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Effects of UV Radiation on Building Materials

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Effects of UV Radiation on Building Materials

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Abstract. During recent years there has been increasing use of polymer-based materials, such as thermoplastics, thermosets and composites, as replacements for the traditional building materials. Although these polymers offer an impressive range of attractive properties, the effect of climatic conditions on the durability and performance of these materials is not fully understood. This paper briefly examines the effects of the UV radiation on the performance and properties of the polymer-based building products. The use of accelerated weathering techniques to assist in assessing the durability of building materials is also briefly discussed.

Introduction

The durability, performance and rate of deterioration of building products are all significantly influenced by both the material composition, as well as the climatic conditions to which they are exposed. This is particularly relevant for synthetic polymer-based materials, which, during recent years, have increasingly been used as replacements for the traditional timber, metal and cement-based building materials. Interest has predominantly been in non-structural applications of polymers, such as cladding, plumbing and coatings, but there is also increasing interest in the use of polymeric materials, particularly polymer-based composites, for structural applications within the building industry. However, the weathering of thermoplastics, thermosets and composites, due to variations in temperatures, moisture/rainfall and UV radiation, is not fully understood. More understanding of the durability and weathering of these materials would enable the useful lifetime of building products to be predicted to a greater accuracy, as well as enable plans to be made for maintenance and replacement of key building components.

Current research at BRANZ is investigating whether climatic variations within New Zealand have a significant effect on the weathering and durability of building plastics. The main emphasis of the research is on the large variations in solar UV radiation within New Zealand, and the resulting photodegradation reactions occurring from exposure at each of four sites across the country.

Polymer Degradation

Most of the commercial organic-based polymers, used in the building and construction industry, undergo photolytic and photo-oxidative reactions during exposure to solar UV radiation. The polymers contain chromophoric groups, such as carbon-carbon double bonds (C=C) and carbonyl groups (C=O), which are capable of absorbing UV energy and are involved in the photoreactions that result in the degradation of the polymer. These chromophoric groups can either exist within the regular structure of the polymer, or exist as a result of impurities present, or through thermal processing of the materials involved.

This is the situation with the polyolefins, polyethylene and polypropylene, which are severely affected by the presence of UV radiation. Although they have no carbonyl or C=C bonds within their regular structure, the chromophoric moieties are introduced into the backbone or side groups through the high temperature injection moulding and extrusion processes, involved in producing the plastic building products. It is also understood that the metal-based additives contained within the polyolefins, catalyse oxidation reactions resulting in photo-oxidative and thermo-oxidative degradation. Initiation of the photochemical degradation reactions can occur via free radical mechanisms, leading to the formation of hydroperoxides and chain scission, and eventually lead to catastrophic failure of building components.

Degradation effects that occur within polymer-based materials range from discolouration on the polymer surface, which affects the aesthetic appeal of the material, through to extensive mechanical damage to the polymers, severely affecting the performance of the building product. The colour changes mainly occur as a consequence of chemical changes within the polymer structure, resulting in yellowing or darkening of the polymer. Another adverse effect of weathering is the synergistic combination of water and UV radiation, which can lead to erosion and fading of the surface of certain types of polymers. This phenomenon is known as chalking and is frequently observed on PVC substrates. The polymer is photodegraded by the UV radiation and the resultant small fragments are washed from the surface by rain or other moisture sources. This exposes the pigments and fillers and results in a chalky appearance to the polymer surface. As the deterioration progresses, these additives are lost from the surface and the degradation of the underlying polymer layers occurs, severely affecting the aesthetic appearance of the building product.

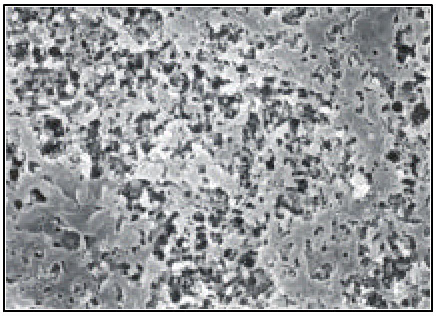

Figure 1. SEM examination of exposed polymer surface

Closer examination of the polymer using scanning electron microscopy (SEM) reveals substantial deterioration to the surface of the material (Figure 1). The chalking phenomenon creates an uneven surface on the polymer, which scatters the light and leads to a faded appearance to the material.

