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Environmental Durability of Hybrid FRP Girder

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ABSTRACT

Hybrid FRP (HFRP) girder is a pultruded FRP member with I shape cross section that contains carbon fibers in the flange part to increase the rigidity of the member and that the other part is made of GFRP. There are some recent application studies of these materials as the main members of FRP footbridges. HFRP is also expected to have a good resistance under severe corrosive environmental conditions for steel; however there are not enough data to confirm this performance of these materials. The authors carried out accelerated weathering test for 4000 hours and water immersion test at 40 degree for 12 months for the HFRP specimens, and evaluated its durability by bending test and interlaminar shear test. Although the results of interlaminar shear test showed slight reduction in the strength, the durability of HFRP was good and was not so different from that of GFRP.

Keywords. FRP, hybrid, carbon fibers, glass fibers, durability

1. INTRODUCTION

The application of Fiber Reinforced Plastics (FRP) in civil engineering was first introduced in Japan about two decades ago with the development of FRP reinforcement and tendons. Japan had been a pioneer in the research and development of FRP materials for reinforced and prestressed concrete structures especially in the bridge engineering. The first JSCE standard specification for the design of FRP reinforcements was published in 1997. The first all FRP bridge, which is a two span continuous girder pedestrian bridge, in Japan was constructed in Okinawa prefecture in 2001. All the structural elements have been made with Glass Fiber Reinforcement Plastics (GFRP). The all FRP solution was chosen for this bridge due to its heavily corrosive environment where the bridge is surrounded by the ocean.

Advantages of the FRP bridge were also reported from the view point of a life-cycle assessment of environmental aspect (Tanaka, 2005).

An innovative hybrid composite girder is being developed in Japan consisting of carbon and glass fibers. The feature of this girder is the optimum use of CFRP and GFRP in flanges to maximize structural performance while reducing the overall cost by using glass fibers in the web section. In order to propose an effective application of FRP materials from the aspect of strength and cost, the authors investigated not only structural performance of a hybrid FRP bridge girder combining Glass Fiber Reinforced Plastics (GFRP) and Carbon Fiber Reinforced Plastics (CFRP) but the durability of it. The fundamental flexural behavior of hybrid FRP girder was investigated (Mutsuyoshi, 2006). HFRP is also expected to have a good resistance under severe corrosive environmental conditions for steel; however there are not enough data to confirm this performance of these materials. The authors carried out accelerated weathering test for 4000 hours and water immersion test at 40 degree for 12 months for the HFRP specimens, and evaluated its durability by bending test and interlaminar shear test.

2. EXPERIMENTAL METHODS

2.1 HFRP girder

Figure 1 shows the typical I shape cross section of the pultruded HFRP girder with 250mm height of girder, 95mm width of flange, 9mm thickness of web and 14mm thickness of flange. Flange part of HFRP girder was made of carbon fibers and GFRP, and the other part, web part, was made of GFRP. The matrix resin was vinylester resin. Table 1 shows the laminate system of the HFRP girder.

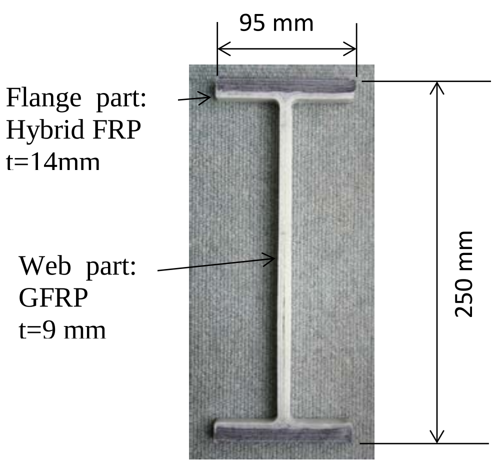

Figure 1 Typical cross section of HFRP

Table 1 Laminate system of HFRP

part	fibers, volumetric ratio			
	CF0°	GF0/90°	GF±45°	CSM
flange	33%	29%	13%	25%
web	0%	32%	42%	26%

2.2 Test methods

Test specimens were cut out from the HFRP girder member. Accelerated weathering test and water immersion test were carried out for specimens and bending test and interlaminar shear test were conducted to evaluate the mechanical properties.

