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DURABILITY AND FIELD APPLICATIONS OF FIBRE REINFORCED POLYMER (FRP) COMPOSITES FOR CONSTRUCTION

DURABILITÉ ET APPLICATIONS DES COMPOSITES EN POLYMÈRES RENFORCÉS DE FIBRES (PRF) POUR LA CONSTRUCTION

DETERIORATION OF MECHANICAL PROPERTIES OF PULTRUDED FRP THROUGH EXPOSURE TESTS

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ABSTRACT

The authors carried out outdoor exposure tests on pultruded GFRPs for six years in four places in Japan with different climates. Three types of pultruded FRPs with different laminate systems were tested. Changes of mechanical properties such as tensile, bending and in-plane shear were measured. The results showed that unpainted pultruded FRP showed a remarkable reduction in mechanical strength, and the retention ratio was about 0.7–0.8 of the initial values by the 6th year. Corresponding painted specimens showed small changes. This result shows that a top coating helps to prevent changes of mechanical properties of pultruded FRP. As regards the difference of the laminate systems, there were specimens whose roving layer ratio was low and showed small changes in some mechanical properties. No significant difference between exposure sites was observed in these tests.

1. INTRODUCTION

Recently, the use of FRP as a structural material has increased due to its expected high resistance to corrosion and light weight. Pultruded FRP is made by a particularly easy method that can produce long members having the same cross section at relatively low cost, and so it is now one of the major structural materials used for construction. The durability of pultruded FRP is thus an important property. There have been some studies [1-5] on the durability of pultruded FRP for construction, but many of them focused on moist environments. When we consider the durability of FRP in an ambient condition, durability data based on outdoor exposure tests that are closer to actual environments is also important. There have been some durability studies [6-10] based on outdoor exposure tests, however, these were mainly on press molded or hand lay-up GFRP, and there is still a lack of information on pultruded FRP. The authors carried out outdoor exposure tests for pultruded FRPs for six years, and studied the long-term performance especially on mechanical properties such as strength and modulus for construction applications.

2. EXPERIMENTAL METHOD

2.1 Specimens

Table 1 shows the laminate systems of the three types of pultruded FRP plates prepared for this study. The FRP was PLALLOY supplied by Asahi Glass Matex Co., Ltd. and made of E-glass fiber and vinylester resin. Each plate was 420 mm wide and 3.2 mm thick. These pultruded FRP plates were cut into 620 mm lengths and used as specimens. Table 2 shows the seven series of the specimens. Six series of the specimens were coated with acrylurethane type top coating material to a thickness of 30 μm. Four exposure sites in Japan having various environmental conditions were used for the tests: Tsukuba is located near Tokyo and has a moderate climate and mild conditions; Asagiri is located near Mt. Fuji at relatively high altitude (920 m); Rikubetsu is located in one of the coldest areas in Japan where the air temperature reaches –30°C in winter; Oogimi is located on an island in the south of Japan with a sub-tropical climate. The specimens were set facing south with 5° slope using steel exposure racks. Figure 1 shows a photo of the specimens under the exposure test. The longest exposure term was planned to be ten years. Four specimens were exposed for one condition, three of which were recovered at the 2nd, 3rd and 6th years.

Table 1: Layer system of the specimens

Type of Specimens	Vf	Layer system
R12	43%	CSM21.0% / Cloth23.0% / ROV12.0% / Cloth23.0% / CSM21.0%
R26	39%	CSM16.0% / Cloth21.5% / ROV26% / Cloth21.5% / CSM16.0%
R43	36%	CSM9.5% / Cloth19.0% / ROV43% / Cloth19.0% / CSM9.5%

Note: CSM (Continuous Strand Mat), ROV (Roving)

Table 2: Specimens used in the test

Name of specimens	Type of specimen & top coat	Exposure site
T-R26	R26, unpainted	Tsukuba
T-R12-T	R12, painted	Tsukuba
T-R26-T	R26, painted	Tsukuba
T-R43-T	R43, painted	Tsukuba
A-R26-T	R26, painted	Asagiri
R-R26-T	R26, painted	Rikubetsu
O-R26-T	R26, painted	Oogimi

Fig. 1: Specimens under exposure test (Asagiri)

2.2 Testing methods

Small test pieces were cut out from the recovered specimens, and a bending test, tensile test and in-plane shear test were carried out. The bending test and tensile test were carried out for two directions as shown in Fig. 2. Each test was carried out for five test pieces.

