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EFFECT OF SURFACE FINISH ON THE DURABILITY OF GRP SHEETS

ANALYZED

by A. Blaga and R.S. Yamasaki

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Effect of surface finish on the durability of GRP sheets

A. BLAGA ⁽¹⁾, R. S. YAMASAKI ⁽¹⁾

Artificial and natural weathering in conjunction with scanning electron microscopy (SEM) was used to study the effect of surface finish on the resistance to deterioration of GRP sheets. When exposed in a xenon arc weathering machine or to outdoor weathering, GRP sheets protected with either a gel-coat or an acrylic lacquer have considerably better resistance to deterioration than sheets with smooth, unprotected surfaces (conventional finish). Temperature-humidity cycling in conjunction with thermal gradients cause no deterioration in gel-coated sheets, but induce cratering in those coated with an acrylic lacquer. Sheets with conventional surface finish undergo usual deterioration in artificial or natural weathering after relatively short periods of exposure.

1. INTRODUCTION

When used in the outdoor environment, conventional glass-fiber reinforced polyester (GRP) sheets undergo undesirable changes in appearance, as a result of surface deterioration. Results reported previously ([1]-[4]) have established that there are two main types of surface degradation, namely, breakdown in the glass-resin interface, which results in fiber prominence (fiber pop out), and matrix microcracking; both affect the appearance of the surface. If deterioration is severe, mechanical and other physical properties are adversely affected.

Fiber prominence occurs first, because the glass-resin interface situated in the surface layer of a GRP composite is more susceptible to environmental attack than the similarly located, more homogeneous matrix resin. It develops under the influence of environmentally induced (thermally and/or by moisture) stress-fatigue [2] which causes fracture of the resin at the interface. Fiber prominence takes place after variable periods of ageing, depending on the GRP material and the service environment.

Surface microcracking, the other type of breakdown, generally occurs on the side of the sheet exposed to radiation, after fiber prominence has become relatively extensive. It takes place under the combined action of physically-induced stress fatigue and radiation-induced tensile stresses in the surface layers of the resin as a result of shrinkage caused by post-crosslinking during weathering ([3], [4]).

By using protective coatings or other means to modify the surface finish texture and by keeping the fibers away from the surface, the physically-induced stresses at the interface should be considerably reduced and the rate of surface breakdown decreased. In addition to reducing stresses in the interface region of the surface layer, some appropriately stabilized, protective coatings can also improve the resistance of the sheet to the destructive action of ultraviolet light.

Studies of the durability of GRP sheets protected with a gel-coat or other type of durable surface finish are few and usually for short periods of exposure to laboratory ageing or outdoor weathering ([5], [6]). Most of these studies are associated with development work by the material suppliers, for the purpose of evaluating and screening gel-coat and other coating formulations for improved resistance of GRP sheets to surface deterioration. Generally, the sheets with the surface protection are subjected to accelerated ageing

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TABLE I
DESCRIPTION OF GRP SHEETING MATERIAL

Sample No.	General Characteristics of Sheets*	Composition
1	Conventional (non gel-coated), made by hand lay-up technique.	Sheet composed of 75 per cent** resin and 25 per cent** glass-reinforcement***. The resin consisted of cured, thermosetting, UV stabilised, general purpose polyester, produced by cross-linking 60 parts** of unsaturated polyester with 40 parts** of styrene using MEK peroxide and cobalt naphthenate without heating.
2	Gel-coated on both sides, made by hand lay-up.	Same composition as sample 1, but with gel-coated 0.25 to 0.35 mm thick and having the same formulation as the matrix.
3	Conventional (uncoated), made by continuous process.	Sheet composed of 75 per cent** resin and 25 per cent** glass-reinforcement***. The resin is an acrylic-modified, cured thermosetting, UV stabilised, general purpose polyester, produced by cross-linking 60 parts** of unsaturated polyester with 40 parts** of a 3:1 mixture** of styrene and methyl methacrylate at 110-140°C.
4	Same as sample 3, but having both surfaces coated with 0.04 mm of UV stabilised, commercial, acrylic lacquer.	The same composition as sample 3, but with lacquer coating.

* Flat, smooth finish surface, colorless and translucent sheets (1.5 mm thick)

** By weight

*** Silane-treated glass-fiber (E-glass) in the form of chopped strand mat.

tests, one of the most frequently used being immersion in boiling water ([5], [7], [8]). Changes in surface properties are assessed by measuring gloss and yellowness; visual examination is also used to assess formation of cracks and fiber prominence.

