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Problems with plastics durability in New Zealand buildings

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Problems with plastics durability in New Zealand buildings

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Abstract Plastics are becoming increasingly important in building in New Zealand. Although usage figures are not immediately available, levels are probably similar to those in Australia where in 1985 plastics constituted 23% of the value of the building materials market. The main uses of plastics are non-structural, for finishes and fittings.

The overall level of problems is low, but individual problems have been quite large. Several case histories are discussed to illustrate: (1) the consequences of the New Zealand environment for plastics; (2) the influence of material specification on plastics durability; (3) the influence of design on plastics durability; and (4) the prediction of plastics durability.

There are two main conclusions from the consideration of plastics problems. The first is that there is a need for better education of building designers and specifiers about plastics properties and their implications for durability. The second is that better means of predicting plastics durability are needed. Education is possible from material presently available, but methods for durability prediction need considerable development.

Keywords Plastics; building industry; durability.

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INTRODUCTION

Plastics have made great inroads in the replacement of more traditional materials in building. Whether the internal or external components of a building are considered, plastics are found in a variety of non-structural uses, for finishes and fittings. An idea of the range of plastics and polymers, and their end uses, can be gained from Table 1, which was compiled from the trade literature of New Zealand manufacturers and suppliers of plastic-based materials for the building industry. It was stated (Anon. 1985) that in 1985 plastics constituted 23% of the value of the building materials market in Australia, and a similar usage is probable in New Zealand.

Overall, the number of problems arising from the use of plastics in building is low. Individual problems can, however, be quite large, and have expensive consequences. Some cases from BRANZ files are discussed below, and serve to illustrate the following points:

(1) The effect of the New Zealand environment on plastics durability.

(2) The influence of material specification on plastics durability.

(3) The influence of design on plastics durability.

(4) The prediction of plastics durability.

The cases discussed draw on the author's experience of the weathering behaviour of plastics, and the use of plastics in food-processing buildings. Although BRANZ is also involved in the measurement and prediction of the behaviour of plastics exposed to fire, this aspect has been deliberately excluded.

EFFECT OF THE NEW ZEALAND ENVIRONMENT

Many of the plastics-based materials used in New Zealand are designed overseas and, at least initially, imported until a local market has built up and local manufacture can commence. This has the advantage that it is often possible to predict coming trends — use of clear plastics in glazing, uPVC weatherboards, and now uPVC windowframes — and try to anticipate problems. Sometimes, though, transferring a product which has performed well in north America or northern Europe to New Zealand can spring a nasty surprise.

PVC-plastisol coated steel had a long and successful history of use as an exterior cladding in Europe, with lifetimes in excess of 20 years, before some of the material was imported into New

Table 1 The main categories of plastics use in New Zealand buildings.

	vapour barriers	soil stabilisers	sheeting, rigid	sheeting, flexible	sealants	screens, mesh	plumbing fixtures	pipes	linings, interior	insulation, thermal	insulation, electrical	flooring, industrial	flooring accessories	flooring	flashings	fittings, interior	fittings, electrical	ducting	door hardware	doors, screen	doors, rigid	doors, flexible	coverings, wall	cladding, exterior	adhesives
ABS			●	●			●		●							●									
acrylic			●				●		●			●												●	●
acetal							●																		
CAB				●																					
CPVC								●																	
epoxy					●							●													●
GRP			●			●	●		●								●							●	
melamine/formaldehyde			●						●												●		●		
nylon							●									●									
phenol/formaldehyde									●	●							●				●		●		
polybutylene								●																	
polycarbonate			●													●								●	
polyester							●					●													●
polyethylene	●			●							●														
polyisocyanurate										●															
polypropylene		●	●				●	●	●																
polystyrene			●						●	●							●								
polyurethane					●					●		●				●									●
polyvinylacetate																									●
polyvinylchloride	●		●	●			●	●	●	●	●	●	●	●		●	●	●				●	●	●	●
polyvinylfluoride																								●	
silicone					●																				
urea/formaldehyde										●															●

Note: Rubbers and concrete admixtures have not been included.

Zealand, and used for roofing and wall cladding. Use of these products here resulted in lifetimes of 5–10 years, far shorter than anticipated. Shrinking and cracking of the PVC-plastisol coating left the underlying steel susceptible to rapid corrosion (see Fig. 1).

Transparent polycarbonate sheet has been extensively marketed as an impact-resistant glazing material. Its durability, in terms of yellowing or reduction in light transmission, proved to be less than expected based on experience elsewhere, particularly in Europe, and so 'second generation' products are now marketed. The approaches adopted have been to use a layer of heavily photostabilised polycarbonate or acrylic on the weathering side of the sheet, and/or to tint sheets a bronze colour to disguise, at least, any early signs of change.

