BRANZ STUDY REPORT

ESTIMATES OF THE DURABILITY OF BUILDING PLASTICS AND RUBBERS IN EXTERIOR APPLICATIONS

W. R. Sharman and N. L. Van Gosliga
PREFACE

This work is part of a BRANZ study of the behaviour of building plastics in the New Zealand environment. The ultimate intention of the study is to better predict the durability of plastics when they are used externally.

This report is intended for manufacturers, suppliers, or importers of plastics-based building products intended for use outside. It is also intended to provide information for product designers in providing weather-resistance data as an aid to selection of plastic type for a particular function.
ESTIMATES OF THE DURABILITY OF BUILDING PLASTICS AND RUBBERS IN EXTERIOR APPLICATIONS

Study Report SR19  W R Sharman and N L van Gosliga

REFERENCE


KEYWORDS

Plastics, Rubbers, Weathering, Durability, New Zealand, Building Materials

ABSTRACT

In New Zealand, the production and use of plastics-based building materials has generally not been accompanied by a good understanding of the behaviour of such materials in use. In particular, the factors which are important in resistance to weathering are not widely known. There is also a popular myth that the New Zealand climate is unusually severe on plastics. The intent of this report is to summarise the potential reaction to the weather of plastics likely to be used in building products, to explain the effects of the New Zealand climate, and to briefly indicate methods of testing the resistance of plastics to weathering. The use of rubber products in building and the resistance of rubbers to weathering are also briefly discussed.
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</table>
INTRODUCTION

Traditional timber, metal, and cement-based building materials are increasingly being replaced or superseded by plastics, particularly in non-structural applications such as cladding, plumbing, window frames and the like. Some current building uses of plastics in New Zealand are shown in Table 1. Engineering plastics - plastics used in place of metals, sometimes as structural components - are beginning to appear in building products intended for use outside. In many cases the potential durability of plastics used in this way is not known. Where choices between plastics are possible, or the weathering resistance of a plastic component which is critical to the performance of some assembly is not known, little guidance exists. Sometimes plastics may be exposed to weathering inadvertently; pipes and insulation are a case in point. Often the formulation and production of plastic products are well understood, but not their likely performance when exposed to weathering.

<table>
<thead>
<tr>
<th>ABS</th>
<th>acrylic</th>
<th>acetal</th>
<th>CAB</th>
<th>CPVC</th>
<th>epoxy</th>
<th>GRP</th>
<th>melamine/formaldehyde</th>
<th>nylon</th>
<th>phenol/formaldehyde</th>
<th>polybutylene</th>
<th>polycarbonate</th>
<th>polyester</th>
<th>polyethylene</th>
<th>polyisocyanurate</th>
<th>polypropylene</th>
<th>polystyrene</th>
<th>polyurethane</th>
<th>polyvinylchloride</th>
<th>polyvinylidene fluoride</th>
<th>urea/formaldehyde</th>
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</tbody>
</table>

TABLE 1: THE MAIN CATEGORIES OF PLASTICS USED IN NEW ZEALAND BUILDINGS

Acknowledgement to New Zealand Journal of Technology
The intention in writing this report has been to gather information which is currently available about the weathering of plastics, and present it in a summarised form which should provide New Zealand manufacturers or other users of plastic building products with some guidance on likely weathering performance.

THE EFFECTS OF THE WEATHER ON PLASTICS AND RUBBERS

Plastics and rubbers are polymers, which are commonly described as a long chain of molecules of the same type, or two or three different types. In its simplest form, the polymer can be thought of as a very long chain of beads. Plastics are usually classified as thermoplastics (heat softening) or thermosets (not softened by heat), see Figure 1. With the exception of thermoplastic types, rubbers are not softened by heating, and have a structure somewhere between thermoplastics and thermosets. Most finished plastics and rubber products contain fillers, colouring agents such as pigments or dyes, and stabilisers. Some may contain plasticisers to make them soft and flexible. Transparent or translucent plastics do not contain fillers.

When any plastic or rubber is exposed to the weather, the way the plastic is affected depends on the chemical type of the molecules from which it is formed. The effect of the weather is due to the effects of its constituents - light, heat or cold, water, as well as oxygen. Cyclic effects - hot/cold, wet/dry - are important. Two or more weathering factors often act together, rather than a single one only being important.

Changes Caused by Weathering

Colour

The simplest change that occurs is loss of appearance due to colour change. Sunlight and oxygen can cause chemical changes that lead to the yellowing of some plastics. Heat leads to darkening of others. Fading can occur either as the result of the breakdown of pigments or dyes, or as a secondary effect of chalking.

Chalking

Light and water-induced chemical changes cause chalking of some filled plastics (see Figure 2). Chalking is the slow erosion of the surface of a plastic. The plastic 'chains' are broken down under the action of light and water and are lost from the surface. The plastic no longer holds the filler and pigment in place, so that they are slowly lost, exposing fresh plastic to be broken down. Chalking is accompanied by fading of colours, since erosion of the surface changes it from a shiny reflective state into a rough state which scatters light in all directions instead of reflecting it. While chalking is an appearance change, it is often accompanied by changes in mechanical properties (see below).

