten bestämdes med hjälp av kloridanalyser på olika djup i betongen och genom att låta punkterna uppfylla ekvationen för icke-linjär regression med ”least square fitting” (CEN TC 51). Kloriddiffusionskoefficienten varierade relativt mycket, dvs mellan ca 6 och 14 x 10^{-12} m^2/s för betongerna med vct 0,40 (se Fig. 12). Samma variation fanns också när man mätte kloridinträngningen med hjälp av Chalmersmetoden, dvs kloridmigrationskoefficienten. Diagrammet i Fig. 13 visar att det finns en god korrelation mellan diffusionskoefficienten och migrationskoeffcienten. Även mellan diffusionskoeffcienten och kapillärkoeffcienten fås en god korrelation för betongerna med vct 0,40 (se Fig. 14).

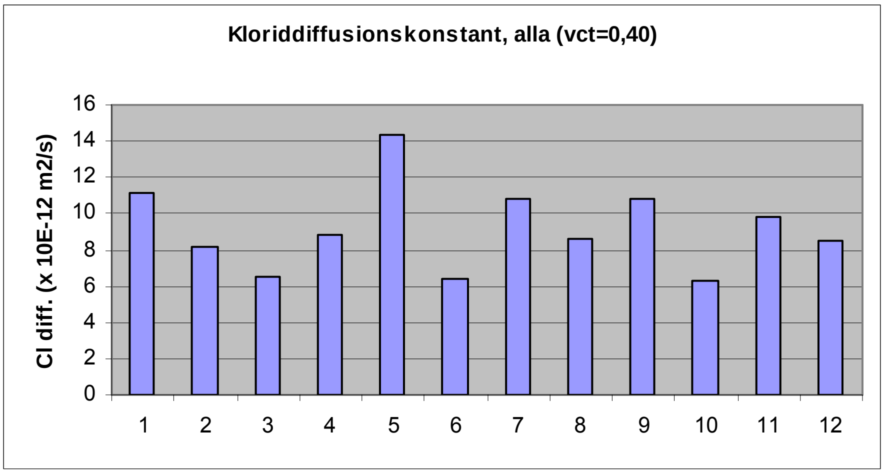


Fig. 12. Kloriddiffusionskoefficienten variation för alla betongerna med vct 0,40. betongerna 10 0ch 11 hade avvikande cementhalt (se Tabell 1).

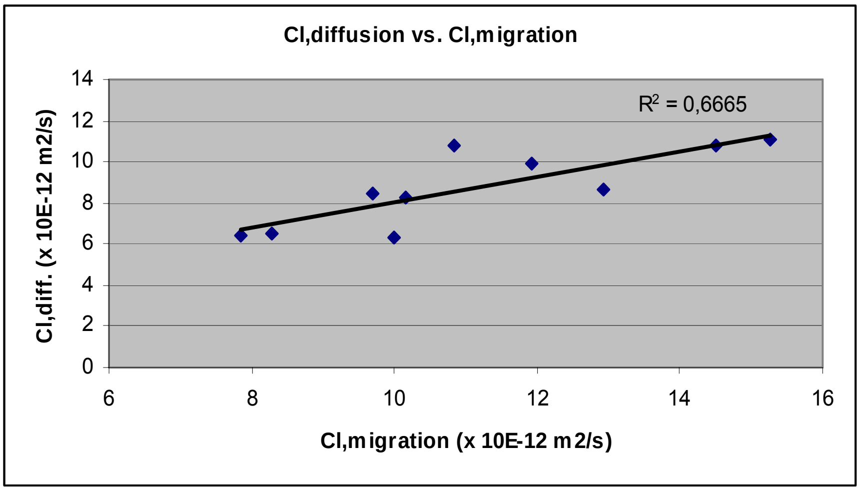


Fig. 13. Korrelationen mellan kloriddiffusionskoeffcienten och kloridmigrationskoeffcienten.