Because breakdown of plastics and organic coatings is frequently more rapid in New Zealand than in the product's country of origin it is commnoly believed that New Zealand experiences very high UV levels. As has been noted elsewhere (Duncan 1985), this is untrue. Fig. 2 shows New Zealand mapped onto its antipodes in Europe — which locates Wellington near Madrid, and Auckland on the Mediterranean coast of Spain. Principally, the UV levels are due to latitude, coupled with clear skies and a closer approach to the sun during summer than Europe. Certainly, for some plastics such as GRP (glass fibre-reinforced polyester) there is the synergistic effect of the higher moisture levels in the New Zealand atmosphere, but since the detailed mechanisms of breakdown are not known for many plastics, the extent of this effect is uncertain.

Plastics which have a good record of durability in climates similar to New Zealand — such as the Australian east coast or the southeastern coast of the United States — should therefore also be durable in New Zealand. More caution should be exercised in the exterior use of plastics where only data from hot, dry exposures, or at latitudes higher than 40° is available. The PVC-plastisol coated steel described earlier

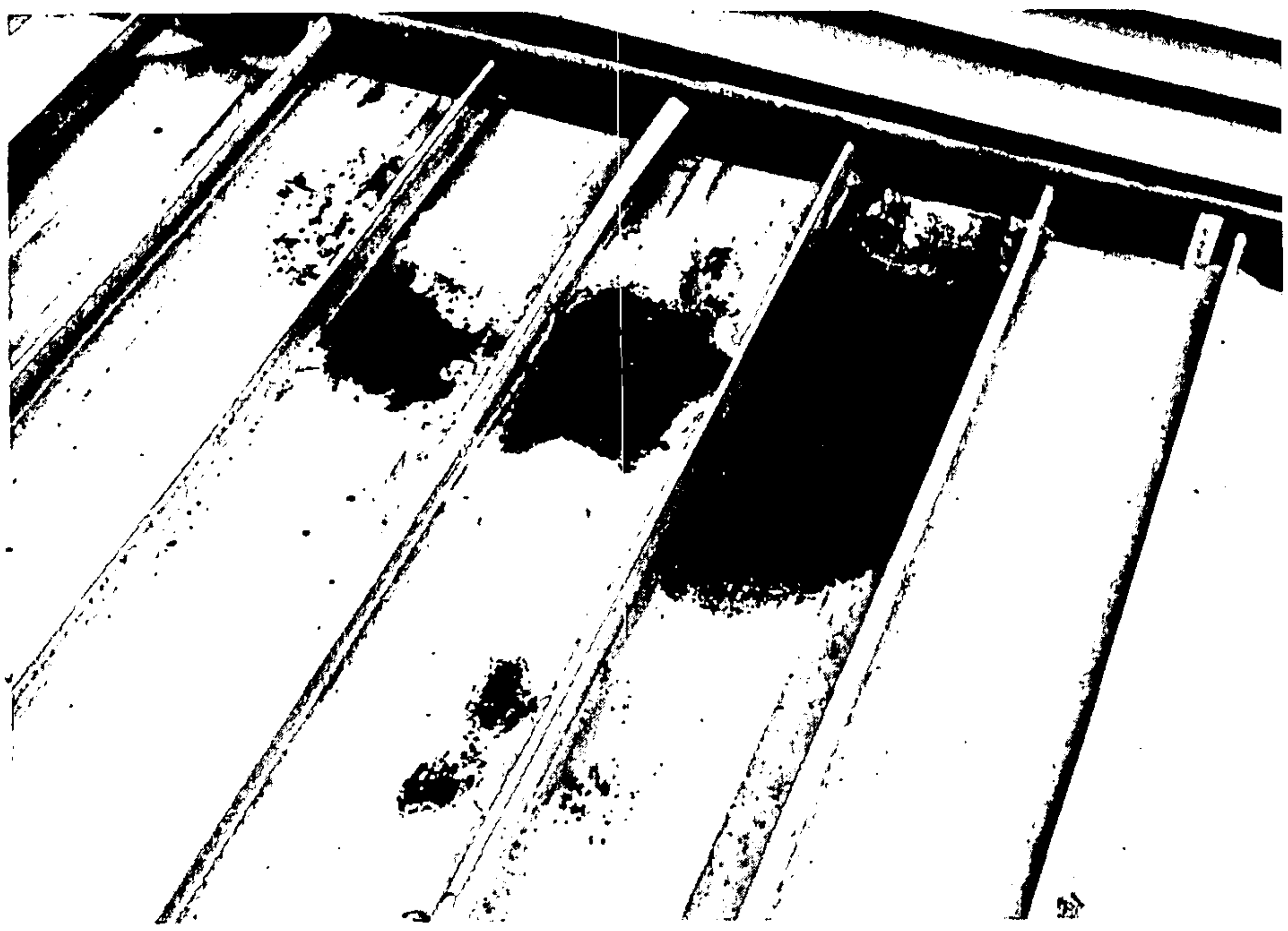

Fig. 1a Degraded PVC plastisol-coated roofing.

Fig. 1b Degraded PVC plastisol-steel-coated window frame.

is now only warranted for use at latitudes higher than 50°, not much use for New Zealand.

