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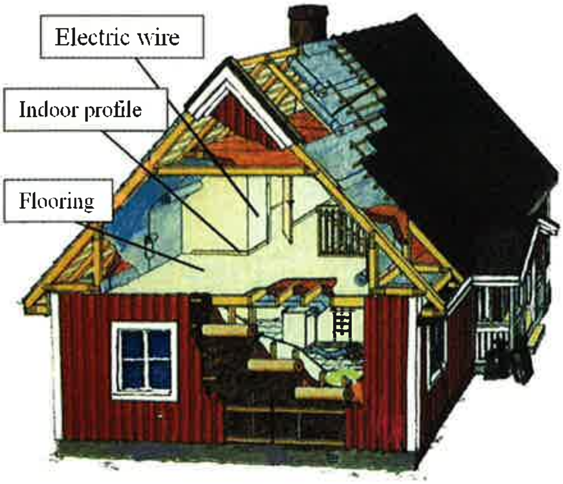

Recycling and Durability of PVC Focusing on Pre- and Post- Consumer Wastes from Building Products

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7 Summary and conclusions

The common goal for the development towards Sustainable Building is a reduction of use of non-renewal resources for desired products or services. One of the most important questions is how to take care of the waste materials in ecologically best way. There are also many connections between durability assessment and service life prediction of buildings materials in the concept of sustainability in construction. Sustainable building implies use of durable materials with little effect on the environment and suitable for recycling. Most of the plastics should offer good prospects for recycling provided that they are not much degraded and not contaminated. As most of the post consumer materials used in buildings derive from long-term applications, it is necessary to gain knowledge about technical quality of the recyclate, need of upgrading, processing stability and the durability of the re-processed material. To gain this knowledge was one of the most important aims of this thesis.

Three residential blocks constructed in the late 1960s and 1970s in Sweden, have been investigated in order to establish quantity of materials, considering difficulty and time of dismantling, degree of purity and possibility of separation of materials. The oldest object contained very little polymeric products exempt flooring, which was heavily degraded. In the other two objects, window profiles, doorframes, pipes, cables and conduits seemed to be the most suitable products for recycling. Plastic floorings constituted the largest part in all objects but the purity of the materials was poor. Dismantling of most products took 10 minutes to 1 hour per flat using simple tools. In most cases, materials were contaminated and to achieve pure materials suitable for recycling, additional separation and purification procedures are needed before reprocessing. One inconvenience in collecting and sorting of products constitutes of changes, which occur during service life. Some products are exchange ones or several times and some materials are used in a very troublesome way (i.e. PVC-flooring glued on linoleum flooring). It is generally not possible to conclude technical quality or remaining lifetime of the collected materials without appropriate testing. It is therefore important to identify suitable, simple and quick methods for evaluation of important properties. As poly vinyl chloride (PVC) was found to be a dominant polymeric material in buildings constructed in the late 1960s and early 1970s the focus of this work was on various PVC materials.

Retained properties and durability are among the most important factors when evaluating the possibility of mechanical recycling of plastic waste. During processing of PVC, which is performed at high temperatures, degradation by dehydrochlorination, chain scission and crosslinking takes place. If the thermal resistance of the PVC recyclate is too low, the material must be restabilised before further processing. The result of our work on dehydrochlorination and stabiliser consumption in rigid and in plasticised PVC has shown that neither repeated processing nor the normal in-use conditions cause any significant depletion of stabilisers. It is an advantage for the old products if they don't need any re-stabilisation, which eliminates a risk for any antagonistic effects provided that waste products containing different stabiliser systems are not mixed together.

The activation energies for the stabilizer consumption in air and in nitrogen were determined to about 101 and 104 kJ/mole for the plasticised PVC. The low rate of stabilizer consumption during the service life of the products made of plasticised PVC such as cables and floorings was confirmed by the measurements of the residual stability of the old materials. The dehydrochlorination process in the rigid PVC material at the temperatures below T_g was revealed. The activation energies for this process were also determined for the materials after various numbers of extrusions and were found to decrease with increasing number of extrusions from about 128 kJ/mole for the material extruded once to about 99 kJ/mole for the material extruded five times. Despite the finding that the estimated lifetime for indoor use at room temperature for the material after five extrusions was one-third of the lifetime of the material extruded only once, a long lifetime can be expected even for the material subjected to five consecutive extrusions, making the material suitable for mechanical recycling.