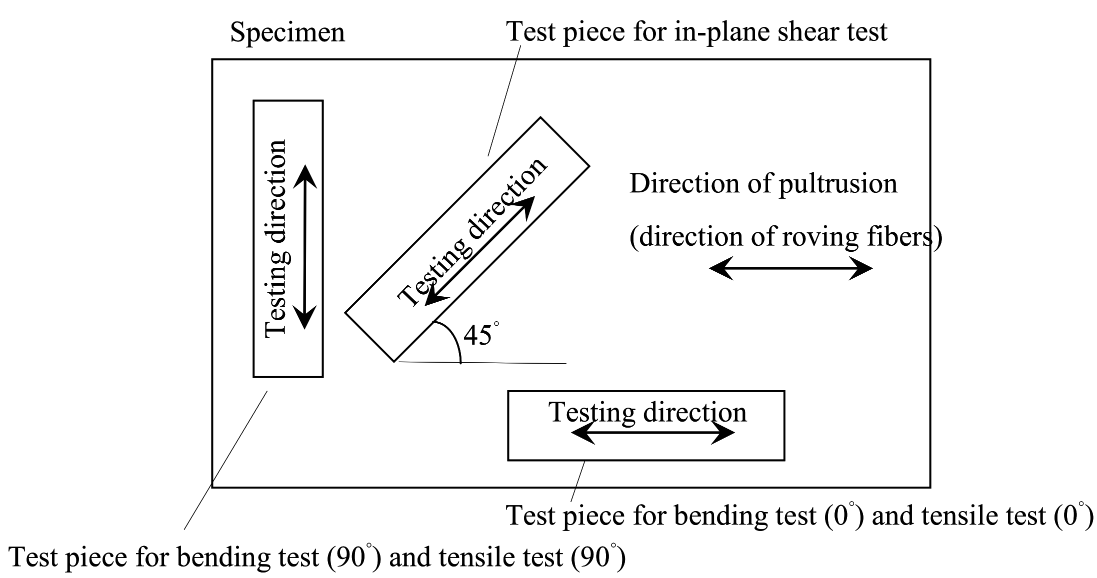

Fig. 2: Test pieces cut out from the exposed specimens

2.2.1 Bending test

The three-point bending test was carried out based on Japan Industrial Standard (JIS) K 7055. The test pieces were 84 mm long and 15 mm wide. The support span was set at 16 times the test piece thickness and the test speed was 2 mm/min. Equation (1) was used to calculate the bending strength. For top coated specimens, the thickness of the paint layer (60 μm) was subtracted from the measured value.

$$\sigma_b = 3 P_b L/2bh^2 \times (1 + 4(\delta/L)^2) \quad (1)$$

σ_b : Bending strength (MPa)
P_b : Maximum load (N)
L : Support span (mm)
b : Width of test piece (mm)
h : Thickness of test piece (mm)
δ : Center deflection at maximum load (mm)

2.2.2 Tensile test

The tensile test was carried out based on ISO 3268. The test piece was 250 mm long and 25 mm wide. The test speed was 1 mm/min. Equation (2) was used to calculate the tensile strength. For top coated specimens, the thickness of the paint layer (60 μm) was subtracted from the measured value.

$$\sigma_t = P_t / bh \quad (2)$$

σ_t : Tensile strength (MPa)
P_t : Maximum tensile load (N)
b : Width of test piece (mm)
h : Thickness of test piece (mm)