There is one other quirk of the New Zealand atmosphere worth mentioning. When uPVC gutters were introduced some years ago, those used in geothermal areas quickly became very dirty in appearance due to the reaction between hydrogen sulphide in the atmosphere and the lead-based stabilisers in the PVC. A potentially more dangerous example of this effect is that the PVC insulation used for sheathing electrical wiring also suffers from this effect, as it too contains lead-based stabilisers. All the insulation turns a chocolate brown colour, resulting in a complete loss of colour-code identification of individual wires. Cadmium-stabilised plastics are also discoloured by hydrogen sulphide (Helsby et al. 1984).

INFLUENCE OF MATERIAL SPECIFICATION ON DURABILITY

The completely inappropriate specification of a plastic material is fairly rare. There is the example of the chemical laboratory in which all the waste pipes from the lab sinks were plumbed in uPVC. The first few lots of solvent which found their way into the waste pipes ensured that the uPVC pipes were replaced by polypropylene, which should have been installed in the first place.

Less rare is monocular specification, the specification of a material on the basis of one property only, and being ignorant of (or ignoring) its other properties. Often where GRP is used, particularly in public buildings, fire retardants must be incorporated in it to improve its reaction to fire characteristics. Fire-retardant fillers, such as alumina trihydrate, can be used, and often a halogen-containing resin is used. Fig. 3 shows GRP cladding panels on a North Island building four years after completion of the building. One of the side effects of using halogenated resins is that the weather

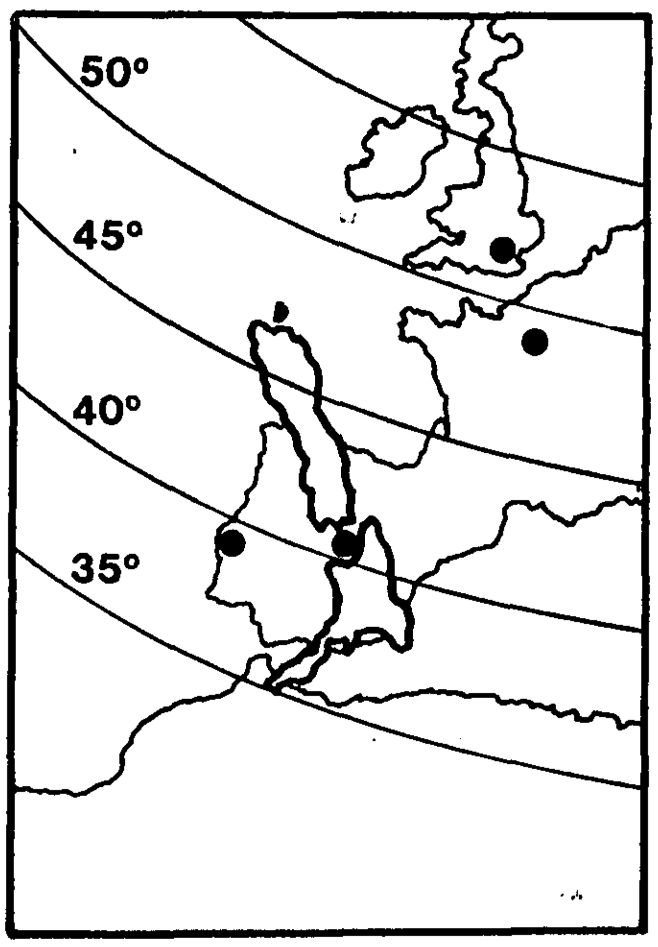

Fig. 2 New Zealand latitudes compared to Spain and southern Europe.