The purpose of the present paper is to report a study of the relative resistance to surface deterioration of GRP sheets protected with either a gel-coat or an acrylic lacquer, as determined by the scanning electron microscope. The deterioration process of some of these materials is described.

2. EXPERIMENTAL

2.1. Materials and methods of ageing

Samples used for the various exposures were prepared from 1.5-mm thick commercial GRP sheets produced by the hand lay-up and continuous processes. Table I gives a detailed description of these materials.

TABLE II
METHODS OF AGEING OF GRP SHEETS

Method No. 6	General Description of Ageing Conditions	Details*
1	Cyclic variation of humidity, temperature and radiation (Atlas Xenon Arc Weather-Ometer)	4 h water spray (100% R.H. and 12°C) and 4 h radiation (50% R.H. and 55°C)**; 3 cycles per day.
2	Outdoor weathering at Ottawa (temperate northern climate)	Samples exposed horizontally with no backing, in accordance with ASTM D1435.
3	Cyclic variation of humidity and temperature (Aminco Climate Lab)	7 h at 100% R.H. and 56°C** and 5 h at 25 to 100% R.H. and 11 to 56°C**; 2 cycles per day.

* Additional details are given in Reference 3, Figures 1 and 2.

** Temperatures measured at panel surface.

To study the relative resistance to surface breakdown of the GRP sheets, samples were subjected to artificial ageing in either an accelerated weathering machine (Weather-Ometer^(R)) or a variable humidity-temperature cabinet, and to outdoor weathering at Ottawa. Details of the methods of exposure are given in table II.

2.2. Examination of surface deterioration by scanning electron microscopy

The occurrence of surface breakdown of the GRP sheets at different times of exposure was followed by a Stereoscan^(R) scanning electron microscope (SEM) using a tilt angle of 45°. The instrument was generally operated at 20 kV; however, a voltage of only 5 kV was used for the examination of sheets protected with poly(methyl methacrylate)-based lacquer to prevent overheating of the surface (higher voltages induce thermal decomposition of the coating).

3. DISCUSSION OF RESULTS

The SEM micrographs in figures 1 to 16 are presented to illustrate the relative resistance to, and the eventual mode of, surface deterioration of conventional, gel-coated and lacquer-protected GRP sheets subjected to artificial and outdoor weathering. The results and conclusions are summarized in tables III and IV.

3.1. Effect of gel-coat on the resistance to surface deterioration at the glass-resin interface

Results presented here indicate that the gel-coated GRP sheets have good resistance to surface deterioration in the glass-resin interface. In the conventional non gel-coated sheet, all the damage features usually occurring in the glass-resin interface were detected after relatively short periods of exposure in the Weather-Ometer, whereas none of these features were found in the gel-coated sheet (table III, method 1). The surface of the non gel-coated control sheet (hand lay-up) and the exposed side of the sheet weathered for different periods are shown in figures 1 to 3. It can be seen in figure 2 that fiber prominence is relatively advanced after 600 cycles of exposure in the non gel-coated sheet. By contrast there is no indication of deterioration in the glass-resin interface of gel-coated sheets even after 1,250 cycles of artificial weathering.

In outdoor weathering, incipient fiber prominence was detected in the non gel-coated sheet after 30 to 32 months of exposure (table III, method 2). At the end of the exposure program (40 months), fiber prominence was relatively advanced (fig. 4), but not widespread. The gel-coated GRP sheet did not show any surface damage associated with the glass-resin interface when subjected to outdoor weathering.

As reported elsewhere [9], surface breakdown proceeds at a faster initial rate (during the first 300 to 350 cycles) at the glass-resin interface in sheets exposed in the Climate Lab^(R) to humidity-temperature cycling (table III, method 3) than on the front side of sheets subjected to Weather-Ometer or outdoor

exposure; subsequently, however, the rate of breakdown is considerably slower. The surface breakdown features at the glass-resin interface are similar to those produced in artificial or outdoor weathering. A site of relatively advanced deterioration in the glass-resin interface after only 300 cycles of exposure to humidity-temperature cycling is shown in figure 5.

