Durability of CFRP Sheet Reinforcement through Exposure Tests

by I. Nishizaki, P. Labossière, and B. Sarsaniuc

Synopsis: Over the last few years, the use of composite materials has become an increasingly popular method of repairing and strengthening ageing civil engineering structures. However, despite the efficiency and attractiveness of this technique, its market progression has been impaired by the relative lack of knowledge on the long-term behavior of the FRP materials themselves and, by extension, on the behavior of the structures strengthened with such products. The authors are conducting a 10-year exposure test program on FRP products, and this paper provides midway results from the first 5 years of exposure data. There was no significant change in the tensile strength of the CFRP laminates after a 5-year exposure, however in-plane shear strength showed a slight decrease. Bending strength of matrix resin also decreased in the early exposure stage. The results suggest a reduction of the bonding properties between carbon fibers and resin.

Keywords: CFRP; concrete; durability; exposure test; rehabilitation; reinforcement; sheet

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INTRODUCTION

The use of composite materials is becoming an increasingly popular method of repairing and strengthening ageing civil engineering structures around the world. In Canada[1,2], most structures reinforced with fiber-reinforced polymers (FRPs) consist of transportation-related constructions, such as road bridges and parking garages. Despite the efficiency and attractiveness of this technique, its market progression has been impaired by factors such as the lack of design codes readily available to the practicing civil engineer, and by the limited knowledge on the long-term behavior of these new products. In Japan, this technology has spread and many concrete bridges are now reinforced with FRP products. While the issue of codes has been addressed in many countries with the recent publication of standards[3] and design manuals[4], the lack of durability data remains a problem that needs to be addressed in near future. In recognition of this need, the authors are conducting a 10-year exposure test program to evaluate the long-term durability of this technology[5]. This paper provides midway results from the exposure data of the first 5 years of the research program.

METHOD

Exposure sites

The exposure program described in this paper was undertaken in 1997. Series of identical specimens were fabricated and installed at three exposure sites exhibiting very different climatic conditions. Two sites are located in Japan and the third one in Canada, in order to study the effect of significantly different weather conditions on the mechanical properties of commercially-available products.

Specimens

Identical specimens are submitted to the natural conditions of the exposure sites for periods of 1, 3, 5, 7 and 10 years, beginning in 1997. The specimens at each exposure site include :

(a) one-ply carbon fiber sheets of products A and B, 150 mm x 380 mm, with fibers in the longitudinal direction. Products A and B are commercially available in Canada and Japan. After exposure, the sheets are tested in tension.

(b) three four-ply CFRP unidirectional laminates, 250 x 300 mm, with the fibers in the longitudinal direction. Plates are made with products A and B; a third plate, AC, is made of product A with a protective coating. After exposure, five specimens can be cut from the laminated plates for tensile testing. The size of the plates allows fabrication of additional specimens that can be used for viscoleastic testing, in bending or torsion.

(c) four-ply $(\pm 45°)_s$ CFRP laminates of products A, B and AC, 250 x 500 mm. Specimens are recovered from these plates for tensile testing.

(d) 160 x 170 mm plates of epoxy matrix, approximately 5 mm thick. These plates are made from each of the matrices usually employed with products A and B. The plates are large enough to cut out specimens for tensile tests, torsion tests and bending tests.

(e) standard concrete cylinders, 150 mm in diameter and 300 mm in length, confined with CFRP products A, B, and AC. Unconfined cylinders are also kept for reference. Uniaxial compression tests are to be performed after 3, 5 and 10 years of exposure.

CFRP laminates, matrix resin plates and carbon fiber sheets are exposed vertically facing south. All the specimens are exposed without any stress because we mainly focused in the appreciation of the materials to the strengthening of bridge piers. The typical appearance of the specimens at the exposure sites is illustrated in Figures 1, 2 and 3.