2.2.3 In-plane shear test

The tensile test was carried out based on JIS 7059. The test piece was 250 mm wide and 25 mm long. The test speed was 1 mm/min. Equation (3) was used to calculate the in-plane shear strength. For top coated specimens, the thickness of the paint layer (60 μm) was subtracted from the measured value.

$$\tau = P_s / 2bh \quad (3)$$

τ : In-plane shear strength (MPa)
P_s : Maximum load (N)
b : Width of test piece (mm)
h : Thickness of test piece (mm)

2.2.4 Statistical test

In order to test the significance of the change of mechanical properties compared with the initial data, the t-test was used to compare the data of the exposed specimen with the initial data at the 1% significance level.

3. RESULTS

3.1 Unpainted specimens

Table 3 shows the initial values of the mechanical properties of specimens. Table 4 shows the results of unpainted and painted specimens of R26 exposed at Tsukuba. Unpainted specimens exposed for 2 years have already shown a significant reduction in 90° bending strength, 90° tensile strength and in-plane shear strength. In addition, 3 years showed a reduction in 0° tensile strength, and the specimens exposed for 6 years showed a significant reduction in every measured property. The retention ratio of strength showed a steady decrease and was about 0.7–0.8 of the initial value at the 6th year. As regards the reduction of modulus, bending modulus in both 0° and 90° showed significant reductions from the 3rd year, however, the tensile modulus or in-plane shear modulus did not show a significant reduction even in the specimens exposed for 6 years.

Table 3: Results of initial values of mechanical properties of the specimens

	R12		R26		R43	
	Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)
Bending test (0°)	275.3	10.6	306.6	10.4	393.2	12.2
Bending test (90°)	262.1	10.7	287.6	11.2	271.4	12.6
Tensile test (0°)	319.2	17.9	369.0	19.2	409.6	20.9
Tensile test (90°)	156.2	12.8	165.8	12.9	135.8	12.5
In-plane shear test	58.0	3.49	56.9	3.79	52.6	3.40

Table 4: Results of R26 exposed at Tsukuba

Name of test	Unpainted specimen (T-R26)								Painted specimen (T-R26-T)							
	Retention ratio of strength for exposed years				Retention ratio of modulus for exposed years				Retention ratio of strength for exposed years				Retention ratio of modulus for exposed years			
	0	2	3	6	0	2	3	6	0	2	3	6	0	2	3	6
Bending test (0°)	1.00	0.99	0.93	0.82	1.00	0.97	0.87	0.7	1.00	1.08	1.04	0.95	1.00	0.97	0.94	0.92
Bending test (90°)	1.00	0.80	0.73	0.67	1.00	0.95	0.84	0.68	1.00	0.95	1.02	0.96	1.00	0.98	0.99	0.97
Tensile test (0°)	1.00	0.90	0.89	0.72	1.00	0.98	0.94	0.95	1.00	0.98	0.87	0.88	1.00	0.99	0.94	0.99
Tensile test (90°)	1.00	0.87	0.83	0.68	1.00	0.97	0.95	1.15	1.00	0.98	0.93	0.90	1.00	1.00	0.97	1.12
In-plane shear test	1.00	0.94	0.88	0.75	1.00	1.03	0.87	1.17	1.00	0.99	0.98	1.01	1.00	1.01	0.90	1.14

Note: The values in dark cells indicate significant probability from the t-test result.

3.2 Effect of top coating

Table 4 also shows the results of painted specimens. Tensile strength, both 0° and 90°, showed a significant reduction after 6 years of exposure, however, bending strength and in-plane shear strength did not show any significant reduction. Comparing the retention ratio of painted specimen with unpainted specimen, the reduction of the painted specimen was less than that of the unpainted specimen. This result shows that top coating has a protective effect against changes of mechanical properties of pultruded FRP.