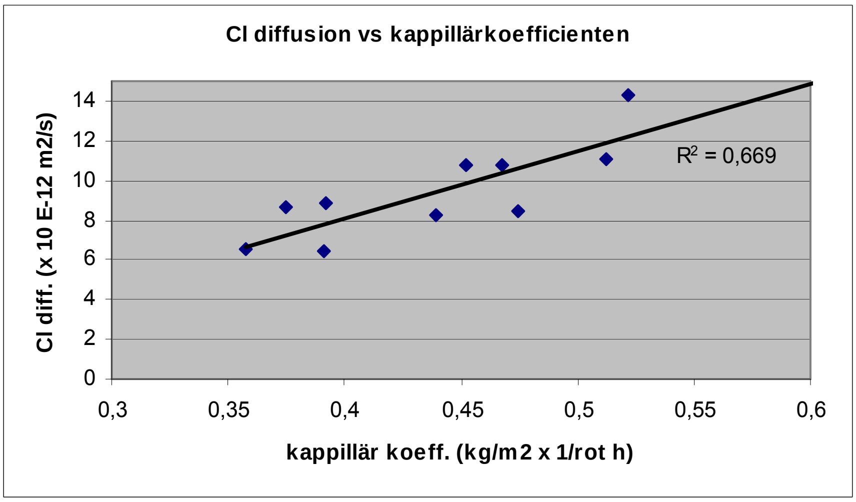


Fig. 14. Korrelationen mellan diffusionskoeffcienten och kapillärkoeffcienten för betongerna med vct 0,40.

4. Salt-frostmotstånd, luftporstruktur

De betonger som salt-frost provades var anläggningsbetonger och hade vct = 0,40. Salt-frost beständigheten för de betonger med 1- 2 kg/m^3 PP-fiber befanns vara mycket god. Detta beror på det faktum att PP-fiberna har ett medel kring mantelytan för att underlätta dispergeringen av fiberna i cementpastan. Medlet fungerar också som en luftporbildare. En viss effekt kan också finnas mellan fibernas omrörning i cementpastan och finfördelning av inblandningsluften som normalt är ca 2 %. Tabell 4 nedan visar resultatet efter olika salt-frost cykler.
Fibernas betydelse för frostmotståndet och luftporfördelningen framgår av Fig. 15 och 16.

Tabell 4. Avflagning efter olika antal salt-frostcykler.

recept	**Avflagning (kg/m^2)**										**Omdöme**
	7	14	28	42	56	70	84	98	112	112 + 1)	
11 >1kg	0,01	0,02	0,08	0,15	0,25	0,34	0,42	0,53	0,59	0,64	god / acceptabel
	0,01	0,02	0,08	0,12	0,15	0,27	0,32	0,36	0,39	0,42	
1	0,20	0,94	3,86	10,46	18,78						inte acceptabel
	0,20	0,85	3,76	10,92	16,28						
2	0,06	0,33	1,48	3,09	4,22						inte acceptabel
	0,04	0,24	1,16	2,39	3,46						
3a >1kg	0,01	0,02	0,03	0,05	0,06	0,08	0,09	0,10	0,10	0,11	mycket god
	0,01	0,01	0,02	0,03	0,03	0,03	0,03	0,03	0,04	0,04	
4 >1kg	0,02	0,04	0,06	0,07	0,11	0,14	0,17	0,19	0,20	0,21	god
	0,01	0,02	0,02	0,03	0,03	0,09	0,12	0,25	0,28	0,30	
13 >1kg	0,01	0,02	0,03	0,04	0,04	0,05	0,06	0,07	0,07	0,07	mycket god
	0,01	0,02	0,04	0,05	0,05	0,07	0,08	0,08	0,08	0,09	
6	0,33	1,21	4,64	8,96	13,82						inte acceptabel
	0,51	1,74	5,71	10,49	16,06						
19	0,02	0,06	0,17	0,28	0,42	0,66	0,91	1,06	1,21		$m_{56}/m_{28} > 2$ → 112 cykler
	0,02	0,06	0,14	0,25	0,35	0,50	0,62	0,77	0,92		inte acceptabel
18	0,06	0,19	1,27	2,50	5,06						inte acceptabel
	0,09	0,26	1,85	2,99	3,62						
16	0,01	0,03	0,09	0,24	0,41	0,57	0,75	0,96	1,19	1,36	$m_{56}/m_{28} > 2$ → 112 cykler
	0,01	0,02	0,12	0,27	0,51	0,72	1,00	1,30	1,67	1,88	inte acceptabel
21 >1kg	0,01	0,01	0,01	0,02	0,02	0,03	0,04	0,06	0,08	0,11	mycket god
	0,01	0,02	0,03	0,04	0,04	0,05	0,06	0,06	0,08	0,08	
22 >1kg	< 0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,02	mycket god
	< 0,01	< 0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	