Microcracking

Surface microcracking can be particularly apparent in clear or translucent
THERMOPLASTICS
- long chains, not joined to each other (like a plate of spaghetti), but well entangled e.g. polyethylene, acrylic, nylon, polycarbonate, PVC
  (ooooooo = polymer chain)

THERMOSETS
- long chains, joined with frequent cross-links between chains e.g. epoxy, polyester, phenol formaldehyde

RUBBER
- long chains, joined with occasional cross-links between chains

FIGURE 1: STRUCTURE OF PLASTICS AND RUBBERS
Before exposure - filler well bound

Progressive exposure of filler and pigment as plastic breaks down and erodes

Ready for next stage of plastic breakdown and plastic/filler/pigment loss

a) Chalking

Before exposure - light reflects off flat plane - glossy appearance

During exposure - light scattered, resulting in fading effect

b) Chalking-induced fading

FIGURE 2: CHALKING
plastics. A microcracked surface is one which has a pattern of very fine microscopic cracks all over it and extending a short distance into it (see Figure 3). Microcracking makes transparent plastics become more opaque, since the network of fine cracks scatters light instead of transmitting it. Microcracking is caused by light, in conjunction with wet/dry or hot/cold cycles. As with chalking, microcracking is an appearance change, but is often accompanied by mechanical changes.

Mechanical changes

Surface changes are often accompanied by great changes in mechanical properties. In particular, impact, tensile strength, elongation and deflection capacity can be markedly reduced. Such mechanical changes as a result of weathering may not show a steady decrease or increase with time. For example, a decrease in impact resistance may occur suddenly, as the result of all the UV or heat stabiliser in a plastic having finally been used up or degraded (see Figure 4.)

FIGURE 3: MICROCRACKED SURFACE OF TRANSPARENT POLYCARBONATE EXPOSED 5 YEARS AT JUDGEFORD (NZ) (43 x magnif)
FIGURE 4: CHANGE IN MECHANICAL PROPERTIES WITH TIME

FIGURE 5: SPECTRUM OF SUNLIGHT (adapted from Davis and Sims, 1983)
Effects of the Individual Components of the Weather

Ultraviolet Light

The principal component of sunlight which damages plastics is the ultraviolet light, or UV. The spectrum of incoming sunlight is shown in Figure 5. In terms of total incoming energy the approximate makeup of sunlight reaching the earth's surface is 5% UV, 45% visible and 50% infrared. The UV is the most energetic part of sunlight, and hence does most of the damage. Although the proportion of incoming UV is small, it comes as large 'packets' of energy compared to the longer wavelengths of light. It has been said that UV has an effect like artillery shells, while in comparison the effect of visible light is more like rifle bullets. Plastics are most sensitive to damage by different wavelengths of UV (see Table 2). UV causes either breakdown of the polymer chains by 'chopping' them up, or further reaction between the chains which makes the plastic become brittle.

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Wavelength, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>acrylic (polymethyl methacrylate)</td>
<td>290 - 315</td>
</tr>
<tr>
<td>ABS (acrylonitrile butadiene styrene)</td>
<td>300 - 310, 370 - 385</td>
</tr>
<tr>
<td>CAB (cellulose acetate butyrate)</td>
<td>296</td>
</tr>
<tr>
<td>nylon</td>
<td>290 - 315</td>
</tr>
<tr>
<td>polyamides (aromatic)</td>
<td>360 - 370</td>
</tr>
<tr>
<td>polycarbonate</td>
<td>290 - 310</td>
</tr>
<tr>
<td>polyester</td>
<td>325</td>
</tr>
<tr>
<td>polyethylene</td>
<td>300 - 310, 340</td>
</tr>
<tr>
<td>polypropylene</td>
<td>290 - 300, 330, 370</td>
</tr>
<tr>
<td>polystyrene</td>
<td>310 - 325</td>
</tr>
<tr>
<td>polyurethane (aromatic)</td>
<td>350 - 415</td>
</tr>
<tr>
<td>PVC</td>
<td>320</td>
</tr>
<tr>
<td>SAN (styrene acrylonitrile)</td>
<td>290, 310 - 330</td>
</tr>
</tbody>
</table>

TABLE 2: PLASTICS - WAVELENGTH OF MAXIMUM PHOTOCHEMICAL SENSITIVITY (data from Berger 1978, Scott 1987)
Moisture

Most plastics are also sensitive to the effects of water as well as to UV. Moisture outdoors can cause physical and chemical degradation. Moisture can dissolve stabilisers, cause loss of plasticisers, and slowly chemically react with some plastics to break them down. On the positive side, moisture can also wash away plastics degradation products which will otherwise catalyse further breakdown. Exposure of plastics to repeated wet and dry conditions can cause cyclic swelling and shrinkage, resulting in fatigue which in turn causes cracking and breakdown of the plastic. When the effect of light is considered as well, many of these effects are not simply additive, but accelerated to greater levels.

Temperature

There are two distinct temperature effects. The first is a consequence of manufacturing, the second due to the way the plastic is exposed.

When a thermoplastic product is manufactured, the temperature and the length of time to which it is exposed to heat during processing can have a profound effect on its subsequent resistance to weathering. PVC is a case in point; prolonged exposure to high temperatures during extrusion drastically reduces its durability. If a thermoplastic is processed at too low a temperature, imperfect fusion may result.