3.3 Difference of layer system

Tables 5, 6, 7 and 8 show the results of the difference of layer system (R43, R26 and R12) for bending test 0°, bending test 90°, tensile test 0° and tensile test 90° respectively. All specimens for the tests had a top coat; hence the change of mechanical properties was not remarkable. However, there were specimens whose roving layer ratio was low and showed small changes in some mechanical properties. (e.g. R12).

Table 5: Retention ratio of bending strength and modulus (0°)

	Strength				Modulus			
Exposed years	0	2	3	6	0	2	3	6
T-R43-T	1.00	1.03	1.10	1.02	1.00	1.06	1.07	1.01
T-R26-T	1.00	1.08	1.04	0.95	1.00	0.97	0.94	0.92
T-R12-T	1.00	1.04	1.04	1.02	1.00	1.07	1.05	1.00

Table 6: Retention ratio of bending strength and modulus (90°)

	Strength				Modulus			
Exposed years	0	2	3	6	0	2	3	6
T-R43-T	1.00	1.03	1.05	1.04	1.00	0.94	0.91	0.88
T-R26-T	1.00	0.95	1.02	0.96	1.00	0.98	0.99	0.97
T-R12-T	1.00	0.97	1.05	1.14	1.00	1.09	1.02	1.16

Note: The values in dark cells indicate significant probability from the t-test result.

Table 7: Retention ratio of tensile strength and modulus (0°)

	Strength				Modulus			
Exposed years	0	2	3	6	0	2	3	6
T-R43-T	1.00	1.11	1.12	1.06	1.00	1.03	1.11	1.13
T-R26-T	1.00	0.98	0.87	0.88	1.00	0.99	0.94	0.99
T-R12-T	1.00	0.99	1.03	0.93	1.00	0.97	1.03	1.06

Note: The values in dark cells indicate significant probability from the t-test result.

Table 8: Retention ratio of tensile strength and modulus (90°)

	Strength				Modulus			
Exposed years	0	2	3	6	0	2	3	6
T-R43-T	1.00	1.00	1.00	0.98	1.00	1.04	0.92	1.15
T-R26-T	1.00	0.98	0.93	0.90	1.00	1.00	0.97	1.12
T-R12-T	1.00	1.00	0.99	0.89	1.00	1.01	1.00	1.23

Note: The values in dark cells indicate significant probability from the t-test result.

3.4 Difference of exposure sites

Painted R26 specimens were exposed in the four exposure sites. As shown in Table 4, painted R26 did not show a significant change, however, the changes in tensile strength in both 0° and 90° after 6 years are remarkable. Table 9 shows the results of tensile strength at the four exposure sites. There was no significant difference between each exposure site, even though the climatic conditions are rather different.

Table 9: Results of tensile strength at four exposure sites

	Retention ratio of tensile strength (0°)			Retention ratio of tensile strength (90°)		
Exposed years	0	3	6	0	3	6
Tsukuba	1.00	0.87	0.88	1.00	0.93	0.90
Asagiri	1.00	0.95	0.89	1.00	0.98	0.89
Rikubetsu	1.00	0.99	0.93	1.00	0.98	0.95
Okinawa	1.00	1.01	0.88	1.00	0.99	0.93

Note 1: The values in dark cells indicate significant probability from the t-test result.
Note 2: All specimens are R26 with top coating

4. CONCLUSIONS

Unpainted pultruded FRP showed a remarkable reduction in mechanical strength, and the retention ratio was about 0.7–0.8 of the initial values at the 6th year. On the other hand, corresponding painted specimens showed small changes. Only tensile strength at the 6th year showed a slight reduction with a retention ratio of about 0.9. This result shows that top coating has a protective effect against changes of mechanical properties of pultruded FRP. Three different layer systems were tested: there were specimens whose roving layer ratio was low and showed small changes in some mechanical properties. The differences of the four exposure sites were also compared, but no significant difference between each exposure site was observed in the tests, even though the climatic conditions are rather different.

5. REFERENCES

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