Testing of specimens

The following tests have been undertaken on the recovered specimens: visual observation of the general appearance of the CFRP laminates; tensile tests on carbon fiber sheets in accordance with ASTM Standard D 4018 *Standard Test Method for Tensile Properties of Fiber-Resin Composites*; tensile tests on FRP laminates in compliance with ASTM Standard D 3039 *Standard Test Method for Tensile Properties of Fiber-Resin Composites*; in-plane shear tests on FRP laminates in accordance with ASTM Standard D 3518M *Standard Practice for In-plane Shear-Strain Response of Unidirectional Polymer Matrix Composites*; bending tests on resin specimens in accordance with ISO 178 *Plastics - Determination of flexural properties*. An evaluation of the recovered resin and CFRP specimens are also sliced in 0.5mm thickness and its cross sections are observed transparently.

RESULTS

This paper shows selected results after 0, 1, 3 and 5 years of exposure. Figures 4 and 5 indicate the evolution of the tensile strength of the specimens made from the uniaxial CFRP plates. Each given data is the average of five tests. Some tensile strength data after one 1 or 3 years of exposure at Tsukuba and Okinawa show a slight decrease from initial data. However, the 5-year data are from 0.88 to 1.00 of the initial value, and statistical test result with initial data shows no significance (two-sided t-test, α=0.05) for both products. This result indicates that after a 5-year exposure, the CFRP sheets maintain a good tensile strength.

Figures 6 and 7 show the results for the in-plane shear strength of the specimens made with the $(\pm 45°)_s$ CFRP laminates. Each data is the average of five tests. The shear strength shows a slight reduction as it reaches 0.8 of the initial data after 5 years of exposure. The differences between three exposure sites were do not appear to be significant.

Tables 1 and 2 indicate the result of bending strength of resin plate. The data shown are the average of five tests. Bending strength shows a quick reduction in the early stage of exposure, for both products. The average value of the reduction ratio at 5^{th} year is 0.72 for product A and 0.55 for product B. This reduction is much more significant than the tensile strength and in-plane shear strength reduction reported above.

Figures 8 and 9 show photographs of the cross section of a matrix plate and of a CFRP laminate of product A, exposed to the weather conditions in Tsukuba. The surface of the 5-year exposed specimens is relatively uneven, however no evolution of deterioration from the surface to the interior of the specimen is observed.

Figures 10 and 11 show similar photographs for product B. Product B shows remarkable color change from blue to yellow with its deterioration evolution. The upper face of the specimen in Figure 10 was facing south during the 5-year exposure. The horizontal lines in Figure 10 show an approximate border delineating the damaged surface, and its depths are also indicated. The depth reaches more than 2mm after 5 years of exposure. On the other hand, Figure 11 shows that although the surface resin layer is deteriorated, the resin between carbon fiber layers is not deteriorated. This result shows that the resin between layers of CFRP is well protected by the carbon fibers. For the resign of product B, the color change does not correlate with the measured strength reduction. However, it indicates that some kind of chemical change occurred, hence it is suggested that similar undetected changes may have happened for product A because both are epoxy resin. These observations also suggests that the main reason behind the reduction of shear strength of CFRP laminates is not the reduction of the strength of matrix resin, but the reduction of bonding properties between carbon fibers and resin.

CONCLUSIONS

The outline of a project aimed at measuring the long-term properties of CFRP laminates was briefly presented. While the tensile strength of CFRP laminates did not change significantly over 5 years of exposure, the in-plane shear strength showed a slight decrease. Bending strength of matrix resin decreased in early exposure stage. The result suggests the reduction of bonding properties between carbon fibers and resin.

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Table 1 Bending strength of the resin plate (Product A)

(unit: MPa)

	Sherbrooke	Tsukuba	Okinawa	Average	Ratio
Initial	96.1	96.1	96.1	96.1	1.00
1 year	94.7	58.6	56.7	70.0	0.73
3 years	69.6	86.1	81.2	79.0	0.82
5 years	75.9	50.6	81.6	69.4	0.72

Table 2 Bending strength of the Resin plate (Product B)

(unit: MPa)

	Sherbrooke	Tsukuba	Okinawa	Average	Ratio
Initial	106.6	106.6	106.6	106.6	1.00
1 year	61.9	74.8	70.3	69.0	0.65
3 years	55.3	65.8	58.5	59.9	0.56
5 years	59.0	63.8	51.5	58.1	0.55