The more serious effects of photodegradation include microcracking and embrittlement of polymeric substrates. These effects are often accompanied by extensive deterioration in the mechanical properties of the materials, such as tensile strength, impact strength and elongation, all of which are important parameters in the performance of a building product.

It is therefore necessary to be able to predict the performance of building products in specific environments, particularly regarding the expected lifetime of materials. In certain cases, the prediction of the effect of UV radiation on plastics by natural weathering exposure is too slow, particularly where product development is concerned. Therefore, artificial weathering of products is often used to provide information on the effects of UV radiation. There are many accelerated weathering methods from simple UV sunlamps through to xenon arc weatherometers. BRANZ has two of the more popular accelerated UV techniques, fluorescent ultraviolet/condensation equipment using both UVA or UVB fluorescent tubes, and the xenon arc lamp weathering apparatus.

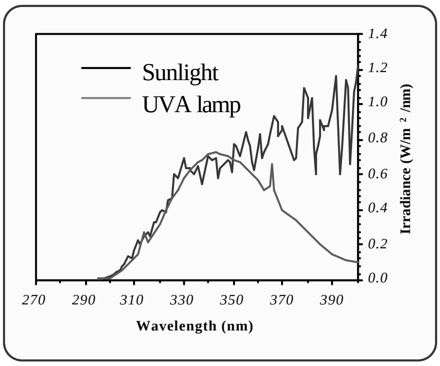

Figure 2. Irradiance output of UVA fluorescent tubes

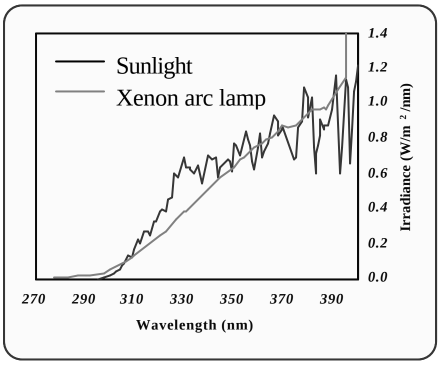

Figure 3. Irradiance output from xenon arc lamp

The short wavelength portion of sunlight is responsible for much of the photodegradation of materials and fluorescent tubes simulate this portion very well (Figure 2), whereas the output of the xenon arc lamps is similar to that of sunlight throughout the whole UV spectrum, which is particularly advantageous (Figure 3). Although there is no direct relationship between the accelerated and natural weathering of building products, due to so many variables within the natural exposure of materials, both the accelerated UV techniques are extremely useful in assessing the durability of materials in the presence of UV radiation.

Due to the effect of UV radiation on the performance of polymers, the rate of photodegradation of polymeric materials is often retarded by the use of UV stabilisers and fillers, such as hindered amine light stabilisers (HALS), carbon black and titanium dioxide. Although each stabiliser acts by different mechanisms, there are two main methods for stabilising polymers, namely protection and inhibition. Additives such as carbon black absorb UV radiation and thereby protect the polymer fom degradation, whereas other stabilisers inhibit the chemical reactions taking place in photodegradation mechanisms, and act by radical scavenging and/or by destroying the radical sources. For example, the HALS stabilisers are photo-oxidised to nitroxide radicals (N-O?), which subsequently trap the radicals responsible for photodegradation reactions and hence inhibit further degradation. They are very efficient as their mechanism involves cyclic regeneration of the nitroxide radicals during use.

BRANZ Research

In determining whether climatic variations within New Zealand have a significant effect on the weathering and durability of building plastics, BRANZ has established four identical exposure sites across the country. The four sites are located at Kaitaia, Paraparaumu, BRANZ at Judgeford, and Invercargill and the climatic conditions are monitored for the exposure period at each site. The plastic samples that have been selected for the UV exposure study are all commonly used within the building and construction industry, including PVC, low density polyethylene and polypropylene sheets. Samples of the plastics have been exposed as non-stressed sheets, and an identical set of plastics have been set-up in an aluminium tension rig under a 1% strain, to simulate the stress encountered by building plastics in certain situations. Two commercial plastic pipes have also been exposed on each of the sites, in addition to the plastics sheets.