The temperature at which a plastic is exposed in service also plays a considerable part in its breakdown. For those plastics affected by heat, there is a simple rule of thumb which states that the rate of breakdown doubles for every 10 degree C rise in temperature. The rate of breakdown caused by light or heat may also increase if the temperature is increased. Although the average yearly air temperature may only be 12 - 15 degrees at a site, use of plastics in positions where they are sheltered from the wind but exposed to the sun will accelerate breakdown. Colour has a tremendous influence. Under some circumstances the surface of black or dark coloured plastics may approach 80 degrees C, whereas that of white or light coloured ones will remain much cooler (see Table 3).

Heat alone can cause loss of plasticiser from plastics. Since the inclusion of the plasticiser in the plastic in the first place is responsible for making it soft and flexible, its loss means that the plastic shrinks, embrittles, splits and cracks. Heat can also cause discolouration, usually as darkening.

Oxygen

Oxygen is important in the breakdown of many plastics under the action of sunlight or heat. The mechanisms involved are complex, in many cases not well understood, and beyond the scope of this report. Further information is available from Davis and Sims (1983) and the research literature generally.

The effect of oxygen in the form of ozone is discussed under rubbers.
Air temperature 39°C

<table>
<thead>
<tr>
<th>Colour</th>
<th>Surface Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>white</td>
<td>33</td>
</tr>
<tr>
<td>yellow</td>
<td>38</td>
</tr>
<tr>
<td>red</td>
<td>40</td>
</tr>
<tr>
<td>blue</td>
<td>41</td>
</tr>
<tr>
<td>green</td>
<td>43</td>
</tr>
<tr>
<td>grey</td>
<td>47</td>
</tr>
<tr>
<td>brown</td>
<td>49</td>
</tr>
<tr>
<td>black</td>
<td>50</td>
</tr>
</tbody>
</table>

Black panel temperature 51°C

a) surface temperatures on different coloured PVC samples (from Berger 1978)

Air temperature 40°C

<table>
<thead>
<tr>
<th>Colour</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>white</td>
<td>68</td>
</tr>
<tr>
<td>black</td>
<td>81</td>
</tr>
</tbody>
</table>

b) surface temperatures on near flat roof (Melbourne, Australia), bitumen over timber substrate (from Martin, 1980)

TABLE 3: SURFACE TEMPERATURES AND COLOUR

Disguising the Effects of Weathering

Product design has a great effect on how visible the effects of weathering are. The effect of colour on temperature has been discussed. Where water is an important agent in causing breakdown, it should be remembered that horizontal surfaces are wetter longer. Flat surfaces should be designed to shed water, using drain holes if necessary. Reducing the time that a plastic surface stays wet generally reduces its rate of breakdown. Avoid flat, shiny surfaces. Patterned or textured surfaces and low gloss finishes obscure the effects of weathering, because loss of gloss and the development of chalking are not nearly so obvious. Light colours also minimise the effect of chalking, because fading is not so evident.

Bronze tints are useful in disguising the onset of yellowing in transparent plastics.
EFFECT OF NEW ZEALAND CLIMATE

Ultraviolet Light

From time to time it has been suggested that UV levels in New Zealand are unusually high. There is no evidence that this is true (see e.g. Nichol and Basher, 1986), although UV levels are higher than for North America or Europe in general. If New Zealand is mapped onto its antipodes in Europe (see Figure 6 a), then most New Zealand population centres correspond to southern European or Mediterranean latitudes. These low latitudes mean that more UV is received than for most of Europe anyway. Added to this are our clearer skies and a closer approach to the sun during summer than for northern hemisphere countries, which additionally increases the amount of incoming UV. This combined effect explains the higher UV levels in New Zealand compared to the USA or Europe, which have most of their populations and manufacturing centres at higher latitudes. A comparison of New Zealand and USA latitudes is given in Figure 6 b.

Although there has been recent publicity about ozone 'holes' in the upper atmosphere, and hence increased UV levels to the south of New Zealand, there is no current evidence to suggest that this has had any effects in New Zealand.

Studies with UV monitors (Martin 1978, Nichol and Basher, 1986) suggest that the levels of UV in New Zealand are no different from Melbourne or south eastern Australia. The reputed more rapid breakdown of polymeric materials including plastics in New Zealand may in fact be due to UV plus the combined effect of the comparatively high moisture and humidity levels encountered in New Zealand.

As far as UV levels are concerned, the main point to be made is that plastic products or formulations which have performed well at higher latitudes than New Zealand should be treated with caution until also proven here. Conversely, a good performance record in a humid, lower latitude country should mean that this plastic should be durable in New Zealand.

Moisture

Although New Zealand UV levels are similar to southeastern Australia, moisture levels in terms of humidity in particular are much higher (see Table 4). While it is not possible to quantify the effect of higher moisture levels, they are certainly likely to lead to the more rapid breakdown of moisture-susceptible plastics such as GRP.

