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Application of Accelerated Weathering Test to Glass-Fiber Reinforced Polyester Sheets of Improved Surface Durability

by R. S Yamasaki and A. Blaga

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SOMMAIRE

On a réalisé un essai de vieillissement accéléré sur trois types de polyester renforcé aux fibres de verre, dont la résistance avait été accrue par l'application de divers revêtements. La nature et la vitesse de la dégradation superficielle ont été contrôlées pendant la totalité l'exposition, au moyen d'un microscope à balayage électronique et, lorsque cela a été possible, les résultats ont été comparés à ceux qu'on a obtenus à Ottawa (Canada) lors d'une exposition horizontale à l'extérieur. Le polyester renforcé et recouvert d'une laque acrylique a subi 6 types de dommages superficiels, entraînant l'exposition du polyester et une microfissuration de sa surface. Les trois premiers types de dommages ont été confirmés par l'exposition à l'extérieur (6 ans jusqu'ici) et ont été accélérés 6 fois. Le polyester renforcé aux fibres de verre et recouvert de gel a subi une microfissuration superficielle, comme celle qu'a produite l'exposition à l'extérieur, mais avec un facteur d'accélération de 9. Le polyester à fibre de verre laminé au PVF a subi 5 types de dommages, entraînant le délaminage du PFV et la microfissuration de la surface de la résine de polyester renforcé non protégé. Les deux premiers types de dommage ont été confirmés par l'exposition à l'extérieur (6 ans jusqu'ici) et ont été accélérés 5 fois.

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R. S. Yamasaki¹ and A. Blaga¹

Application of Accelerated Weathering Test to Glass-Fiber Reinforced Polyester Sheets of Improved Surface Durability

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ABSTRACT: An accelerated weathering test has been applied to three types of commercial glass-fiber reinforced polyester (GRP), the durability of which has been improved by the application of various surface finishes. The nature and rate of induced surface degradation were monitored throughout the exposure period by scanning electron microscopy and, where possible, compared with those produced by horizontal outdoor exposure at Ottawa, Canada. Acrylic-lacquer-coated GRP underwent six types of surface damage leading to exposure and surface microcracking of the GRP substrate. The first three types of damage produced by artificial weathering were similar to those induced so far after six years of outdoor weathering, resulting in an acceleration factor of 6. Gel-coated GRP sustained surface microcracking as for outdoor exposure with an acceleration factor of 9. Poly(vinyl fluoride)-laminated (PVF) GRP underwent five types of damage, resulting in delamination of PVF and surface microcracking of the unprotected GRP resin. The first two types of damage have been verified to date after six years of outdoor exposure and were accelerated by a factor of 5.

KEY WORDS: accelerated tests, composite materials, durability, surface-laminated glass-fiber reinforced polyester, surface degradation, scanning electron microscopy

In a previous investigation [1], an accelerated weathering test with a cycle of 2-h xenon arc radiation followed by 0.67-h cold water spray (2-0.67 cycle) was developed and successfully tested on three types of commercial glass-fiber reinforced polyester (GRP) sheets. This paper reports results of the application of this test to GRPs, the durability of which has been improved by application of various surface finishes.

Experimental Procedure

Materials

Three types of commercial GRP—acrylic-lacquer-coated, gel-coated, and poly(vinyl fluoride) (PVF)-laminated—were selected. Detailed descriptions of the materials are presented in Table 1.

Scanning Electron Microscopy

The surface degradation was assessed with a Stereoscan® scanning electron microscope (SEM) using a tilt angle of 45 deg.

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For examination of acrylic-lacquer-coated and PVF-laminated GRPs, the instrument was operated at 5 kV rather than 20 kV to prevent thermal decomposition of the surface. Specimens were prepared for SEM examination by ultrasonic cleaning prior to coating them with carbon and gold to render them conductive.

Procedure

The GRP panels (165 by 57 by 1.5 mm) were subjected to accelerated weathering (2-0.67 cycle) in a xenon arc Weather-Ometer® (Atlas Model 65 WR), with the same conditions as for the previous investigation (Footnote 2) but with the 6000-W burner replaced by a longer-life 6500-W burner.

At appropriate intervals 15- by 15-mm specimens were cut from the exposed samples and surveyed with an optical stereomicroscope prior to SEM examination. The nature and rate of induced surface degradation were monitored throughout the exposure period and, where possible, compared with that produced by horizontal outdoor exposure at Ottawa (humid continental climate). Acceleration factors were then calculated from these results as a ratio of outdoor to accelerated exposure times.