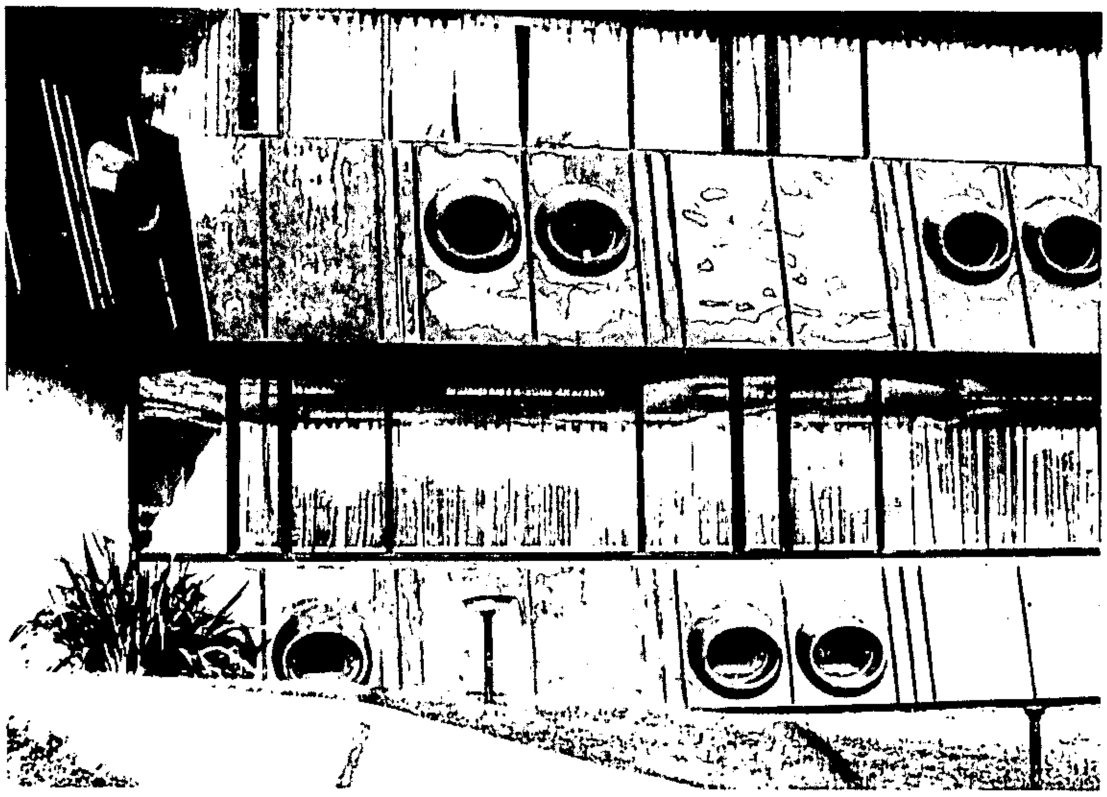

Fig. 3 Weathered GRP panels containing fire-retardant resin.

resistance of the GRP is reduced, and in this case the effect was emphasised by the bright red colour specified. The specification of a halogenated resin for the glass-fibre-reinforced layers, and a conventional, or non-retardant resin for the gel coat (which is exposed to the weather) would have prevented the effect seen.

Polyester resin filled with quartz or sand aggregate is in common use as a trowel-applied abrasion- and corrosion-resistant floor topping in large-scale industrial food-processing buildings. It is an expensive finish, costing in the region of $100/m². As with building in general, in the food-processing industry there is considerable pressure to complete building work and get the factory into operation. A 125 mm thick concrete floor was poured for one particular factory, and 5–7 weeks later a polyester topping was laid over the concrete. Over the following 12 months extensive areas of the topping failed and had to be replaced. The cause of the failure was moisture from the concrete base slab, which had not been left to dry for long enough before the polyester topping was applied. There are epoxy resin-based floor topping systems available which are much better able to tolerate water in base concrete, and the specification of such an epoxy-based system should have prevented failure.

Clear or structured polycarbonate has been extensively marketed recently as a highly impact-resistant glazing material, which has the added ability to be formed to curves on-site, without special equipment. Both of these claims are true, but some of the limitations of polycarbonate when exposed to the weather were described above. A number of glazing materials — acrylic, glass, GRP, polycarbonate, PVC — and their properties — resistance to impact, fire, and weathering — and costs are shown in Table 2. The material to be selected depends on the importance allotted to each of these properties by the building designer, and certainly will (or should) be dependent on the end use of the building. Even Table 2 is a gross oversimplification. There are polycarbonates available with various surface treatments to improve either weather or scratch resistance, special solar control-coated or fire-resistant glasses, and so on. GRP, for instance, can be extensively tailored to fit its end use. A similar spectrum of choices faces a designer when specifying most plastic building components.

INFLUENCE OF DESIGN

As well as their mechanical and physical properties, plastics are marketed as allowing designers freedom from constraint in building design. This is very definitely a two-edged sword: to successfully design with plastics it is necessary to be aware of their strengths and weaknesses, and particularly their mechanical properties, which are very different from those of conventional materials such as concrete, wood, and metals. As well as building design, product design is also a consideration.

Building design

The early and mid 1980s saw a boom in the use of site-formed clear plastics — principally polycarbonate, but also acrylic and PVC — to produce new, unconventional architectural forms. To stem some of the enquiries on how these plastics should be used, basic principles were described by BRANZ (e.g., Building Research Association of New Zealand 1985). In some cases the production of these came too late, or they were ignored. Fig. 4 shows a portion of a curved verandah roof consisting of rectangular sections of curved polycarbonate held in a painted steel frame. The upward bulge of the polycarbonate sheets in profile against the top edge of the verandah is due solely to lack of provision for thermal expansion. It has taken some time for the message that plastics have thermal expansion coefficients up to seven times that of glass to get across. A similar structure had the polycarbonate sheets tightly fixed by screws passing through snug holes, a fatal error. Thermal movement cracked the sheet quickly. Screws should always be fitted through oversize holes with deformable washers. A fact not always appreciated is that plastics often have a very low crack propagation energy. This means that any nicks or scratches in a sheet, or square corners cut into a sheet, can act as stress concentrators and cause cracking if the sheet is even lightly stressed.