2.2.1 Bending test

Bending test was performed according to JIS K 7017- “Fibre-reinforced plastics composites− Determination of flexural properties”. The test was conducted by three-point loading. In flange parts, span length/flange thickness was 40 and flange length/ flange thickness was 50. In web parts, span length/web thickness was 20 and web length/ web thickness was 30. In the bending test of flange specimen, width of specimen was 30mm and span length was 560mm. In the bending test of web specimen, width of specimen was 15mm and span length was 180mm. Figure 2 shows the bending test of flange specimen.

Figure 2 Bending test of flange specimen

2.2.2 Interlaminar shear test

Interlaminar shear test was performed according to JIS K 7057-” Fibre-reinforced plastic composites − Determination of apparent interlaminar shear strength by short-beam method”. The test was conducted by three-point loading. In the tests, span length/thickness was 5 and length/ thickness was 10. Loading velocity was 1mm/min. and interlaminar shear strength was calculated by using equation (1). Figure 3 shows the interlaminar shear test of flange specimen.

$$\tau = \frac{3P}{4wt} \qquad (1)$$

τ : interlaminar shear strength (N/mm^2)
P : interlaminar shear load (N)
w : width of specimen (mm)
t : thickness of specimen(mm)

Figure 3 Interlaminar shear test of flange specimen

2.3 Deterioration tests

2.3.1 Accelerated weathering test

Accelerated weathering test was performed by the accelerated weathering test machine using Xenon lamp. Test conditions were as follows; irradiation strength was 40W/m^2, irradiation time ratio was 100% (102 minutes of irradiation time and 18 minutes of irradiation time with water spray).

Specimens were scheduled to be tested after 1000, 2000 and 4000 hours. Five specimens were prepared for flange part and web part. One set of specimens was also tested before exposure in order to obtain reference values.

2.3.2 Water immersion test

Water immersion test was performed by using a constant temperature water tank of 40 degrees of Celsius. HFRP specimens, which were 1.0m-length of unpainted HFRP girder and 0.3m-length of HFRP girder with 25 μm thicknesses of fluorine resin top coat, were immersed in the water tank. Specimens were scheduled to be tested after three, six and twelve months.

2.3.3 Natural exposure test

The exposure test was initiated from October in 2008 at Oogimi in Okinawa in Japan, where the main climatic characteristic was subtropical and close to sea shore. Two kinds of test specimens were placed at exposure site. One was a 1.5m-length of HFRP girder with 25 μm thicknesses of fluorine resin top coat and the other was a same size with unpainted. Number of test specimens was two pieces, respectively. Exposed specimens are scheduled to be examined after five and ten years of exposure. Bending test, interlaminar shear test and compressive test will be conducted, respectively.

3 TEST RESULTS

3.2 Accelerated weathering test

3.2.1 Bending test

Table 2 and Table 3 show bending test results of flange part and web part, respectively.

The outside of the flange part was made of layers HFRP, and the inside of it was made of layers GFRP. In the flange part, two kinds of bending test were carried out. One, load was added to the outer surface of flange (HFRP part). The other, load was added to the inner surface of the flange (GFRP part).

According to test results, bending strength in the case of outer surface of the flange was greater than that in the case of inner surface of the flange. The reason is on the outer surface of the flange part was rich in carbon fibers. There were no significant changes in the bending strength up to 4000 hours exposure time in the case of flange parts.

In the case of web parts, there were no significant changes in the bending strength between 1000 hours to 2000 hours exposure time. But, the bending strength tended to decrease after 4000 hours exposure time. In this test, initial values of bending strengths were higher than the others. The reason there was a difference in the test results was due to differences between the support conditions in the bending test. The initial value therefore was shown as a reference value. Figure 4 and Figure 5 show the relationship between bending strength and displacement at the flange part and web part, respectively.