Temperature

Mean temperature levels in New Zealand are higher than Northern Europe or Northern North America, but in general cooler than Australia. Historically, this difference has been enough to mean that where heat has been an important degradation factor, in plasticiser loss, for example, some products which have proven durable in Northern Europe have not been durable in New Zealand. Conversely, heat-sensitive plastics which are durable in other countries of latitudes similar to or lower than that of New Zealand should be durable.
<table>
<thead>
<tr>
<th>City</th>
<th>Latitude</th>
<th>Annual Average</th>
<th>Sunshine (hrs)</th>
<th>UV %**</th>
<th>Temperature (deg C)</th>
<th>Humidity (9 am) %</th>
<th>Rainfall mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auckland</td>
<td>36°51'S</td>
<td>2102</td>
<td>5.5</td>
<td>15.3</td>
<td>77</td>
<td>1185</td>
<td></td>
</tr>
<tr>
<td>Wellington</td>
<td>41°17'S</td>
<td>2020</td>
<td>5.8</td>
<td>12.5</td>
<td>81</td>
<td>1240</td>
<td></td>
</tr>
<tr>
<td>Christchurch</td>
<td>43°32'S</td>
<td>1984</td>
<td>11.6</td>
<td>77</td>
<td>666</td>
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<tr>
<td>Dunedin</td>
<td>45°52'S</td>
<td>1689</td>
<td>10.2</td>
<td>74</td>
<td>69</td>
<td>659</td>
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<tr>
<td>Brisbane</td>
<td>27°03'S</td>
<td>2737</td>
<td>20.5</td>
<td>66</td>
<td>69</td>
<td>1157</td>
<td></td>
</tr>
<tr>
<td>Perth</td>
<td>31°58'S</td>
<td>2883</td>
<td>6.9</td>
<td>18.2</td>
<td>62</td>
<td>879</td>
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<tr>
<td>Sydney</td>
<td>33°55'S</td>
<td>2445</td>
<td>4.6</td>
<td>17.4</td>
<td>69</td>
<td>1215</td>
<td></td>
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<tr>
<td>Adelaide</td>
<td>34°56'S</td>
<td>2518</td>
<td>17.1</td>
<td>56</td>
<td>531</td>
<td></td>
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</tr>
<tr>
<td>Melbourne</td>
<td>37°45'S</td>
<td>2080</td>
<td>4.8</td>
<td>14.8</td>
<td>69</td>
<td>661</td>
<td></td>
</tr>
<tr>
<td>Hobart</td>
<td>42°54'S</td>
<td>2153</td>
<td>8.5</td>
<td>12.4</td>
<td>67</td>
<td>633</td>
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</table>

**Incoming UV expressed as % of all incoming light energy.

TABLE 4: CLIMATE COMPARISONS, NEW ZEALAND AND AUSTRALIA
(data for annual averages from Duncan and Whitney 1982, Martin 1977, New Zealand Meteorological Service 1983)
FIGURE 6A: NEW ZEALAND MAPPED ON TO ITS ANTIPODES IN EUROPE

FIGURE 6B: NEW ZEALAND LATITUDES COMPARED TO THE USA
Geothermal Areas

New Zealand has one peculiar aspect to its climate. In geothermal areas there is a considerable amount of hydrogen sulphide gas released into the air. This reacts in particular with lead-based stabilisers, producing a dirty black discolouration. Lead-based or other stabilisers which produce coloured compounds with hydrogen sulphide should not be included in plastic building products to be used in geothermal areas.

ESTIMATES OF PLASTICS DURABILITY

Effect of Stabilisers

Stabilisers are chemicals used to try and reduce or eliminate the effects of weathering on plastics. The heat and/or UV stabiliser systems used in a particular plastic formulation have a great influence on its resistance to weathering. Stabilisers can improve resistance to light, heat, or both.

UV stabilisers should have the following properties:

a) Inherent stability to heat and light.
b) High UV absorptivity coupled with the ability to effectively get rid of the absorbed energy.
c) High solubility in and compatibility with the plastic in which it is used.
d) Low volatility at both manufacturing and use temperatures.

One of the most effective fillers used to minimise UV degradation is carbon black, used at a level of 2 - 3 per cent of resin weight. Titanium dioxide is also effective, levels of 6 - 12 per cent by weight of resin are usual. Otherwise, specialist organic UV absorbers are used at levels around 0.2 per cent. Stabiliser systems for specific plastics are a specialist area (see, for example, Flick 1986, Davis and Sims 1983). Even for a specific plastic type, formulation makes a great difference in behaviour (see Figure 7 for example).
FIGURE 7: PHOTOMICROGRAPHS (21 x) OF PVC EXPOSED AT JUDGEFORD (NZ), SHOWING FORMULATION-DEPENDENT DEGREES OF FUNGAL COLONISATION

(a) exposed for 15 years

(b) exposed for 4 years
Estimates

Durability estimates in this section are derived principally from the book by Davis and Sims (1983), which currently provides the most comprehensive collection of information available. Where possible, the information has been supplemented with what is known (but frequently unpublished) from BRANZ's experiences with the weathering of plastics in New Zealand, or published information from New Zealand and Australia.

Estimates of durability are given as broad bands. These are:

- **not durable**: extensive signs of breakdown within the first few months of exposure.
- **low durability**: signs of breakdown in terms of surface appearance changes and considerable loss of mechanical properties within three years of exposure.
- **durable**: signs of breakdown in terms of surface appearance changes after four or five years. Considerable loss of mechanical properties after seven to 10 years of exposure.
- **very durable**: very little sign of breakdown for at least 10 years.

These bands of durability estimates are for 'normal' use, assumed as vertical north facing. In practice, the way a plastic building product is actually used on a specific construction will determine its ultimate life. The following simple example illustrates this.