Returning to the field of polyester floor toppings, a food factory floor design specified a lightly filled polyester floor topping (hence with a high thermal expansion coefficient compared to the concrete base), which, when combined with hot washdown water and no provision of movement joints, resulted in detachment of the polyester topping by shear failure between topping and base (Sharman 1985).

Table 2 The comparative ranking of glazing materials on a single property selected.

	Single Property Selected			
	Cost	Impact Resistance	Fire Resistance	Weathering Resistance
high	polycarbonate	GRP	PVC	glass
	GRP	polycarbonate	polycarbonate	acrylic
	acrylic	acrylic	GRP	GRP
low	glass	PVC	acrylic	PVC, polycarbonate
	PVC	glass	glass	

Note: 'Glass' is assumed to be soda-lime glass. The properties of both glass and GRP can be extensively modified to meet end use requirements.

'Fire Resistance' can be divided into a number of ratings depending on the test used, and is usually determined by tests on full scale assemblies (e.g., complete windows including frames).

Fig. 4 Polycarbonate verandah detail showing distortion caused by restrained thermal expansion.

Sandwich panel construction — in which a central slab of polystyrene foam core insulation is sandwiched between two outer skins of coated galvanised steel or aluminium — is a popular material for coldstores, and more recently for other industrial buildings, and housing. Electrical wiring has to to be run in all such buildings. The insulation on the electrical wiring is usually plasticised PVC.

Polystyrene is a very good sink for dioctyl phthalate and other phthalates which are the usual plasticisers used in cable insulation. For this reason electrical supply authorities worldwide have been reluctant to allow electrical wiring to be run in direct contact with polystyrene foam, in case there is sufficient loss of plasticiser from the cable insulation to cause it to break down, and fires to result. The popularity of sandwich panel construction, and the potential use of blown foamed polystyrene beads as retrofit insulation, prompted BRANZ to make a study of rate of loss of plasticiser from PVC cable insulation in contact with plasticised PVC at elevated temperatures (Bennett 1987). This study has shown that there is unlikely to be sufficient plasticiser loss in normal use to constitute a hazard.

Product design

Product design by manufacturers is an area which can also cause problems. For example, polyethylene sheet, usually in laminate form, is used as a barrier against water vapour and liquid under concrete ground floor slabs. There are several examples on the market at the moment which have a brightly coloured top layer, and a black lower layer that the installer is instructed to place in contact with the ground. In practice, these vapour barriers may be exposed to the weather for some time before being covered, and if they are damaged will no longer serve their function.

Polyethylene is best stabilised to light damage by carbon black, which is the colouring agent in the layer in contact with the ground. The exposed brightly coloured layers are not nearly as stable, and degrade (see Fig. 5), apparently not rapidly enough to cause problems, although the margin may not be great. For marketing reasons it

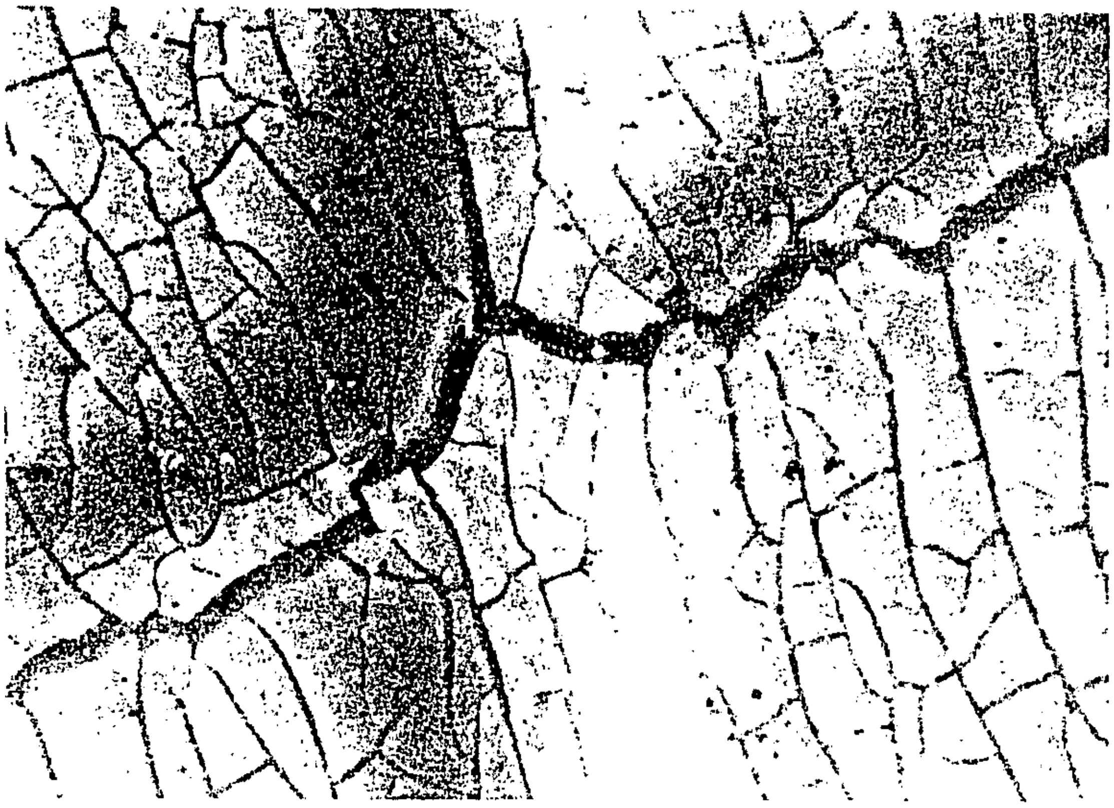

Fig. 5 Microphotograph of weathered unstabilised polyethylene vapour barrier (approx. ×50 magnification).