Results and Discussion

Acrylic-Lacquer-Coated GRP

Exposure of acrylic-lacquer-coated GRP to the 2-0.67 cycle led to surface deterioration characterized by six distinct types of damage (Figs. 1 and 2). The first change to occur was fiber ridging, in which the lacquer or lacquer-resin layer formed ripples or round ridges above the glass filaments near the surface as illustrated in Fig. 1b. The next damage feature was characterized by the lacquer-resin layer generally rupturing at the trough of such ridges (Fig. 1b) rather than at the peak position as found for the degradation of unprotected GRP [1,2]. In the third stage, the glass fibers became essentially free of the substrate, producing the so-called fiber pop-out (Fig. 1b). The fourth type of damage was characterized by the lacquer coating undergoing wrinkling (Fig. 2a). This damage probably occurred because of the unequal dimensional change of the lacquer with respect to the substrate accompanied by loss of adhesion as a result of the deterioration of the lacquer. Later, the wrinkled lacquer became so brittle that it cracked open and no longer protected the GRP substrate (Fig. 2b). As a consequence, in the sixth stage the unprotected resin underwent surface microcracking (Fig. 2c).

The different types of damage brought about by accelerated

TABLE 1—Description of GRP sheet material.

Characteristics	Composition
Acrylic-lacquer-coated (conventional GRP made by a continuous process; each surface coated with 0.04 mm of UV stabilized commercial, acrylic lacquer)	Substrate composed of 75% acrylic-modified resin and 25% glass reinforcement; resin consists of 60 parts thermosetting, UV-stabilized, general-purpose polyester, cross-linked (at 110–140°C) with 40 parts of a 3:1 mixture of styrene and methyl methacrylate
Gel-coated (conventional GRP made by hand lay-up technique; each surface coated with 0.3-mm-thick resin of the same formulation as the matrix)	Substrate composed of 75% resin and 25% glass reinforcement; resin consists of 60 parts thermosetting, UV-stabilized, general-purpose polyester, cross-linked (without heating) with 40 parts of styrene using methyl ethyl ketone peroxide and cobalt naphthenate
PVF-laminated (fire-retardant GRP made by continuous process; each surface laminated with 0.03 mm of PVF film)	Substrate composed of 75% resin and 25% glass-reinforcement; resin consists of 70 parts thermosetting, tetrachlorophthalic acid-modified, light-stabilized unsaturated polyester cross-linked with 30 parts of styrene

FIG. 1—Fiber ridging, cracking of resin adjacent to fibers, and fiber pop-out of acrylic-lacquer-coated GRP produced by artificial and outdoor weathering.

FIG. 2—Advanced modes of degradation of acrylic-lacquer-coated GRP induced by artificial weathering.

weathering were compared with those produced by outdoor weathering (Fig. 1). The first three stages had also occurred outdoors and the corresponding breakdown features were similar at each stage. The subsequent three types of damage have not occurred to date after six years of outdoor exposure but are expected to do so after a longer exposure period.

The rates at which surface degradation proceeded in the two exposures were determined and compared based on the duration of exposure leading to inception of, on the average, a number of two to three damages for each 15- by 15-mm sample (Table 2). The 2-0.67 cycle produced surface degradation leading to and including fiber pop-out about 6.0 to 6.8 times faster than did outdoor exposure. Thus, the test period was reduced from about four years (outdoor weathering) to seven months (artificial weathering).

Gel-Coated GRP

Exposure of gel-coated GRP to the 2-0.67 cycle resulted in surface deterioration characterized by isolated and, subsequently, a

TABLE 2—Rate of surface degradation of acrylic-lacquer-coated GRP produced by artificial and outdoor weathering.

Nature of Surface Degradation	Period of Exposure to First Occurrence of Degradation, days		Acceleration Factor, Outdoors/2-0.67
	2-0.67 cycle	Outdoors ^a	
1. Fiber ridging	122	730	6.0
2. Cracking of resin adjacent to fibers	177	1100	6.2
3. Fiber pop-out	189	1280	6.8
4. Wrinkling of lacquer coating	290	...	...
5. Cracking of wrinkled lacquer coating	340	...	...
6. Surface microcracking of unprotected resin	380	...	...

^aExposure initiated 22 Feb. 1973 and specimens examined microscopically at six-month intervals.

^bThis type of damage has not occurred to date after 2190 days of exposure.

network of surface microcracking. Degradation leading to and including fiber pop-out did not occur probably because of the relatively thick (0.3 mm) surface layer of resin gel that does not contain glass fibers. Outdoor weathering also resulted in degradation characterized only by these two stages of surface microcracking. The microcracks for both exposures, illustrated in Fig. 3, resemble each other in that they exhibit random orientation and are similar in shape and dimension. Thus, degradation of gel-coated GRP induced by the two exposures are similar in nature and appearance for this type of failure.