Plasticicers are used to improve the processability, and to improve flexibility of PVC products. A loss of the original plasticiser content leads to a loss of the mechanical properties and to brittleness in the recyclate. For most applications in use, a loss of plasticiser by evaporation is believed to be the most important factor. In the case of PVC floorings in contact with moist concrete, chemical degradation of the plasticiser can take place in addition.
The results of this work indicated that the mass loss by evaporation is the dominant process in ageing of plasticized PVC at low temperatures. The activation energies for this process were determined to be about 98-99 kJ/mole in air and in nitrogen. The maximum change in the content of extractable matter that was observed after accelerated ageing corresponding to more then 40 years was 1 %. It was shown that high alkalinity of the moist concrete can cause decomposition of the plasticiser when PVC flooring is glued onto it. The proportion of the plasticiser depletion due to the chemical degradation is however very small in relation to the mass loss of the plasticiser by evaporation and this amount is insignificant in relation to the possibility of mechanical recycling. Nevertheless, the decomposition products can cause indoor environmental problems. For this reason and because mechanical recycling is less favourable due to troublesome dismantling and high degree of contamination from the glue, gluing directly onto fresh concrete should be avoided. The heat content in PVC floorings is dependent on the proportions of PVC and plasticiser. As the loss of plasticiser has been found to be in the range of 1 % after more then 40 years, the expected changes in the heat content caused by long-term use of PVC floorings should be insignificant.

Retention of mechanical properties is one of the most important criteria for the assessment of technical quality and durability of polymeric materials. Change in elongation at break is a very sensitive measures of the changes in the status of the material due to ageing and also important not only for the prediction of service life but also for the recycling of materials. Accelerated ageing of the plasticised PVC at 80 °C and 90 °C for up to 8 weeks caused no significant changes in elongation at break. At 100 °C and 110 °C the maximum change in elongation at breaking was about one third of the original value, which corresponded to the maximum mass loss of about one third of the original amount of the plasticiser. Insignificant change in elongation at break of cables and floorings due to normal service life conditions was shown even after 34 years of use compared to the reference values. Considering very small decrease in plasticiser content in all plasticised materials investigated, after heat ageing at 80 °C, unchanged tensile properties was an expected result.

Changes in elongation at break of the rigid PVC as the consequence of the various numbers of repeated extrusions was explained by the change in the degree of gelation of the PVC material. A dramatic change in elongation at break upon heat treatment at various temperatures both below and above glass transition temperature (T_g) was observed. When the new and old materials were re-extruded, the original values of elongation at break were obtained again. A decrease of elongation at break in samples annealed at temperatures below T_g was explained by the effect of physical ageing, while a decrease of elongation at break in samples annealed at temperatures above T_g was explained by the annihilation of the orientation in the materials. A big difference was observed between elongation at break in machine and cross direction of the extrusion, which also indicated strongly that these effects are caused by orientation in the material. This hypothesis explained also why the original elongation at break was not attained by any heat treatment but by re-extrusion only. This orientation effect was also followed up by the DSC measurements. Our interpretation of the DSC results was that the orientation in the material due to extrusion creates an exothermal peak immediately above T_g in the DSC thermogrames. This orientation is not affected by heat treatment below T_g but above T_g the heat treatment annihilate the orientation and the crystallization peak fails to appear in DSC thermograms. When the material is re-extruded, the original orientation is recreated in the material and thus the crystallization peak appears again in DSC. Thus the conclusion is that upon recycling (re-extrusion) the material has "forgotten" its thermal history and previous heat ageing it may have undergone is erased. Simultaneously, extrusion restores the orientation in the material and consequently the mechanical properties.