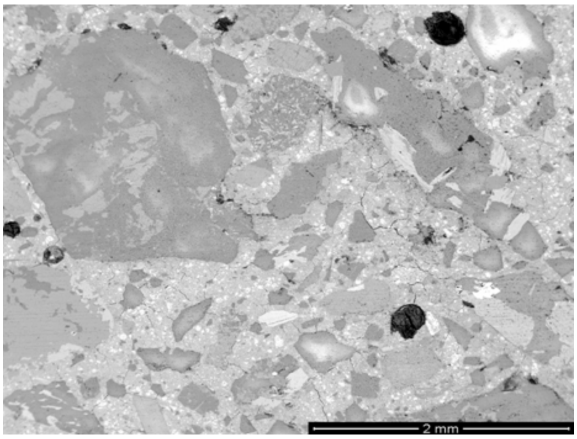
1) Borstning med stålborste.

Referens utan pp-fiber efter 56 dygnSKB
med CEM I
vct = 0,40; v/p-tal = 0,25

Referens utan pp-fiber efter 56 dygnSKB
med CEM I
vct = 0,40; v/p-tal = 0,25

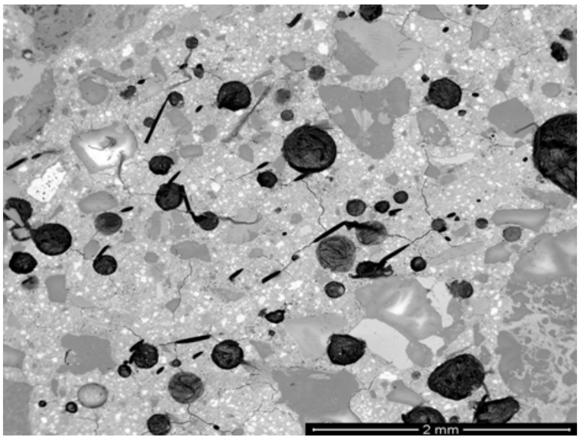
1,5 kg pp-fiber/m^3 betong (Ø=18 µm, L=6 mm) efter 56 dygn**.**
SKB med CEM I
Vct = 0,40; v/p-tal = 0,25

Fig. 15. Exempel på frysning efter 56 cykler för betong med PP-fiber och utan fiber.



SKB med CEM I; v/p-tal = 0,30
Referens utan fiber.

Powers avståndsfaktor: 0,45



SKB med CEM I; v/p-tal = 0,30
2 kg PP-fiber / m^3 betong. Ø =32 µm.

Powers avståndsfaktor: 0,34

Fig. 16. Exempel på hur luftporsystemet utvecklades i betong med PP-fiber och betong utan fiber. Svarta cirklar är luftporer och svarta streck PP-fiber.

För betonger med samma vct (0,40), beror lufthalten och avståndsfaktorn dels på fibermängden men också på vatten-pulvertalet, dvs viskositeten för pastan. Diagrammen i Fig. 17 och 18 visar fibermängdens betydelse för avskalningen, dvs salt-frostmotståndet. Diagrammet i Fig. 19 visar betydelsen av vatten-pulvertalet/viskositeten för lufthalten i den färska massan.