Table 2 Bending strength of flanges

Testing time	Outer surface of the flange		Inner surface of the flange		Average
Initial values	614	621	443	407	521
1000hr.	600	636	407	414	514
2000hr.	650	564	421	429	516
4000hr.	586	571	414	493	516

(Unit: N/mm^2)

Table 3 Bending strength of webs

Testing time	1	2	3	4	Average
Initial values	(344)	(311)	(311)	(356)	(331)
1000hr.	207	229	200	229	216
2000hr.	200	207	236	221	216
4000hr.	200	193	179	171	186

(Unit: N/mm^2)

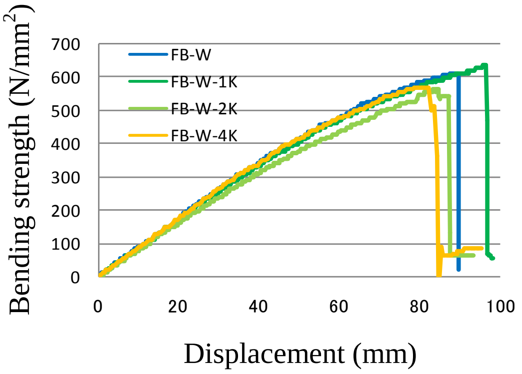

Figure 4 Bending strength vs. displacement (flanges part)

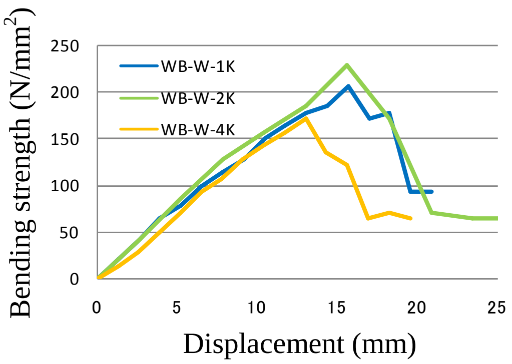

Figure 5 Bending strength vs. displacement (webs part)

3.2.2 Interlaminar shear test

Table 4 and Table 5 show interlaminar shear test results of flange part and web part, respectively. In this test, both painted specimens and unpainted specimens were examined. In the case of painted flange specimens, there were no changes in interlaminar shear strength, regardless of elapsed time. On the other hand, in the case of unpainted flange specimens, interlaminar shear strength tended to decrease slightly in accordance with the elapsed time. In the case of painted web specimens, as with the flange portion, there were no changes in interlaminar shear strength, regardless of elapsed time. On the other hand, in the case of unpainted web specimens, interlaminar shear strength tended to decrease slightly in accordance with the elapsed time. From the above results, the painting on the specimens had a protective effect against the accelerated weathering test.

Figure 6 shows the relationship between accelerated weathering test time and the interlaminar shear strength ratio (interlaminar shear strengths/initial values). According to the Figure 6, the strength of the unpainted specimens tended to decrease slightly in accordance with the elapsed time compared with the strength of the painted specimens.

Table 4 Interlaminar shear strength of flanges

Testing time	1	2	3	4	Average
Initial values (Unpainted)	32.9	32.9	34.3	32.1	33.0
1000hr.	33.9	34.0	33.0	32.9	33.5
2000hr.	31.1	29.7	26.9	30.0	30.2
4000hr.	29.7	30.7	30.3	29.8	30.1
Initial values (Painted)	33.6	32.2	31.8	33.2	32.7
1000hr.	30.7	34.0	33.0	31.8	32.4
2000hr.	28.4	31.6	29.0	30.8	30.0
4000hr.	30.7	33.1	31.5	30.4	31.4

(Unit: N/mm^2)

Table 5 Interlaminar shear strength of webs

Testing time	1	2	3	4	Average
Initial values (Unpainted)	35.1	35.7	35.0	33.8	34.9
1000hr.	33.0	35.8	32.1	33.1	33.5
2000hr.	33.4	30.2	30.5	34.6	32.2
4000hr.	33.3	26.8	32.5	29.9	30.6
Initial values (Painted)	33.8	35.7	33.3	35.7	34.6
1000hr.	34.2	35.6	31.7	32.0	33.4
2000hr.	33.4	33.3	35.6	34.2	34.1
4000hr.	35.0	35.5	32.9	34.2	34.4