When a gel-coat is applied to a GRP sheet, the reinforcing glass-fibers are no longer in the surface layer. The resulting resin-rich surface thus consists of a more homogeneous component. As a result the environmentally induced stresses normally operating in the surface region and, more particularly, in the glass-resin interface [2] are reduced, thus preventing formation of fiber prominence.

3.2. Effect of gel-coat on the resistance to surface microcracking

The resistance of the matrix to weathering depends on the chemical nature of the polyester resin and its

formulation. As both the conventional and the gel-coated GRP samples contained the same resin, it was logical to expect that the sheets would have similar resistances to surface microcracking under the combined influence of radiation and environmentally induced stress fatigue. In fact, the exposed surface of both types of sheets developed microcracks or microfractures after approximately the same period of exposure to artificial weathering (950 to 1,000 cycles) (table III, method 1).

The pattern of microcracks induced in the conventional sheet (figs. 3 and 6) is different from the surface deterioration produced in the gel-coated sheets shown at different magnifications in figures 7 and 8. In conventional sheets, the cracks are produced under the predominant influence of stresses induced by the differential response of the resin and the underlying glass-fibers to the fluctuating environmental factors (such as humidity and temperature) in addition to the surface gradient-dominated stresses caused by shrinkage of the resin as a result of post-crosslinking. In gel-coated

TABLE III
EFFECT OF GEL-COAT ON THE DURABILITY OF GRP SHEET

Type of Exposure	Description of Sheet Sample*	Type of Surface Deterioration and Time of First Occurrence in Cycles				Total Exposure (in cycles)	CONCLUSIONS
		Fiber Ridging	Cracks Along Fibers	Fiber Prominence	Surface Micro-Cracking		
1	Conventional (non gel-coated)	4-6	42-60	500-550	950-1000	1250	The non gel-coated GRP sheet undergoes surface breakdown (fiber prominence and surface microcracking) after a relatively short period in the Weather-Ometer.
1	Gel-coated	None	None	None	950-1000	1250	The resin-rich surface layer protects the glass-resin interface against the effect of moisture and/or temperature induced stress-fatigue (2,3) and thus no fiber prominence occurs. The surface microfractures are randomly oriented and are caused by the combined effect of radiation and stresses resulting from moisture -and/or temperature gradients and inhomogeneities (flaws and defects).
2**	Conventional (non gel-coated)	<2 mos.	12 mos.	30-32 mos.	34-36 mos.	40 mos.	The non gel-coated GRP sheet undergoes surface breakdown (fiber prominence and microcracking) after a relatively short period of outdoor weathering.
2**	Gel-coated	None	None	None	None	40 mos.	The resin-rich surface layer protects the glass-resin interface against the effect of moisture and/or temperature induced stress-fatigue. Surface microcracking did not occur, probably owing to the relatively short period of exposure.
3	Conventional (non gel-coated)	<4-6	36-50	200-250	None	2280	Relatively severe stress-fatigue*** operating at the glass-resin interface produces initial breakdown at a faster rate in sheets exposed to humidity-temperature cycling than in artificial weathering (method 1); surface microcracking does not occur in the absence of radiation (1,3).
3	Gel-coated	None	None	None	None	2280	The resin-rich surface layer protects the glass-resin interface against the effect of moisture and/or temperature induced stress-fatigue, and thus fiber prominence cannot occur. Surface microcracking does not occur in the absence of radiation (1,3).

* The sheets were produced by the hand lay-up technique.

** Outdoor weathering time could not be converted into cycles, and is thus given in months (mos).

*** As a result of cyclic variation of humidity and/or temperature, the surface region is normally subjected to alternating stresses (induced by differential dimensional changes due to gradients, and dissimilarity in properties between glass and resin). These stresses exert a stress-fatigue on the surface material (2,3).

Fig. 1. — Surface of non gel-coated (made by hand lay-up) GRP Control.

Fig. 4. — Surface of non gel-coated GRP sheet weathered outdoors for 40 months.

Fig. 2. — Surface of non gel-coated GRP sheet aged for 600 cycles in the Weather-Ometer.

Fig. 5. — Surface of non gel-coated GRP sheet subjected to humidity-temperature cycling for 300 cycles.

Fig. 3. — Surface of non gel-coated GRP sheet aged for 1,200 cycles in the Weather-Ometer.

Fig. 6. — Surface of non gel-coated GRP sheet aged in the Weather-Ometer for 1,200 cycles.