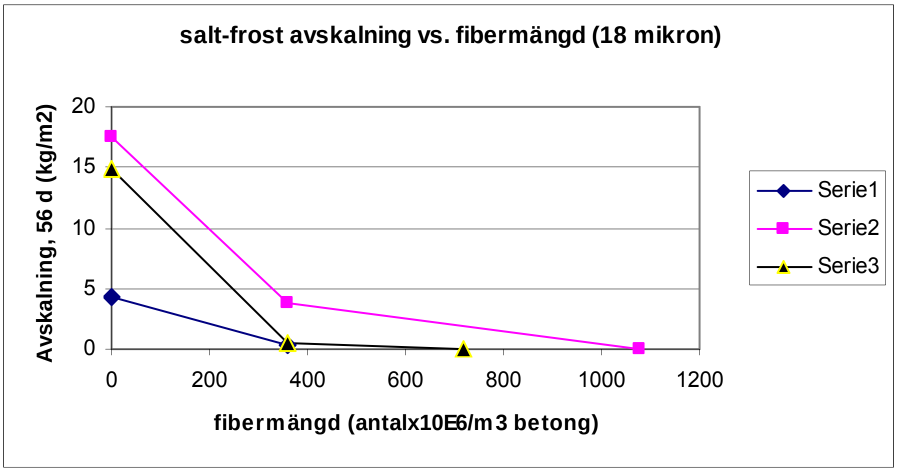


Fig. 17. Sambandet mellan salt-frostavskalning och fibermängd (diameter=18 mikron).

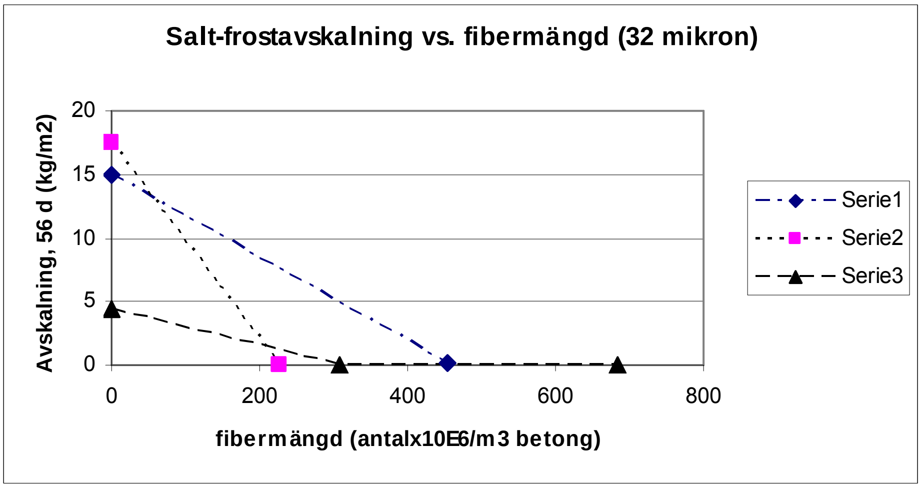


Fig. 18. Sambandet mellan salt-frostavskalning och fibermängd (diameter=32 mikron).

För att fastställa hur överensstämmelsen mellan mätning av luft i färskt tillstånd och hårdnat tillstånd var, mättes båda två. Korrelationen framgår av Fig. 20 och får tolkas som tillfredsställande.