(Unit: N/mm^2)

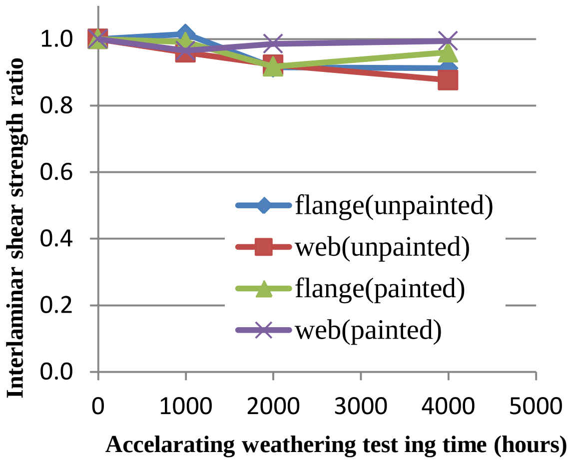

Figure 6 Interlaminate shear strength ratio vs. accelerating weathering test time

3.3 Water immersion test

3.3.1 Bending test

Table 6 and Table 7 show bending test results of flange part and web part, respectively. The load was applied to the outer surface of the flange and also applied to the inner surface of the flange. According to test results, bending strength in the case of outer surface of the flange was greater than that in the case of inner surface of the flange. The reason is on the outer surface of the flange part was rich in carbon fibers. There were no significant changes in the bending strength up to 12 months in the case of flange parts.

In the case of web parts, it seems to be no significant changes in the bending strength between 3 months to 12 months. The reason is because the coefficient of variation of bending test was extremely large. There seems to be no significant differences between painted specimen and unpainted specimen for the same reason.

In this test, initial values of bending strengths were higher than the others. The reason there was a difference in the test results was due to differences between the fulcrum conditions in the bending test. The initial value therefore was shown as a reference value.

Table 6 Bending strength of flanges

Testing time	Outer surface of the flange		Inner surface of the flange		Average
Initial values	614	621	443	407	521
3 months	621	593	450	443	527
6 months	600	600	479	557	559
12months	629	593	464	421	527

(Unit: N/mm^2)

Table 7 Bending strength of webs

Testing time	1	2	3	4	Average
Initial values	(344)	(311)	(311)	(356)	(331)
(Unpainted) 3 months	200	207	193	186	196
6 months	250	264	207	193	229
12 months	243	179	200	179	200
(Painted) 3 months	207	229	221	207	216
6 months	207	207	200	193	229
12 months	186	186	164	200	184

(Unit: N/mm^2)

3.3.2 Interlaminar shear test

Table 8 and Table 9 show interlaminar shear test results of flange part and web part, respectively. In this test, both painted specimens and unpainted specimens were examined. In both cases of painted flange specimens and unpainted specimens, interlaminar shear strengths tended to decrease slightly in accordance with the elapsed time. In the case of painted web specimens, as with the flange portion, interlaminar shear strengths tended to decrease slightly in accordance with the elapsed time. Figure 7 shows the relationship between water immersion test time and the interlaminar shear strength ratio (interlaminar shear strengths/initial values). According to the Figure 7, interlaminar shear strengths of all cases tended to decrease slightly in accordance with the elapsed time and interlaminar shear strengths after one year were approximately 0.93 to 0.91 of the initial values. From the above results, the painting on the specimens has not a protective effect against the water immersion test.