Fig 7. — Surface of gel-coated GRP sheet (made by hand lay-up) aged for 1,200 cycles in the Weather-Ometer (the control is similar in appearance to figure 1).

Fig. 10. — Gel-coated GRP sheet weathered outdoors for 40 months.

Fig. 8. — Surface of gel-coated GRP sheet aged in the Weather-Ometer for 1,200 cycles.

Fig. 11. — Uncoated GRP sheet (made by continuous process) aged for 1,200 cycles in the Weather-Ometer (the control is similar in appearance to figure 1).

Fig. 9. — Surface of non gel-coated GRP sheet weathered outdoors for 40 months.

Fig. 12. — Surface of acrylic lacquer-coated GRP sheet (made by continuous process) aged for 1,200 cycles in the Weather-Ometer (the control is similar in appearance to figure 1).

Fig. 13. — Uncoated GRP sheet (continuous process) weathered outdoors for 40 months.

Fig. 14. — Acrylic lacquer-coated GRP sheet (continuous process) weathered outdoors for 40 months.

sheet, owing to the absence of glass-fibers in the surface layer, the stress-fatigue resulting from the differential interaction of the glass and resin is considerably reduced or no longer operative. The environmentally induced stress-fatigue, in this instance, is the result of random inhomogeneities in the resin, and thermal and moisture gradients. These gradients may be in planes parallel to the surface, owing to inhomogeneities, and from the surface inward. The presence of inhomogeneities accounts for the random orientation of the surface microfractures in the gel-coated sheets.

The exposed surface of non gel-coated GRP sheet developed very fine surface cracks after approximately 34 to 36 months of outdoor weathering. Figure 9 illustrates its appearance when weathered outdoors for 40 months. The areas confined by the intersecting cracks are still relatively large, possibly because surface microcracking is still in the early stage. No microcracking was detected on the exposed side of gel-coated sheets (table III, method 2 and *fig. 10*).

Fig. 15. — Acrylic coated GRP sheet subjected to humidity-temperature cycling for 4 cycles.

Fig. 16. — Acrylic lacquer-coated GRP sheet subjected to humidity-temperature cycling for 2,280 cycles.

3.3. Resistance to surface breakdown of GRP sheets coated with acrylic lacquer

Acrylic resins are known to have very good resistance to weathering [10]. Consequently, they are sometimes used by the industry as a surface finish to improve the resistance of GRP to surface breakdown in outdoor applications.

Whereas the conventional uncoated sheet develops all the features of surface damage in the glass-fiber interface after relatively short periods of ageing in the Weather-Ometer and ultimately undergoes surface microcracking, only incipient fiber ridging was detected in the sheet coated with acrylic lacquer after approximately 1,200 cycles (table IV, method 1). The surfaces of uncoated and coated sheet after 1,200 cycles in the Weather-Ometer are shown in figures 11 and 12.

Weathering outdoors induced formation of the usual features of surface deterioration at the glass-resin interface in the uncoated GRP (table IV and *fig. 13*).

TABLE IV
EFFECT OF ACRYLIC LACQUER COATING ON THE DURABILITY OF GRP SHEET

Type of Exposure	Description of Sheet Sample*	Type of Surface Deterioration and Time of First Occurrence in Cycles					Total Exposure (in cycles)	CONCLUSIONS
		Fiber Ridging	Cracks Along Fibers	Fiber Prominence	Surface Micro-cracking	Cratering		
1	Conventional (uncoated)	3-4	15-18	800-900	1225-1250	None	1250	Uncoated GRP sheet undergoes surface breakdown (fiber prominence and microcracking) after a relatively short period in the Weather-Ometer.
1	Coated on both sides with acrylic lacquer	1200	None	None	None	None	1250	The acrylic coating protects the glass-resin interface from the direct effect of environmental factors, such as humidity and temperature, and the matrix resin of GRP sheet against the harmful action of the UV light.
2**	Conventional (uncoated)	<2 mos.	10-12 mos.	18-20 mos.	>40 mos.	None	40 mos.	Uncoated GRP sheet develops fiber prominence after a relatively short period of outdoor weathering. Outdoor exposure period was probably too short to produce surface microcracks.
2**	Coated on both sides with acrylic lacquer	None	None	None	None	None	40 mos.	The acrylic coating protects the glass-resin interface from the direct effect of environmental factors, such as humidity, temperature and solar radiation so that no damage occurs.
3	Conventional (uncoated)	<8	8-10	250-350	None	None	2280	Owing to relatively severe stress-fatigue operating at the glass-resin interface, initial fiber prominence occurs at a faster rate than in artificial weathering. In the absence of radiation, no surface microcracking occurs.
3	Coated on both sides with acrylic lacquer	None	None	None	None	4-6	2280	The acrylic coating protects the glass-resin interface from the direct effect of environmental factors, and thus no fiber prominence occurs. Formation of craters in the coating results from bursting of blisters formed because of pressure exerted by accumulation of water, as a result of thermal gradients in the coated sheet and high humidity in the environment.