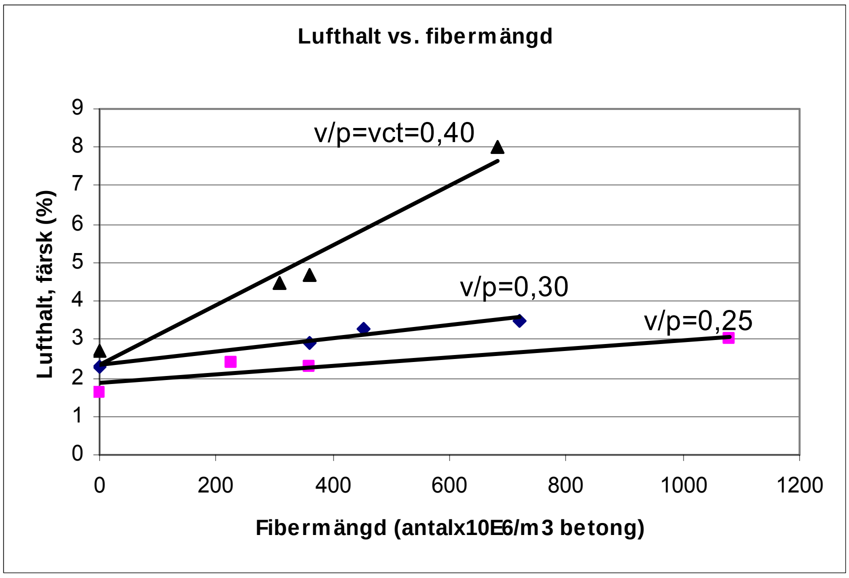


Fig. 19. Sambandet mellan lufthalt, fibermängd och vatten-pulvertalet/viskositet.

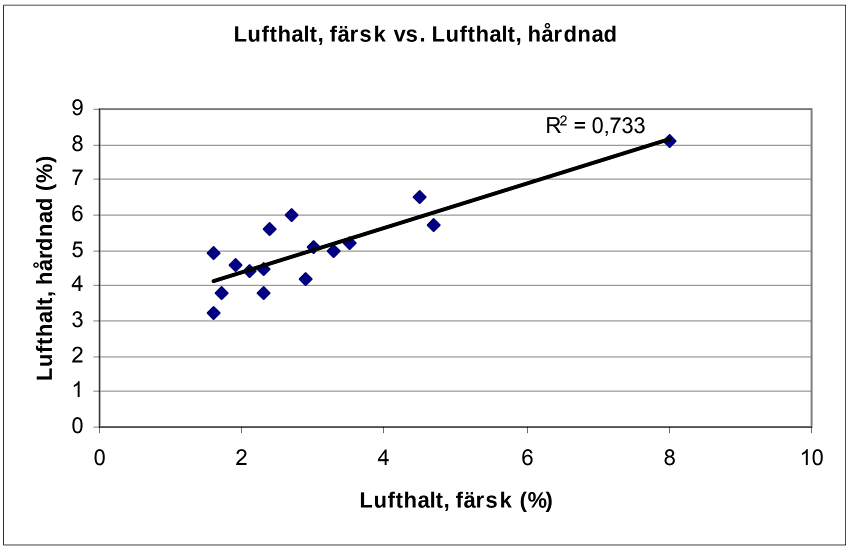


Fig. 20. Korrelationen mellan lufthalten mätt i färsk och hårdnad betong.

5. Karbonatisering

Samtliga betonger placerades i en CO_2-kammare med ca 40 % koldioxidkoncentration. Karbonatiseringsdjupet för betongerna mättes med jämna mellanrum och en hastighetskoefficient bestämdes (A). Efter 12 månader var vissa av anläggningsbetongerna med vct 0,40 fortfarande okarbonatiserade medan andra hade karbonatiserat upp till 15 mm. Betongerna med vct 0,65 var helt karbonatiserade, dvs 34 mm, efter 2 månader. Diagrammen i Fig. 21 visar korrelationen mellan karbonatiseringskoefficienten och kapillärkoeffcicenten för alla betongerna och Fig. 22 visar samma korrelation för betongerna med vct 0,40. Korrelationen är god men bygger på för få punkter. Försöken fortsätter för anläggningsbetongerna i Fig. 21.