Suppose a clear plastic is used as glazing on a building so that it is exposed at an angle of 45 degrees to the horizontal, facing due north. This is the angle and direction which maximises the effects of the sun. Also suppose that the same plastic is installed as vertical glazing on the south facing wall of the same building. This angle and direction minimises the effects of the sun. The difference in lifetimes of the same plastic on the same building in the same geographic location may vary by the order of two or three times. This is known as the microenvironmental effect. This effect often overwhelms simple considerations of latitude or climate.

Where it is necessary to differentiate between different forms of the same plastic, this has been done. The differences between transparent, opaque, and foamed forms are obvious. The difference between opaque and carbon black-filled forms is less obvious, since carbon black filled plastics are also opaque. The reason for making separate comments about carbon black filled plastics is because of the UV resistance properties conferred by the use of carbon black, as discussed under stabilisers above.

ABS (acrylonitrile butadiene styrene) not durable

Weathering results in darkening, loss of impact resistance, embrittlement. Use of stabilisers or carbon black filler improves durability, but use of carbon black decreases initial mechanical properties. Substitution of the polybutadiene by acrylic or EPM rubbers improves durability. Laminates of acrylic over ABS are claimed to be very durable.
ACETAL not durable
Weathering produces surface erosion, decrease in tensile strength and elongation, decrease in impact resistance. Exposure to stress increase breakdown rate. Copolymerisation plus the use of stabilisers improves resistance, carbon black filler is also effective. High humidity reduces the rate of degradation.

ACRYLIC very durable
Usually used as transparent glazing. Long term decreases in MoR (modulus of rupture) and strain at rupture (deflection capability), and a decrease in impact strength result from exposure to the weather. Small decreases in light transmission also occur. Polymethyl methacrylate is the most durable form of acrylic. See also BRANZ Building Information Bulletins 241 and 242.

CAB (cellulose acetate butyrate) opaque durable
TRANSPARENT CAB has been suggested as an alternative to acrylic. Durability is very dependent on the stabiliser system used, unstabilised transparent CAB undergoes rapid breakdown (embrittlement).

CPVC no information
(Chlorinated polyvinyl chloride)
(There is a tentative suggestion that performance may be similar to PVC).

EPOXY low durability - durable
Usually exposed as glass fibre reinforced composites. Durability is very dependent on the specific epoxy resin type, glass type and content. Weathering effects include decreases in tensile strength and MoR, and surface erosion.

GRP (glass fibre-reinforced polyester) opaque very durable
Usually exposed as glass fibre reinforced composites with an unreinforced exposed surface layer (gel coat). GRP exposed to the weather without a gel coat or some other form of surface protection, as may be the case with pultruded components, is not durable (see Figure 8). Durability is very dependent on the type of polyester resin used for the gel coat. Fire retardant grades of resin have low durability. Curing conditions also markedly affect performance. Curing should not be carried out on site, but under controlled conditions of temperature and humidity. Surface-applied layers of clear acrylic coatings or PVF2 film increase durability (e.g., Figure 9). (See BRANZ Building Information Bulletins 228, 229, 241, 242.)

For opaque GRP the first effects of weathering are chalking and fading of colours, followed eventually by exposure of the glass fibres. The effects of weathering show up more rapidly if dark colours are used. Transparent or translucent GRP may show initial yellowing, and the fibre pattern
FIGURE 9: EIGHT YEAR OLD TRANSLUCENT GRP SHOWING THE BENEFITS OF A PVF<sub>2</sub> SURFACE PROTECTIVE FILM. LEFT - PROTECTIVE FILM, RIGHT - NO FILM.
FIGURE 8: PHOTOMICROGRAPH (21 x) OF SURFACE OF PULTRUDED GRP EXPOSED AT JUDGEFORD (NZ) FOR FOUR YEARS

Note - exposed fibres
- extensive cracking of resin
- extensive colonisation by fungi
becomes more prominent. Fibre exposure follows. In all cases surface effects are accompanied by decreases in MoR and strain (deflection) capacity. High humidity will increase the deterioration rate.

**MELAMINE FORMALDEHYDE**

Low durability

Melamine formaldehyde resins normally form the transparent layer above a printed paper pattern backed by a phenol formaldehyde laminate. Weathering performance is thus determined by the resistance to bleaching or fading of the printing inks or dyes comprising the pattern. If these are light-stable, then the effect of weathering is loss of gloss, dulling and fading due to loss of clarity of the melamine resin.

**NYLON**

Low durability

Exposure of nylon to the weather will cause yellowing, surface cracking and crazing. Absorption of water causes decreases in tensile strength and MoE (Modulus of Elasticity). Resistance to the weather increases in the order Nylon types 11, 610, 66, 6. Carbon black filler significantly increases durability.

**PHENOL/FORMALDEHYDE**

Durable

Seldom used externally due to dark colour. Heavily impregnated laminates provide the best weather resistance. Loss of gloss and fading will occur early during exposure.

**POLYAMIDES**

Not durable

See nylon (the main polyamide used in building products) also. The limited information available suggests that the high performance polyamides are generally not resistant to weathering.

**POLYBUTYLENE**

Opaque low durability?

Carbon black no information

Published information on the weathering resistance of polybutylene is minimal. There is a little information on the weathering performance of polybutylene which does not contain carbon black filler, but none on carbon black-filled polybutylene.