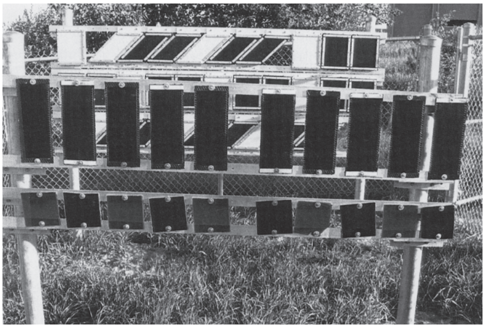

Figure 1 Exposure test in Sherbrooke

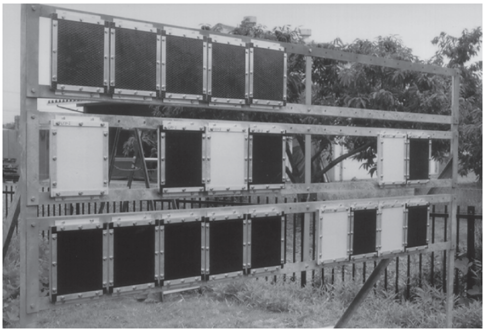

Figure 2 Exposure test in Tsukuba

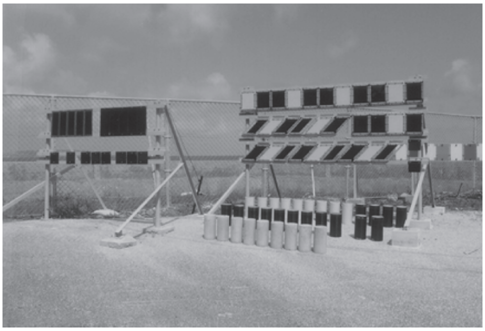

Figure 3 Exposure test in Okinawa

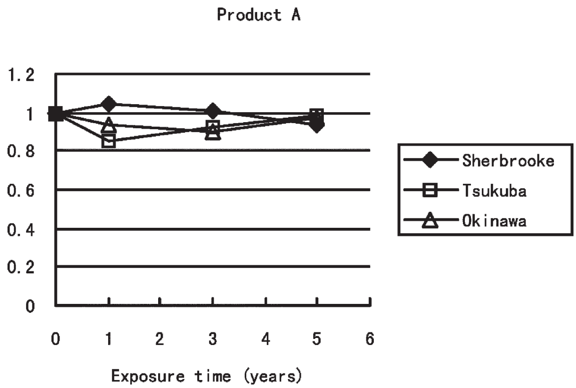

Figure 4 Tensile strength of Product A

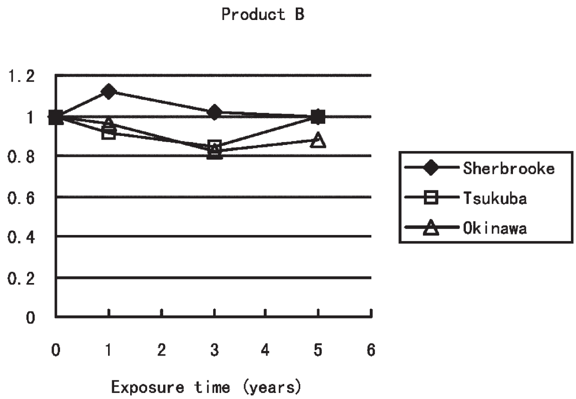

Figure 5 Tensile strength of Product B

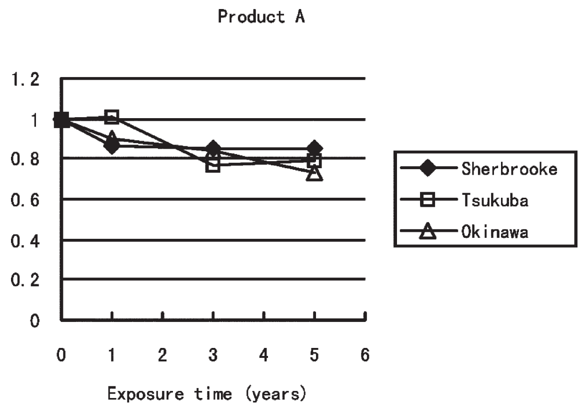

Figure 6 In-plane shear strength of Product A