is desirable that the uniquely coloured side is exposed for specific brand-name identity.

uPVC 'weatherboards' have gained extensive usage in the USA over the past twenty years as a so-called low-maintenance exterior cladding. Since 1980 they have become increasingly popular in New Zealand. The traditional system of building in the USA includes a layer of plywood sheathing fixed to the outside of the house framing, over which the uPVC weatherboards are fixed. Initially, BRANZ's concern was whether uPVC weatherboards would provide adequate weather penetration resistance when used in the traditional way with building paper instead of plywood as the layer within the wall. Although the answer is a qualified 'yes' based on laboratory work (Bishop 1987), consideration of on-site practice has led to the suggestion that a rigid, self-supporting building paper is the minimum necessary. The specific point is that a plastic — or any building product — designed for use by the building industry of a country other than New Zealand may require a modification of traditional New Zealand building methods to ensure its successful use here.

PREDICTION OF PLASTICS DURABILITY

It is a common expectation of builders, designers, and manufacturers that on the basis of a few 'scientific' tests it should be possible to state that the life of a particular plastic exposed to the weather is x years. As touched upon above, the prediction of likely service life for plastics-based building products is not a trivial problem. The degree of accuracy to which predictions can be made is very limited because of the individual conditions governing each use. A simple example shows this.

Suppose a plastic cladding product — corrugated roofing, say — is used on a building so that it is exposed at an angle of 45° to the horizontal and facing due north. This is the angle and direction which will ensure maximum solar flux. Also suppose that the same plastic is installed as a vertical cladding on the south-facing wall of the same building. This angle and direction will result in minimum solar flux.

The difference in lifetimes of the same plastic material on the same building in the same geographical location may vary by a factor of two or three simply as a result of the different exposures, the different microenvironmental effect!

A further complication is that the breakdown mechanisms of most plastics are not known in detail. Even for something as common as PVC the exact chemical nature and molecular structure after processing are unknown, and while the general course and consequences resulting from the exposure of PVC to heat and light are known, the detailed mechanism is not (see, for example, Starnes 1981; Davis et al. 1983).

Given these constraints, what can be done about predicting plastics durability? As far as resistance to weathering is concerned, it is useful to routinely expose examples of plastic building products to natural weathering. This is done at BRANZ's exposure site at Judgeford (near Wellington), where samples are exposed on racks at 45° to the horizontal, facing due north (Fig. 6), and examined periodically with both the naked eye and under a microscope. This technique provides background information on the 'typical' performance of 'typical' plastics and products. Its great disadvantage is that it is very slow; for specific products it is not a viable proposition to wait 20 or 30 years for an answer.

Accelerated test methods are available, in either complex or simple form. A number have been described (Davis et al. 1983). In general, the reliability of the result of an accelerated test is inversely proportional to the degree of acceleration. Without delving deeply into the philosophy of accelerated durability testing, which has been and still is being discussed at great length, the following points can be made:

A. Accelerated testing can be used to establish the types of breakdown liable to occur in service. This statement has several corollaries:

- Because sample size is small, the effects on weathering of factors like stresses imposed from fixing methods are difficult to model.
- The accelerated method used must accelerate only those factors which will occur in the real world. For example, use of unfiltered short wavelength UV lamps will quickly degrade most plastics, but since the UV wavelengths involved do not occur in the solar spectrum this test is inappropriate as it activates break-