**POLYCARBONATE**

Clear durable

Opaque no information

Carbon black very durable

Unstabilised polycarbonate shows low durability with loss of impact strength. UV stabilised polycarbonate, or polycarbonate with a weather-resistant surface layer has better resistance to weathering. Clear polycarbonate may show yellowing as a result of weathering, and the surface will microcrack as a result of temperature and/or humidity cycling in conjunction with UV effects. (see BRANZ Building Information Bulletins 241 and 242).

**POLYESTER**

See GRP.
Unstabilised polyethylene is not durable, and becomes brittle quite quickly when exposed to the weather. Stabilised clear or translucent polyethylene film is used as a temporary weather barrier on building sites and also as a greenhouse cover. Stabilised coloured opaque films used as vapour barriers have low durability unless they are pigmented with carbon black. Carbon black pigmented polyethylene has also proven very durable as pipes and other building products when exposed to weathering.

POLYETHYLENE

<table>
<thead>
<tr>
<th>Type</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear</td>
<td>Not durable, low durability</td>
</tr>
<tr>
<td>Foam</td>
<td>No information</td>
</tr>
<tr>
<td>Opaque</td>
<td>Not durable, low durability</td>
</tr>
<tr>
<td>Carbon black</td>
<td>Very durable</td>
</tr>
</tbody>
</table>

Unless pigmented with carbon black, which experience has shown to make polypropylene products such as pipe extremely durable when exposed to the weather, then polypropylene has at best low durability, and becomes brittle.

POLYPROPYLENE

<table>
<thead>
<tr>
<th>Type</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque</td>
<td>Not durable, low durability</td>
</tr>
<tr>
<td>Carbon black</td>
<td>Very durable</td>
</tr>
</tbody>
</table>

Polystyrene foam, normally used as insulating material, is not durable. Exposure to the weather may cause yellowing, and the surface of the foam becomes friable and easily rubbed away. The surface will continually erode during exposure.

POLYSTYRENE

<table>
<thead>
<tr>
<th>Type</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear</td>
<td>Low durability</td>
</tr>
<tr>
<td>Foam</td>
<td>Not durable</td>
</tr>
</tbody>
</table>

Unstabilised polystyrene is not durable. Clear grades can be stabilised, but long term resistance to weathering has not been obtained. Weathering causes yellowing, loss of impact strength, and embrittlement.

POLYSULPHONE

<table>
<thead>
<tr>
<th>Type</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparent</td>
<td>Not durable?</td>
</tr>
<tr>
<td>Opaque</td>
<td>Not durable?</td>
</tr>
</tbody>
</table>

Very little information is available. That which is suggests that even carbon black filled polysulphone is not durable when exposed to weathering.

POLYURETHANE

<table>
<thead>
<tr>
<th>Type</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid foam</td>
<td>Low durability</td>
</tr>
</tbody>
</table>

Rigid polyurethane foam is widely used as an insulant. Early signs of weathering include darkening and colour changes. More advanced weathering includes water absorption and retention (hence loss of insulating properties), and surface erosion.

PVC (polyvinyl chloride)

<table>
<thead>
<tr>
<th>Type</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear</td>
<td>Low durability-durable</td>
</tr>
<tr>
<td>Foam</td>
<td>No information</td>
</tr>
<tr>
<td>Plasticised</td>
<td>Low durability-durable</td>
</tr>
<tr>
<td>Opaque</td>
<td>Low durability-very durable</td>
</tr>
</tbody>
</table>
Clear or translucent grades of uPVC (unplasticised PVC) are commonly used as glazing materials (see Building Information Bulletins 241 and 242). Resistance to weathering is very dependent on the stabiliser system used. Surface protection, usually as a thin layer of acrylic, also improves weather resistance. Weathering can result in one or both of two main effects. Whitening or fading, and loss of transparency is a result of light damage. Blackening, particularly where the transparent sheet is supported from behind and thus insulated, is a result of heat damage (see Figure 10). Loss of impact resistance and embrittlement will also occur.

FIGURE 10: HEAT AND LIGHT DAMAGED TRANSLUCENT uPVC
Opaque rigid or unplasticised PVC (uPVC) is finding increasing use in exterior building products. Well formulated products containing heat and light stabilisers as well as impact modifiers are expected to be very durable. Eventually fading of colours and loss of toughness and impact resistance will occur. Less well formulated uPVC's will show correspondingly less durability. Lead-based stabiliser systems should not be used in products which are liable to be exposed in geothermal areas (see section on Effects of NZ Climate).

PVC foams find their principal use as weather stripping or draft excluders. Their durability in exterior exposure is unknown.

Plasticised PVC shows a response to weathering which depends on the way in which it has been plasticised. Formulations which contain plasticisers which are free to migrate within the PVC, and are relatively volatile, will be lost and the PVC will shrink, crack and embrittle. Plasticisers which are non-volatile, or chemically linked to the PVC will result in a better resistance to weathering.

The formulation and stabilisation of PVC products is a highly specialised and complex subject (see, for example, Owen (1984), Titow (1984)).

PVF₂ (polyvinylidene fluoride) very durable

Usually used as a transparent thin film laminated over other plastics or coatings to give long-term protection against weathering. Plastics based on fluorine-containing polymers generally have good weathering resistance.