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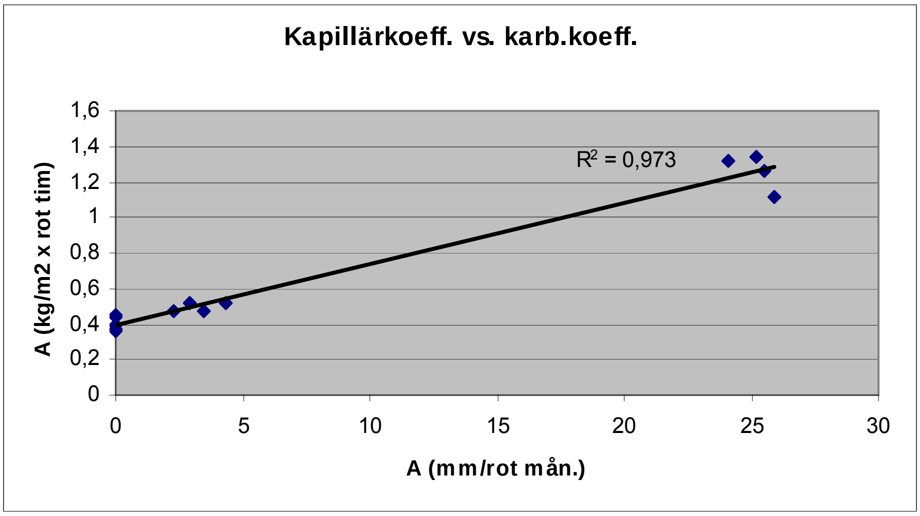

Fig. 21. Korrelationen mellan kapillärkoefficienten och karbonatiseringskoefficienten för samtliga betonger

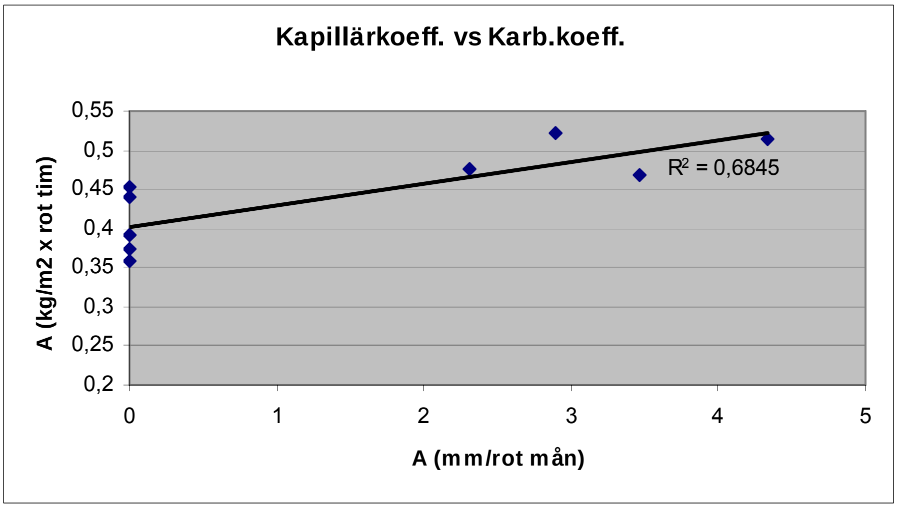

Fig. 22. Korrelationen mellan kapillärkoefficienten och karbonatiseringskoefficienten för betongerna med vct 0,40. Av 10 prov hade 6 inte börjat karbonatisera efter 12 månader.

Tabell 5. Karbonatiseringsdjup efter 12 mån (anläggningsbetong, vct 0,40) och 2 mån. (husbyggnadsbetong, vct 0,65).

prov	tid, mån	djup,mm	vct
1	12	15	0,40
2	12	0	0,40
3a	12	0	0,40
4	12	0	0,40
6	12	10	0,40
11	12	0	0,40
13	12	12	0,40
16	12	0	0,40
18	12	0	0,40
19	12	8	0,40
39	2	36,5	0,65
40	2	34	0,65
41a1	2	35,5	0,65
42	2	36	0,65

6. Slutsatser

För att erhålla ett karaktäristiskt mått på kapillärporstrukturen användes vattenabsorption som metod. Kapillärkoefficienten bestämdes och användes därmed som en enkel karaktäristik på porstrukturen. Givet ungefär samma porvolym så medför ett lågt värde att porstrukturen är fint fördelad (högre andel fina porer) vilket i sin tur medför ett högre motstånd mot transport i kapillärporerna. För anläggningsbetongerna med vct 0,40 kunde det konstateras att det fanns ett brett intervall med avseende på finheten i kapillärporsystemet. Detta medför i sin tur att det finns flera olika vct-ekvivalenter och olika motstånd mot transport i vätske- och gasfas för betongerna, trots att vct var samma för betongen när de blandades. Kapillärporstrukturen påverkar egenskaper såsom beständighet (kloridinträngning, karbonatisering, krav på luftporstruktur för frostkänslighet etc.) och tryckhållfasthet. Nedan ges kortfattat de slutsatser som studien kommit fram till och en trolig orsak till kapillärporstrukturens variation:

- Anläggningsbetongerna med vct 0,40 och inblandad PP-fiber > 1 kg/m^3 visade en större täthet mot inträngning av vätska och gas. Orsaken till detta är ännu oklar men nedan anges en hypotes. Samma betonger visade också en ökad frostbeständighet. Tabell 6 nedan visar en sammanställning för de mätta transportkoefficienterna:

Tabell 6. Uppmätta transortkoefficienter.

Recept	A(karb)	A(kap)	$DCl_{(diff.)}$	$DCl_{(migr)}$
1	4,34	0,513	11,1	15,27
2	0	0,439	8,22	10,17
3a	0	0,358	6,51	8,27
4	0	0,392	8,88	
6	2,89	0,522	14,3	8,57
11	0	0,391	6,41	7,84
13	3,46	0,468	10,8	10,84
16	0	0,374	8,61	12,93
18	0	0,452	10,8	14,5
19	2,31	0,475	6,34	10
21	0	0,6696	9,87	11,92
22	0	0,6134	8,5	9,7
39	25,88	1,12	-	-
40	24,11	1,32	-	-
41a1	25,17	1,34	-	-
42	25,53	1,26	-	-

- Vad orsakade kapillärporsystemets variation? Studien visar på tre samband varav ett är den sannolika orsaken och de andra två s.k. sekundära samband som följer av det primära orsakssambandet. Den sannolika direkta orsaken till kapillärporstrukturens variation bedöms vara dispergeringsgraden (flytdosen) av cementkorn och fillerkorn i pastan. En effektivare dispergering får till följd att cementkornen hydratiserar effektivare och dispergeringen motverkar flokulering av både cementkorn och kalkfillerkorn. En jämnare fördelning av kalkfillerkornen i mikro- och nanoskala kan också bidra till att en homogenare kapillärporstruktur utvecklas. Dispergeringsgraden representeras i diagrammen av dosen flyttillsatsmedel som kan tillsättas utan att separation inträffar. De sekundära sambanden var: Mängden PP-fiber och viskositet (T50). Båda dessa faktorer följer av varandra, dvs en ökad mängd PP-fiber medför en mer trögflytande massa. Det medför också en ökad mängd flyttillsatsmedel som i sin tur ökar dispergeringsgraden.
  De uppmätta max.- och min.- värdena i kapillärkoefficient, som var lägst ca 0,35 och högst ca 0,65 kg/m^{2}x rot h, motsvarar erfarenhetsmässigt en ungefärlig skillnad i vct mellan 0,35 och 0,50 för en normalproportionerad SKB.

Mängden PP-fiber är således troligen inte den direkta orsaken till en minskad kloridinträngning eller vattenabsortionsförmåga i kapillärporsystemet, vilket skulle vara fallet enligt [3] och [13]. I [13] dras slutsatsen att permeabilitetskoefficienten (vattenflöde under tryck) minskar drastiskt när PP-fiber blandas i betongen.

- Påverkade PP-fiberna mikrostrukturen? Kring PP-fiberna bildades ett ca 2-3 mikrometer tjockt portlanditskikt som medförde att övergångszonen mellan fiber och cementpasta blev tätare. Vid förhöjd temperatur, tex brandexponering, börjar portlanditstrukturen att brytas ner vid ca 370 °C och har fullständigt kollapsat vid ca 580 °C. När Portlanditen bryts ner bildas calsiumoxid och vatten. Eftersom det vatten som bildas momentant övergår i ångfas vid tex brand, kan detta lokalt påverka ångtrycket kring fiberna. Möjligen kan detta vara en bidragande faktor för sprickpropagering från fiberna vid brand.
  Bildandet av ett portlanditskikt kring PP-fiber och andra typer av fiber har rapporterats tidigare av [5], [6], [7] och [8].