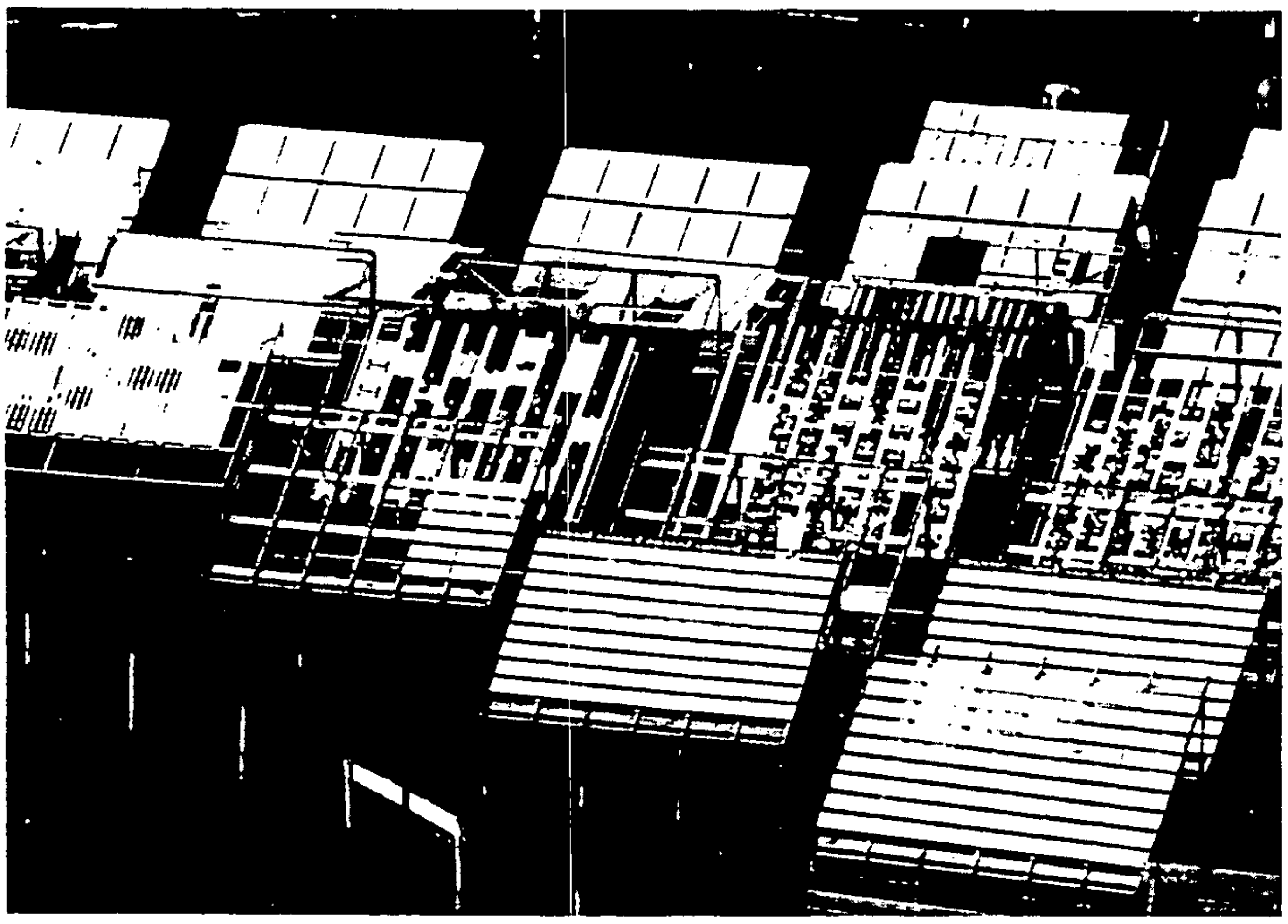

Fig. 6 Part of BRANZ natural weathering site, Judgeford (near Wellington).

down mechanisms which will not occur in the real world.

- It is useful either to expose samples of different origin but the same generic type for comparison, or know in general how generic types of plastic respond to the accelerated method used. This gives a guide as to whether the breakdown modes of the specific formulation under test are 'typical' of type.

B. It is generally not possible to correlate results from an accelerated test to actual lifetime(s) in use.

The exception to this is the use of extrapolations where there is known to be only a single factor causing degradation. For example, the use of Arrhenius-type methods in the specific case when heat is known to be the sole degrading factor, as in the case of plasticiser migration from cable insulation described above. In the case of the effects of weathering where a number of factors may be operating synergistically, such attempted correlations are downright misleading.

The added influence of conditions of actual use, or microenvironment, was described above.

C. So-called accelerated test methods may still take some time.

BRANZ's 'standard' xenon arc weatherometer test is 5000 hours of lamp time, or roughly 10 months.

D. It is good insurance, and imperative for a plastic or product of which there is no previous experience, to place samples outside for natural weathering, or into whatever other real-life situation has been modelled, for its long-term change to be monitored and compared to the results from the accelerated tests.

DISCUSSION

There are two main themes which run through the problems described above. The first is that of education. Plastics have different requirements from other building materials in the way they are incorporated into the fabric of a building, and a different reaction to the particular environment to which they are exposed. Furthermore, products formed from what is nominally the same plastic, PVC for example, are far from identical. The addition of fillers, stabilisers, processing aids, impact modifiers, etc. sees to that.

Education

Education is needed on a broad front. Designers, specifiers, and installers need to be aware of the overall consequences of their decisions regarding plastic products, particularly in aspects in which they do not normally deal. Sales personnel, and others marketing plastics-based materials, have a duty to their customers to inform them of both the good and bad points of their products. Nowhere, for instance, in trade literature describing polycarbonates for glazing, does it state that their impact resistance reduces on exposure to weathering — but it does (Brydson 1982), as it does for most plastics.