The research involves determining changes in the mechanical, chemical and physical properties of each of the exposed sheets and plastic pipes. These properties are assessed at regular intervals, and the results are correlated with the climate data for each of the four sites. Rainfall, temperature, sunshine hours and particularly the amount of

UV radiation are all monitored at each of the exposure sites. The extent of the differences in each of the properties will determine whether the study will be extended to include more exposure sites across the country, and whether to increase the number and type of polymeric building products on each of the exposure sites. Ultimately, the objective of the study is to devise an exposure map of New Zealand, indicating the effect of differing climatic conditions on the durability and lifetimes of polymeric materials used within the building industry. This would enable users to identify and select appropriate products for specific environments, particularly where durability issues are of significance.

Results and Discussion

The research results that have been collected so far indicate significant differences in the mechanical strengths of the plastics at each of the four exposure sites. There are noticeable trends developing with the tensile strengths of the polyolefins. Figure 4 shows the difference between the tensile strengths of polypropylene exposed at each of the four New Zealand sites. These trends also correlate reasonably well with the UV measurements taken at the corresponding sites. The clear polypropylene and polyethylene sheets from Kaitaia both show signs of cracking and microcracking (Figure 5), whereas there is no such damage on similar samples from each of the other three sites, indicating that the onset of photodegradation is clearly more established in the far north of the country. FTIR analyses of the exposed samples of the clear polyolefin samples also reveal the presence of carbonyl groups within the polymer structure, which are consistent with photodegradation of these materials.

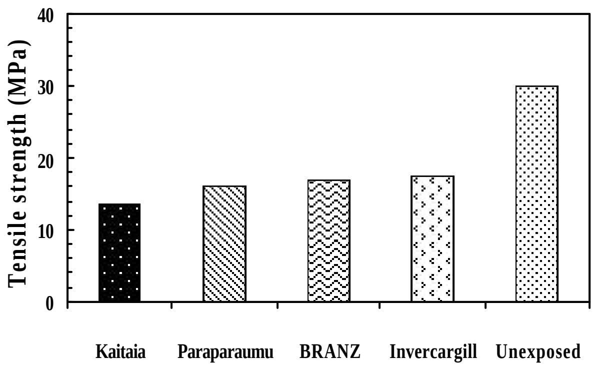

Figure 4. Tensile strengths of exposed polypropylene

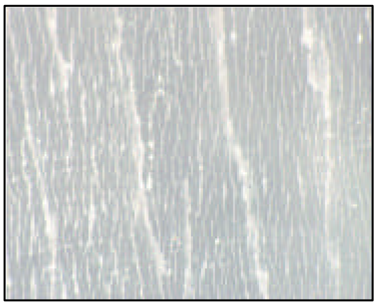

Figure 5. Microcracking of UV exposed polypropylene

There do not appear to be any significant differences between the mechanical properties of the black polyethylene sheets and pipes from each of the exposure sites at this stage. The black polyethylene samples contain carbon black UV stabilisers, which undoubtedly retard the photodegradative effect of the solar UV radiation. Similar results are observed with the white PVC sheets and pipes, which contain titanium dioxide pigments to counter the effects of UV degradation. It is envisaged that extended exposure of these materials will reveal some mechanical property differences due to photodegradation in the longer term.

Conclusions

The initial findings suggest that there are noticeable differences in the weathering of the building plastics at each of the four exposure sites. Although other climatic factors would have a slight effect on the results, the differing rates of degradation of the polymeric materials are believed to be due primarily to the variations in solar UV radiation between sites. Microscopic examinations and analysis of the mechanical properties of the exposed plastics clearly indicate that the photo-oxidative degradation reactions are taking place at a quicker rate at Kaitaia than at any of the other sites. It is envisaged that more trends will become evident as the plastics weathering project progresses over the next few years.

Acknowledgements

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