* The sheets were produced by a continuous, automated process. Being cross-linked with a mixture of styrene methyl methacrylate (Table I), these uncoated sheets have better resistance to surface deterioration than those cross-linked with styrene alone (Table I and III). This is well known [15].

** Outdoor weathering time could not be converted into cycles and is thus given in months (mos.).

No surface damage of any kind was detected in the acrylic lacquer-coated GRP sheet, even at the end of 40 months of exposure (table IV and *fig. 14*).

As expected, exposure of the coated sheet to humidity-temperature cycling did not induce any surface breakdown in the glass-resin interface region; however it resulted in relatively severe damage to the acrylic surface coating after a very short period of exposure. The surface of lacquer-coated sheet is shown in figures 15 and 16, after 4 and 2,280 cycles of exposure, respectively. The microscopic texture of the surface layer was drastically changed even after a relatively short exposure (15 to 20 cycles), as evidenced by the presence of extensive craters. The shapes of the craters suggest that this type of surface deterioration results from the bursting of blisters formed probably at the interface between the coating material and the GRP substrate and/or within the coating.

Examination of coated GRP samples by optical microscopy indicated that the craters were formed during the humidity-temperature cycling and thus could not result from subjection to vacuum during specimen

preparation for SEM observation. Indeed, when sheets exposed for short periods (3 to 5 cycles) were observed, the surface contained blisters almost exclusively, whereas surfaces of the same sheets aged for somewhat longer periods (about 20 to 25 cycles) contained a very large proportion of craters.

Unlike the other two exposures, the humidity-temperature cycling (table II, method 3) involves exposure of the coated GRP sheet to high humidity (approx. 100% R.H.) in addition to the relatively high temperature (56°C). Furthermore, over a certain period of the cycle, while the relative humidity is about 100%, the temperature increases from approximately 11 to 56°C ([2], [3]). Given the low thermal conductivity of plastic material, the temperature during this period is continuously higher in the surface coating layer than in the underlying layers or at the interface. Thus, under the influence of high humidity and temperature gradients, the moisture diffuses into the sheet and accumulates into the colder region of the coating and/or at the interface, more particularly at sites of micro-flaws (including voids, low density regions, and

occluded extraneous particles). It is generally assumed that the blisters form because of pressure exerted by this accumulation of water ([11]-[14]). Osmosis does not play a role in the formation of blisters in the acrylic coated GRP sheets because there are no significant water soluble materials within the coating, or at the interface to give rise to an osmotic pressure.

The coating resin forming the outer portion of the blister wall undergoes distension by viscoelastic flow; thus, with each cycle, as more and more water is accumulated, the blister wall becomes thinner. In the early stages, the resin of the blister wall is probably plasticized by the residual solvent originally used in the lacquer. In addition to the stresses by the water pressure, the blister resin wall is subjected to physically induced stress-fatigue (thermally and/or by moisture). The ability of the resin in the wall of the blister to the stress-fatigue is produced by differential dimensional changes between the coating material and the GRP substrate ([2], [4]), mainly as a result of differences in thermal expansion coefficients ($8.3 \times 10^{-5} \text{C}^{-1}$ versus $2.2 \times 10^{-5} \text{C}^{-1}$) and equilibrium water of absorption (2.2% versus 1.1%; McBain quartz balance, 100% R.H., 23°C; data from the DBR laboratory).

With exposure, the resin in the blister wall becomes more rigid as a result of loss of residual solvent and exudation of the lower molecular weight polymer. Thus the ability of the resin in the wall of the blister to undergo plastic deformation is gradually reduced, and it ruptures under the combined effect of the stress caused by pressure of the accumulated water and the physically induced stress-fatigue.