Table 3 shows that the 2-0.67 cycle induced isolated, and a network of, surface microcracking of gel-coated GRP, 8.8 and 9.1 times faster, respectively, than outdoor exposure and, hence, reduced the test period for gel-coated GRP from about four and a half years (outdoor weathering) to six months (artificial weathering).

PVF-Laminated GRP

Exposure of PVF-laminated GRP to the 2-0.67 cycle led to deterioration categorized by five types of damage, shown in Figs. 4 through 6.

In the first stage, glass fibers located at the PVF-resin interface region became optically conspicuous against the green color of the resin substrate, as shown in Fig. 4b. This was probably due to in-

TABLE 3—Rate of surface degradation of gel-coated GRP produced by artificial and outdoor weathering.

Nature of Surface Degradation	Period of Exposure to First Occurrence of Degradation, days		Acceleration Factor, Outdoors/2-0.67
	2-0.67 cycle	Outdoors ^a	
1. Isolated surface microcracking	155	1370	8.8
2. Network of surface microcracking	167	1520	9.1

^aExposure initiated 22 Feb. 1973 and specimens examined microscopically at six-month intervals.

(a) Control
(b) 2-0.67 cycle, 178 days exposure
(c) Outdoors, 1640 days exposure

FIG. 3—Network of surface microcracking of gel-coated GRP produced by artificial and outdoor weathering.

FIG. 4—Optical conspicuousness of glass fibers at PVF-resin interface of PVF-laminated GRP induced by artificial and outdoor weathering.

FIG. 5—Blistering of PVF-laminate, located above optically conspicuous glass fibers, produced by artificial and outdoor weathering.

(a) 467 days exposure—cracking of PVF blister
 (b) 600 days exposure—general delamination of PVF laminate
 (c) 600 days exposure—surface microcracking of unprotected GRP resin

FIG. 6—Advanced modes of degradation of PVF-laminated GRP produced by artificial weathering.

creased reflection of light from the glass-gas interface created by the delamination of PVF from the glass fiber. Next, the PVF-laminate above this area formed blisters surrounded by small wrinkles (Fig. 5a). Soon the PVF blister split open, revealing the glass filament occupying the blister cavity and providing evidence that upward movement of the glass fibers was probably responsible for blistering of PVF (Fig. 6a). A fourth type of damage, the delamination of PVF, which generally began as a blister, eventually became so widespread that it left much of the GRP unprotected (Fig. 6b). Finally, the unprotected resin soon underwent surface microcracking (Fig. 6c).

These changes were compared with those produced on outdoor exposure. As shown in Figs. 4c and 5b, the first two types of damage also occurred outdoors, corresponding degradation characteristics being similar at both stages. More advanced damage has not been observed to date (six years of exposure) but is expected to follow.

Table 4 shows that the 2-0.67 cycle accelerated initiation of the first two stages of degradation of PVF-laminated GRP by factors of 5 and 4.5, respectively, thus reducing the test period from about five years (outdoors) to just over one year (artificial weathering).

Conclusions

The 2-0.67 accelerated weathering cycle induced six types of surface damage to acrylic-lacquer-coated GRP, leading to exposure and surface microcracking of GRP substrate. The first three types of damage have been confirmed to date (six years, Ottawa) on outdoor exposure. The 2-0.67 cycle accelerated initiation of such damages so as to reduce the test period from four years (outdoors) to seven months (artificial weathering).

When subjected to the accelerated weathering test, gel-coated GRP underwent degradation characterized by surface microcracking, which was confirmed by outdoor exposure. The initiation of degradation was accelerated so as to reduce the test period from four and a half years (outdoors) to six months (artificial weathering).

On accelerated weathering, PVF-laminated GRP underwent five

TABLE 4—Rate of surface degradation of PVF-laminated GRP produced by artificial and outdoor weathering.

Nature of Surface Degradation	Period of Exposure to First Occurrence of Degradation, days		Acceleration Factor, Outdoors/2-0.67
	2-0.67 cycle	Outdoors ^a	
1. Optical conspicuousness of glass fibers at PVF-resin interface	70	360	5.0
2. Blistering of PVF above optically conspicuous glass fibers	378	1700	4.5
3. Cracking of PVF blister	446	+++ ^b	+++
4. General delamination of PVF	555	+++ ^b	+++
5. Surface microcracking of unprotected GRP resin	600	+++ ^b	+++

^a Exposure initiated 22 Feb. 1973 and specimens examined microscopically at six-month intervals.

^b This type of damage has not occurred to date after 2190 days of exposure.

types of damage, resulting in delamination of PVF and surface microcracking of unprotected GRP resin. The first two types of damage have been verified to date (six years, Ottawa) by outdoor exposure and their inception was accelerated to reduce the test period from about five years (outdoors) to one year (artificial weathering).

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