SAN (styrene acrylonitrile) low durability

Styrene acrylonitrile shows very similar weathering behaviour to polystyrene, (see above) but does not degrade quite so rapidly.

UREA FORMALDEHYDE foam not durable

Urea formaldehyde foam finds some use as a retrofit insulation material. It is not durable when exposed to weathering.

PREDICTION OF THE EFFECT OF WEATHERING ON PLASTICS

Natural Weathering

The most reliable method of assessing the weathering behaviour of a plastic is to expose it outdoors and wait upon results. For product development purposes this usually takes far too long, so artificial methods are used. Nevertheless there is a great deal to be gained by routinely carrying out natural weathering trials on plastic building products. A base line of known performance can be generated, which is available for comparison if unusually early failures of the product occur elsewhere. It also provides a basis for monitoring the effects of formulation modification on long term weathering behaviour. Figure 11 shows part of a natural weathering site. To maximise exposure to sunlight,
FIGURE 11: PART OF THE BRANZ NATURAL WEATHERING SITE AT JUDGEFORD, NORTH OF WELLINGTON

(Samples exposed on racks at an angle of 45° to the horizontal, and facing due north to maximise exposure to sunlight)

racks face due North, and are sloped at 45° to the horizontal, which is similar to New Zealand's latitude. There are standards available (e.g. AS CK24 Part 1 and AS 1745 Part 2, or ASTM G 7) which suggest details for sites and racks, and also the types of properties that can be measured. Even a very simple installation, with regular exposure of examples of the plastic items being manufactured or imported, coupled with a yearly look at the exposed samples under a microscope, can reveal a great deal. Exposure site testing is available commercially both in New Zealand and Australia.
Artificial Weathering

Artificial weathering gives useful data about the way a plastic may react to weathering and the ways in which it may break down. This provides a pointer for the factors to look for in natural weathering, and enables them to be picked up early, or provide confirmation that a formulation change to an existing product has not caused any drastic changes in properties. Artificial weathering can also be used to rank very similar materials - a series of one plastic formulation type differing only in UV stabiliser type or content perhaps - for likely resistance to weathering. Attempted rankings of dissimilar plastics are likely to be misleading.

It is not possible to correlate artificial weathering with natural weathering. Statements such as '2000 hours machine time is equivalent to seven years exposure in Auckland' are simply not supportable. For one thing, as described on page 8, there is the effect of the specific way the plastic product is installed on the building - what degree of exposure it has to sun, wind and rain. For another, there is plenty of evidence to show that even natural weathering is not reproducible. Winter and summer exposures give different results, even weathering an identical material for the same successive exposure periods will not yield the same result in detail. In addition, artificial weathering cannot model or accelerate all factors causing breakdown. For instance, stresses imposed by fixing methods will accelerate breakdown, but are seldom included in artificial aging tests.

There are a great number of accelerated aging/weathering methods available for plastics or polymers in general (see Davis and Sims, 1983). In New Zealand only four types are in use. These are simple UV lamps, carbon arc, fluorescent ultraviolet and condensation cabinets, and xenon arc weathering machines. There is a simple rule of thumb associated with all artificial durability testing. The greater the amount of acceleration associated with the artificial method, the more unreliable the result.

Testing with simple UV lamps is not reliable. Unfiltered short wave length (and therefore high energy) UV light will quickly degrade most plastics. Since the wavelengths involved do not occur in sunlight, this test is unrepresentative and will give misleading results.

Carbon arc weathering machines have samples rotating around a central carbon arc source. Samples may be sprayed with water periodically. There is not a good match between the carbon arc light output and sunlight. Carbon arc machines were the first type of artificial weathering machine developed, and were used extensively. General descriptions of machines and operating cycles are given in ASTM G 23.

A fluorescent ultraviolet/condensation cabinet consists of a box, two sides of which are filled with samples exposed to UV light from fluorescent tubes. The light corresponds either to UV A or UV B radiation (see Figure 5), as required. Periods of exposure to UV light are alternated with periods of water condensation on the samples (see ASTM G 53).

Xenon arc weathering machines are very similar in design to carbon arc, except that the light source is a xenon arc lamp. The light is filtered to
provide an output which resembles sunlight. Periods of water spraying the samples may also be included (see ASTM G 26).

Carbon arc, fluorescent UV - water condensation apparatus, and xenon arc weatherometers are run at higher than normal temperatures which also accelerates breakdown. All methods need to be used with care, as unless results are very carefully interpreted they can be misleading.

Artificial weathering tests are available on a commercial basis in New Zealand.

RUBBERS

Rubbers are much less widely used in building than plastics. Some typical building uses are shown in Table 5. In general rubbers are more resistant to the effects of weathering than plastics, but tend to weather in a different way in that some rubbers are attacked by ozone.

Estimates of Rubber Durability

There is much less published information on the resistance of rubbers to weathering than for plastics. As for plastics, the effect of weathering on any individual rubber is totally dependent on the way that particular rubber has been formulated (known as compounded for rubbers), how it has been installed on the building, and its exposure to the weather. The main information is summarised in Table 6. The current New Zealand estimate for the durability of one brand of butyl rubber single ply roofing is 15 years, and for EPDM 20 years.

The resistance of rubbers to weathering can be grouped into three types.