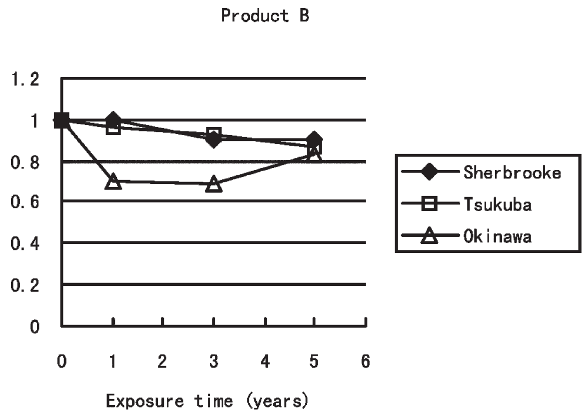

Figure 7 In-plane shear strength of Product B

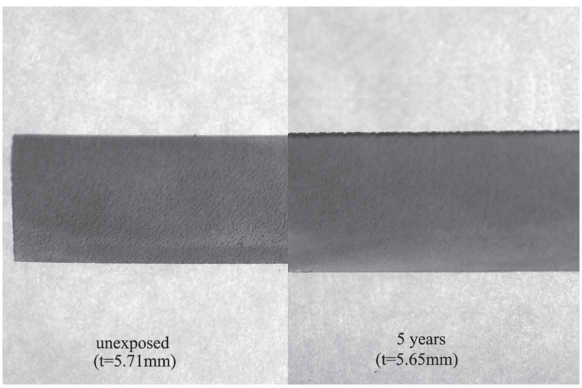

Figure 8 Observation of the cross section of Resin (product A)

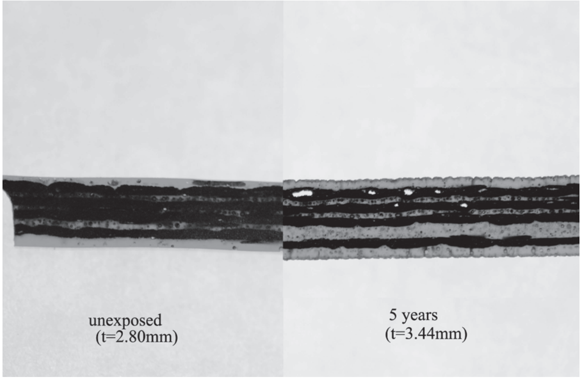

Figure 9 Observation of the cross section of CFRP (product A)

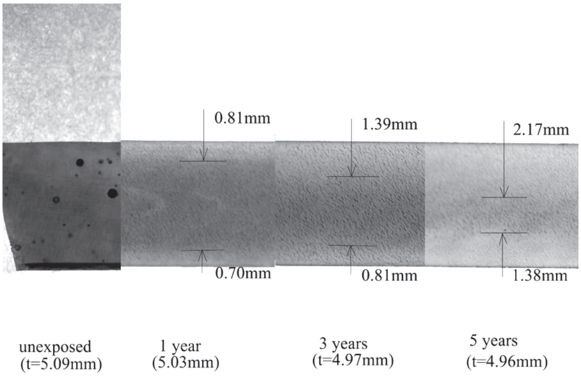

Figure 10 Observation of the cross section of Resin (product B)

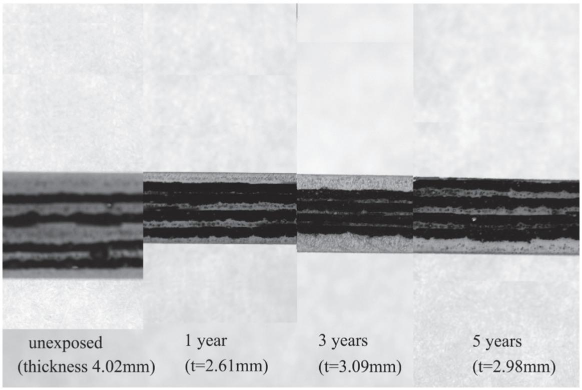

Figure 11 Observation of the cross section of CFRP (product B)