The form this education should take is uncertain. The mass of material to be assimilated is daunting, and the building industry is awash with paper already. Alternatives that BRANZ is considering using are a video for suppliers and installers of PVC exterior claddings, and computer-based interrogative or 'knowledge-based' systems. Another method appears to be to introduce more about plastics into the preliminary training and undergraduate courses for architects, civil engineers, building technologists, and builders themselves, with the aim of preventing problems, rather than just solving them. This effectively means appropriate training for the technical institute staff, and university lecturers. Who is to do this, when the number of people qualified to undertake such teaching in New Zealand is extremely small?

Durability prediction

It is not unreasonable for designers and material specifiers to expect some indication of the durability of a plastic product, and provided it is given and stated as being given in general terms, this is quite useful. Such statements as:

> 'Product X can be expected to have a serviceable life of at least 30 years under normal conditions of exposure. As the product ages, loss of gloss will occur, white cladding will chalk and coloured claddings will fade. Resistance to impact will decrease with age.' (Building Research Association of New Zealand 1987a)

set out what is known about the product based on experience with the same generic type in the USA and Australia, experience with the weathering behaviour of uPVC in general, and accelerated and natural weathering tests on the specific product described. Changes are generally stated in qualitative terms: we know what is expected to change, but not by how much since this can only be measured in 30 years time. Such statements are routinely produced by BRANZ provided there is, in its opinion, adequate evidence to support them. The statement 'normal conditions of exposure' says nothing about microenvironmental effects, although it does imply that unusual uses may shorten product life. However, perhaps it is incumbent on BRANZ to explicitly mention microenvironments and their effects.

Part of the education process needs to be that such general or qualitative statements are at present all that is technically supportable so that statements for generic-type products may well be identical. Added to that should be that 'Brand X versus Brand Y' type comparisons can be misleading if based on accelerated tests or natural weathering, and long-term performance over time is not known (see, for example, Fig. 7 — impact resistance could be light transmission, fatigue resistance, cracking resistance, etc., and the scales are not necessarily linear).

Improvement in predictive methods for plastics durability must come initially from basic research into the mechanisms of change. Alternative approaches, such as measurement of early changes in a physical property and prediction of long-term behaviour from a known previously determined relationship are also promising (e.g., Roux et al. 1981), and from the practical viewpoint probably the only area of prediction to which New Zealand can contribute.

Training of durability specialists for plastics is on the job, since there are no tertiary institutions offering such courses. In a similar fashion, in the past, information on plastics durability has been gathered passively, as the result of someone else's often expensive problem. Much information comes from the international scientific literature, and informal contact with overseas researchers, but needs to be interpreted with care when being applied to New Zealand. Information also comes from company technical staff, both New Zealand and overseas-based, although there may be limits on how some information can be used. Recently BRANZ has started a more active research programme into aspects of plastics use in the building industry, with the ultimate objective of anticipating problems rather than dealing with them as they arise (Building Research Association of New Zealand 1987b). It is hoped that this will improve the information flow on plastics use and durability in building.

Better knowledge of New Zealand's climate, including UV levels, when coupled with better knowledge of breakdown mechanisms, will also help improve the reliability of durability prediction.

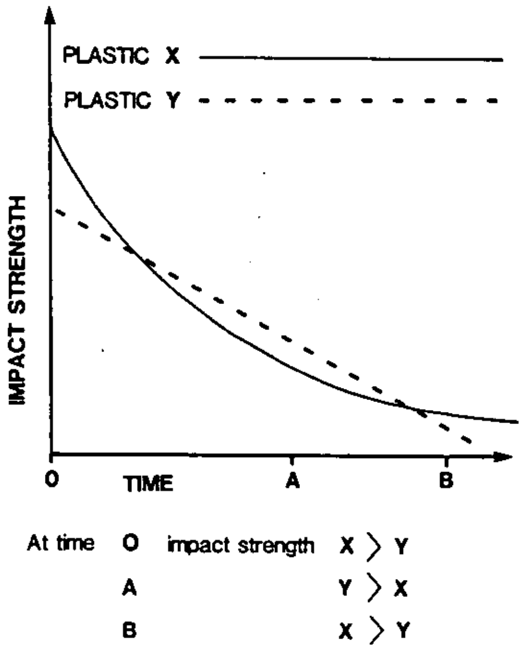

Fig. 7 Comparisons of properties at different points in time.

CONCLUDING COMMENTS

A number of examples of plastics problems in buildings have been used to illustrate that there are two main reasons for such problems occurring. The first is a lack of appreciation by designers, specifiers, and installers of plastics of the particular requirements of and performance of plastics-based building products. As a corollary, such people need to be better informed about these properties. The second factor is the need for better predictive methods for plastics durability in general.

Finally, this paper has highlighted plastics problems. In fact, most plastics usage is problem-free, as witnessed by the extensive use of such items as melamine-formaldehyde laminates for internal surface finishes, polybutylene plumbing systems, and a wide range of other plastic building products.

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N. van Gosliga derived and prepared Table 1.

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