TABLE 5: TYPES AND USES OF RUBBER IN BUILDINGS
Rubber Type | Resistance to: | Ozone | Weathering
---|---|---|---
Butadiene | 2/3 | 1 | 2/3
Butyl | 2/3 | 3 | 3
Chloroprene (Neoprene) | 2/3 | 3/4 | 3/4
Chlorosulphonated Polyethylene (Hypalon) | 2/3 | 3/4 | 3/4
Ethylene Propylene Monomer (EPM)* | 3 | 4 | 4
Ethylene Propylene Diene Monomer (EPDM) | 3 | 4 | 4
Natural | 2/3 | 1 | 2/3
Silicone | 3/4 | 3/4 | 4
Styrene Butadiene | 2/3 | 1 | 2/3

Key: 1 = poor
2 = moderate
3 = good
4 = outstanding

* interpolated from Davis and Sims, 1983

TABLE 6: ESTIMATES OF THE RESISTANCE OF RUBBERS TO WEATHERING
(adapted from Blow and Hepburn, 1982)

Unsaturated rubbers

Natural rubber, polybutadiene, styrene-butadiene and nitrile (butadiene-acrylonitrile) rubbers are known as unsaturated rubbers. Their chemical structure is such that they can be attacked by ozone, which is always present in trace quantities in the air, and this is the most important effect for these rubbers. Ozone attack causes the appearance of numbers of fine, parallel cracks which eventually cause failure (Figure 12). Stressing the rubber (such as stretching it at fixing points or over upstands or at corners) increases the rate of attack. Polychloroprene (neoprene) is also an unsaturated rubber, but it has been chemically modified to make it much more resistant to ozone attack.

Saturated rubbers

Apart from butyl (isobutylene-isoprene) rubber, saturated rubbers such as EPM, EPDM and chlorosulphonated polyethylene (hypalon) are resistant to ozone attack, and butyl rubber is only slightly susceptible. These rubbers weather by slow erosion (e.g. Figure 13).
Specialist rubbers

Specialist rubbers, such as silicone rubber, also weather by fading and slow erosion.

As for plastics, the use of carbon black as a filler gives added durability to those rubbers where breakdown is due to the action of light rather than ozone. In general, coloured (non-black) rubbers are expected to weather less well than black.

Prediction of the Effects of Weathering on Rubbers

As for plastics, natural weathering, often in a stressed form, is the most reliable method (see e.g. ASTM D 1171, ASTM G 7). Artificial weathering methods, assessing the effects of heat, ozone, or light, are also used (see e.g. ASTM D 518, ASTM D 1149, ASTM G 26, BS 903 Pts A19, A43, A44).

Natural and artificial weathering or aging tests on rubbers are available commercially in New Zealand.

FIGURE 12: OZONE-INDUCED CRACKING OF STRESSED NITRILE RUBBER (7 x magnif)

Nitrile rubber O-ring exposed to the atmosphere under tension. Ring twisted to show depth of cracks

(Photo courtesy Southern Industrial Development Division, DSIR)
FIGURE 13a: WEATHERED BUTYL RUBBER POND LINING EXPOSED SURFACE (50 x magnif)
FIGURE 13b: WEATHERED BUTYL RUBBER POND LINING CROSS-SECTION (50 x magnif)
SOURCES OF INFORMATION


Scott, J.L. 1987. Laboratory accelerated tests can work for you. In Proceedings, Fourth International Conference on Durability of Building


GLOSSARY

CHALKING - slow erosion of binder from the surface of a material leaving pigment and/or filler particles exposed.

COPOLYMERISATION - simultaneous chemical reactions in which the molecules in simple substances (monomers) are linked to form large molecules.

CRAZING - distinct surface cracks or minute frost-like internal cracks resulting from stresses within the material which exceeds its tensile strength.

CURE - to change the properties of a plastic or resin by chemical reaction eg. condensation or polymerisation, usually achieved by the action of either heat or catalyst or both and with or without pressure. The term is not ordinarily used for hardening of thermoplastics by physical methods such as heating, cooling or evaporation of solvents.

FILLER - a relatively inert substance used to reduce the cost of a material and/or to improve physical properties, particularly hardness, stiffness and impact strength.

MoE - Modulus of Elasticity = ratio of stress (nominal) to corresponding strain below the proportional limit of a material.

MoR - Modulus of Rupture or flexural strength = the maximum stress in the outer fibre of a material, at the moment of crack or break.

PIGMENT - colouring agent, can be organic/inorganic or natural/synthetic. They are insoluble in the medium in which they are used. Some fillers can also act as pigments eg. Carbon black, chalk and titanium dioxide.

PLASTICISER - a substance which increases the flexibility, workability or distensibility of a compound.

PULTRUDED - a reinforced plastic formed by continuously producing constant cross-sectional profiles, both solid and tubular. This yields continuous lengths of material with high unidirectional strengths for use as golf club shafts, fishing rods, pipe etc.

STABILISER - used in the compounding of some plastics to assist in maintaining the physical and chemical properties at suitable values throughout the processing and service life of the material and/or the parts made therefrom.

UNSATURATED - a compound which is capable of adding atoms to its structure by breaking double bonds.
Estimates of the durability of building plastics
The Building Research Association of New Zealand is an industry-backed, independent research and testing organisation set up to acquire, apply and distribute knowledge about building which will benefit the industry and through it the community at large.

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