Although the humidity in the Weather-Ometer is high (100% R.H.) for half (4 hours) of the cycle, conditions are not favourable for blister formation. The thermal gradients at the panel are of very short duration because of rapid temperature changes [3] taking place when the arc comes on and goes out (table II). Similarly, the R.H. is also changing rapidly especially at the sample surface; thus there are no significantly long periods in which high humidity and temperature gradients are simultaneously prevailing. It can be shown that the relation between high relative humidity and temperature gradients prevailing outdoors is similar to that existing in the Weather-Ometer.

4. CONCLUSIONS

Gel-coated GRP sheets do not undergo breakdown in the glass-resin interface when subjected to natural or artificial weathering. The resin-rich surface of the sheets consists of a more homogeneous component, and thus protects the glass-resin interface by reducing the environmentally induced stresses normally occurring in the surface region. The gel-coated sheet develops surface microfractures on the exposed side when subjected to accelerated weathering in the Weather-Ometer for the same number of cycles as the non gel-coated sheet. In outdoor weathering, the gel-coated sheet has better resistance to surface breakdown of the matrix. To produce a GRP sheet with considerably improved resistance to surface microcracking, a gel-coat with good ultraviolet light stability should be used. In particular, such gel-coats should be used to

improve the outdoor performance of GRP sheets known to have poor weathering resistance e.g., the fire retardant type [9].

When subjected to ageing in the Weather-Ometer or weathered outdoors, GRP sheets protected with acrylic coating did not develop surface breakdown. Similarly, exposure to humidity-temperature cycling did not produce fiber prominence or surface microcracking, but resulted in cratering of the acrylic coating. It is believed that craters are produced by bursting of blisters which are formed by pressure exerted by the accumulation of water as a result of thermal gradients in the coated sheet during periods of high humidity.

Thus acrylic lacquer-coated GRP sheets should not be used where thermal gradients and high humidity prevail in the service environment (e.g., shower rooms).

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RÉSUMÉ

Influence de la finition des surfaces sur la durabilité des feuilles de plastique renforcées de fibres de verre (GRP). — On a étudié l'influence de la finition des surfaces sur la résistance des feuilles de GRP sur des échantillons soumis à différentes actions de vieillissement : arc de Xénon, cycles humidité/température (en conjonction avec l'effet de gradient thermique) et exposition naturelle. Les modifications de structure des surfaces ont été contrôlées au microscope électronique à balayage. On s'est servi de quatre types de feuilles de GRP : des feuilles préparées manuellement à partir d'une résine polyester thermodurcissable réticulée par du styrène, à revêtement de gel ou à finition conventionnelle (à surface lisse, non revêtue) ; des feuilles obtenues par un procédé automatique en continu, avec une résine réticulée avec un mélange de styrène et de méthacrylate de méthyl, à finition conventionnelle ou revêtues d'un vernis acrylique.

Les feuilles à revêtement de gel n'ont pas développé de saillies fibreuses après des périodes relativement longues d'exposition dans les trois ambiances ; les feuilles correspondantes à finition conventionnelle ont montré des saillies fibreuses assez prononcées après une courte durée des mêmes expositions. Les feuilles à revêtement de gel soumises à l'arc de xénon présentent une micro-

fissuration superficielle de la matrice du côté exposé après le même nombre de cycles que les feuilles sans revêtement de gel, ce qui est probablement dû au fait que les deux types de feuille ont été confectionnés à partir de la même résine. Afin d'améliorer la résistance à la microfissuration de surface des feuilles de GRP, il faudrait utiliser un revêtement de gel ayant une bonne stabilité au rayonnement ultraviolet. En exposition naturelle, les feuilles à revêtement de gel montrent une meilleure résistance à la détérioration superficielle de la matrice.

Les feuilles de GRP revêtues de vernis acrylique soumises à l'arc de xénon ou à l'exposition naturelle n'ont pas montré de détérioration. De même, sous l'effet des cycles humidité/température, elles n'ont pas révélé de saillies fibreuses ou de microfissures en surface mais la formation de cratères dans le revêtement acrylique. Les cratères résultent de l'éclatement de cloques formées sous l'influence des gradients thermiques durant des périodes de forte humidité. Les feuilles correspondantes à finition conventionnelle ont subi en général des détériorations habituelles dans les trois types d'exposition.