Table 8 Interlaminar shear strength of flanges

Testing time	1	2	3	4	Average
Initial values (Unpainted)	32.9	32.9	34.3	32.1	33.0
3 months	33.9	32.1	31.4	34.4	32.9
6 months	32.9	30.6	31.1	30.0	31.1
12months	28.6	30.6	29.7	31.0	30.0
Initial values (Painted)	33.6	32.2	31.8	33.2	32.7
3 months	31.4	34.0	31.3	31.0	31.9
6 months	31.0	30.6	29.6	30.4	30.4
12months	31.1	30.7	31.0	29.2	30.5

(Unit: N/mm^2)

Table 9 Interlaminar shear strength of webs

Testing time	1	2	3	4	Average
Initial values (Unpainted)	35.1	35.7	35.0	33.8	34.9
3 months	32.0	32.0	31.9	29.2	31.3
6 months	34.1	32.5	33.7	34.5	33.7
12months	34.1	29.6	32.4	33.6	32.4
Initial values (Painted)	33.8	35.7	33.3	35.7	34.6
3 months	31.8	31.7	29.7	31.9	31.3
6 months	34.1	35.5	34.0	31.9	33.9
12months	30.6	33.0	31.5	33.0	32.0

(Unit: N/mm^2)

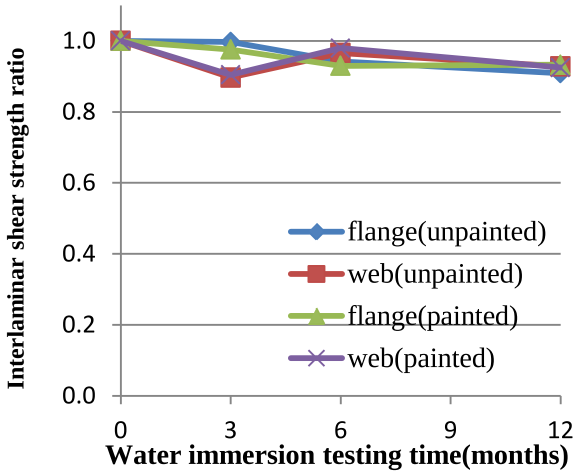

Figure 7 Interlaminate shear strength ratio vs. water immersion test time

3.4 Natural exposure test

Figure 6 shows test specimens that are an ongoing exposure test. The photo on the left was the state immediately after installation, photo on the right was the state almost after three and a half years. According to visual observation, in the case of HFRP unpainted, discoloration has been begun, the fibers on the surface have been observed. The reason is due to the fact that the resin has started to fall off. On the other hand, in the case of HFRP painted, a significant change has not been observed.

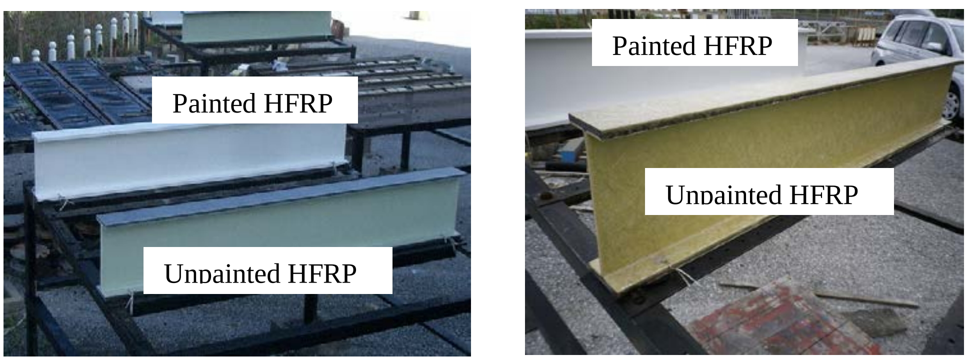

Figure 6 Test specimens under exposure test

4 CONCLUSIONS

Accelerated weathering test for 4000 hours and water immersion test at 40 degree for 12 months for the HFRP, that were mainly made of pultruded GFRP and had carbon fibre layers in the flanges, were carried out and its durability were evaluated by the bending test and the interlaminar shear test. The findings of this study are as follows:

1) There were no significant changes in the bending strengths both in accelerated weathering test of 4000 hours and in water immersion test at 40 degree of 12 months.
2) The interlaminar shear strengths tended to decrease slightly in accordance with the elapsed time in accelerated weathering test and in water immersion test as well. Although the interlaminar shear strengths decreased about 10% compared with initial values, the HFRP materials still had a good durability.
3) The protective effect of painting against degradation of mechanical properties was observed in the accelerated weathering test. On the other hand, the protective effect of painting was not observed clearly in the water immersion test.

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