- Varierade kloridinträngningen på samma sätt som kapillärporstrukturen? Undersökningen visade att det fanns en god korrelation mellan kloriddiffusionskoefficienten eller kloridmigrationskoefficienten och kapillärkoefficienten. En lägre kapillärkoefficient motsvarade ett ökat motstånd mot kloridinträngning.
  Enligt [10] och [11] minskar PP-fiberna sprickvidderna vid plastisk krympning och på så sätt ökas självläkningsförmågan och vattenupptagningsförmåga och kloridinträngning reducerades därmed. Enligt [11] innebar detta att korrosionshastigheten på armeringen minskade vilket också mättes. Enligt [12] minskas kloridinträngningen av PP-fiber på grund av en liknande ”crack-bridging effect”.

- Varierade tryckhållfastheten på samma sätt som kapillärporstrukturen? Ja i viss mån, korrelationen mellan kapillärkoefficienten och tryckhållfastheten var 0,64. Med tanke på att variationer i lufthalten förekom så är korrelationen tillfredställande. Tryckhållfastheten varierade ca 20 MPa för anläggningsbetongerna med vct 0,40 (56-76 MPa).

- Varierade karbonatiseringshastigheten på samma sätt som kapillärporstrukturen? Preliminära resultat visar att det finns en god korrelation mellan hastighetskoefficienten för karbonatisering och kapillärkoefficienten. Dessa försök är inte slutförda eftersom det tar lång tid att karbonatisera anläggningsbetong med vct 0,40. Försöken har pågått i 15 månader.
  Enligt [10] och [11] minskar PP-fiberna sprickvidderna vid plastisk krympning och på så sätt ökas självläkningsförmågan och karbonatiseringen reduceras.

- Hur påverkade PP-fiberna frostbeständigheten? Salt-frostbeständigheten förbättrades markant med andelen fibrer i SKB (utan lufttillsats). Med fiberhalter mellan 1-2 kg/m^3 var frostbeständigheten mycket god efter 56 fryscykler. Lufthalten i den hårdnade betongen varierade mellan 3,8-8 %. Orsaken till den förbättrade frostbeständigheten är sannolikt den ökade lufthalten och det mer jämnt fördelade luftporsystem som skapas av pp-fiberna vid själva blandningen av betongen. Exempel på faktorer som gör att luftporsystemet får en tillräckligt god struktur för att klara kriteriet för salt-frostbeständighet är blandningsteknik/ordning, konsistens, fiberhalt och framför allt **att mantelytan på fiberna är behandlade med ett dispergeringsmedel som också verkar som en luftporbildare**. Lufthalter kring 5 % och Powers avståndsfaktor < 0,3 mm var tillräckligt för att klara frostprovningen efter 56 cykler. I projektet har kombinationen SKB och ca 1kg/m^3 betong av 6 mm långa pp-fiber varit tillräckligt för att skapa ett luftporsystem utan tillsättning av extra luftporbildare. Liknande resultat har tidigare rapporterats och uppmärksammats i USA [2].

Rekommendationer för fortsatt forskning

Den primära orsaken till det ökade motståndet för transport av vatten, kloridjoner och koldioxid i betonger med PP-fibrer är inte helt belagd. I undersökningen anges dispergeringsgraden (flytmedelsdosen), inte PP-fibermängden, som den sannolika orsaken.
Fortsatt undersökning i syfte att fastställa den primära orsaken kommer att göras i ett projekt som löper under 2008-09 på CBI.

Om flytmedelsdosen/dispergeringsgraden påverkar kapillärporsystemets utveckling och porstorleksfördelning (även gelporstrukturen) kan det ha betydelse för betongens krympegenskaper. Hur krympegenskaperna påverkas borde i så fall undersökas eftersom användningen av effektivare flyttillsatsmedel ökar. Ett sådant projektförslag har gjorts av undertecknad till CBIs A-konsortium. Projektet är tänkt att starta våren 2009.

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