Reliability Evaluation Technologies for Carbon Fiber Reinforced Plastics (CFRP)

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Abstract

When applying high-strength and light mass Carbon Fiber Reinforced Plastics (CFRP) to products, a long-term heat exposure test is indispensable. In order to predict long-term characteristic changes under a reliability test where a chemical reaction is caused at a high temperature, we conducted a long-term accelerated thermal exposure test. For this testing, we used a one-directional CFRP flat plate to measure its tensile strength after exposure to high temperatures of 160℃, 170℃, and 180℃ for 1000 hours and 2000 hours. The test result indicated that a material of fiber direction angle 0° showed no change in strength up to 2000 hours, while materials of fiber direction angles 15°, 45°, and 90° showed strength degradation after 1000 hours. After the lapse of further hours, however, there was almost no change in strength of these materials. Such a test result implies that the one-directional CFRP gives rise to strength deterioration of resin or fiber/resin interface under conditions of high-temperatures at a comparatively early stage of exposure.

1 Preface

Since Carbon Fiber Reinforced Plastics (CFRP) can create high mechanical strength and light mass, they are used as structural members for aircraft and automobiles. When applying the CFRP to structural members, however, it is necessary to carry out prediction of long-term characteristic changes. In fact, there have been many prediction reports in regard to long-term characteristic changes due to physical factors such as material fatigue and creep(1)(2). Since the CFRP is composed of carbon fiber and resin, however, it is indispensable to predict long-term characteristic changes causing chemical reactions due to temperatures and humidity under operating condition, in the same manner as general resin materials are examined. This paper introduces a result of the prediction of long-term strength characteristic changes in one-directional CFRP by means of a long-term accelerated thermal exposure test(3) that is generally applied to the evaluation of the life of resin materials.

2 Test Method

(1) Material used, a prepreg sheet (a fiber-state material impregnated with resin)

We made prepreg sheets (a fiber-state material impregnated with resin) by using T800 (made by Toray Industries, Inc.) which is carbon fiber and high-heat resistant resin of Tg approx. 200℃ for matrix resin.

(2) Test piece

A one-directional CFRP laminated plate was made by using a 9-layer prepreg sheet. This plate was processed to make up a one-directional CFRP test piece. **Table 1** shows conditions for test pieces and **Fig. 1** shows the definition of CFRP test piece direction angles.

(3) Long-term heat exposure test

For the long-term accelerated thermal exposure test, a test piece was put in an air-circulated thermostatic tank PVH-212 (made by ESPEC

Table 1 Conditions for the Test Piece

Conditions for test pieces used for testing this time are shown.

Item	Conditions
Fiber direction angle	0°・15°・45°・90°
Test piece size	W15 × T1.0 × L200 mm
Vf (Fiber content rate)	60%

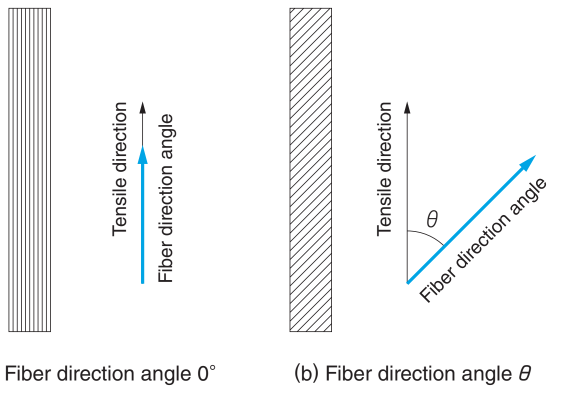

Fig. 1 Definition of CFRP Test Piece Direction Angles

Images to define direction angles are shown for CFRP test pieces.

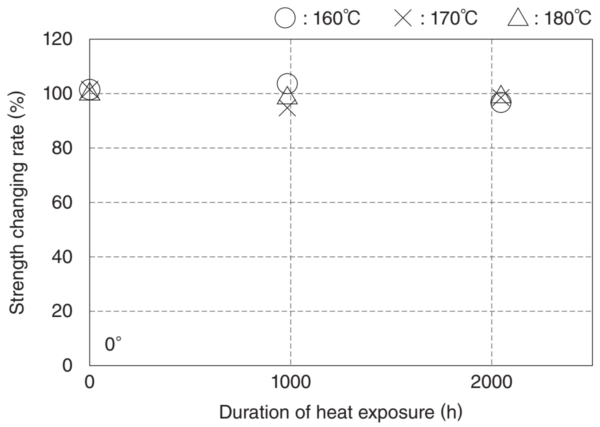

Fig. 2 Strength Changing Rate of One-Directional CFRP at Fiber Direction Angle 0°

The strength changing rate at the fiber direction angle of 0° is shown under the conditions of 0 hour (virgin), 1000 hours, and 2000 hours of heat exposure and at 160℃, 170℃, and 180℃, respectively.

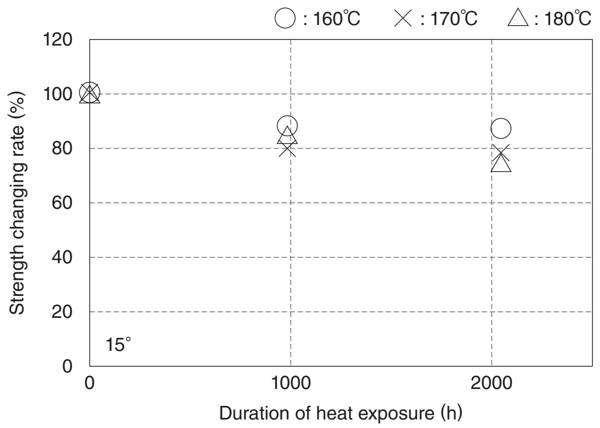

Fig. 3 Strength Changing Rate of One-Directional CFRP at Fiber Direction Angle 15°

The strength changing rate at the fiber direction angle of 15° is shown under the conditions of 0 hour (virgin), 1000 hours, and 2000 hours of heat exposure and at 160℃, 170℃, and 180℃, respectively.

CORP.) and was left to stand still. The test piece was taken out after 1000 hours and after 2000 hours. The exposure temperature was set at 160℃, 170℃, and 180℃, respectively. After exposure, the tensile test was carried out at a room temperature.

(4) Tensile test

Tensile test was carried out on test pieces, a virgin piece without a heat exposure test and another two pieces after a heat exposure test for 1000 hours and 2000 hours respectively. Based on the strength results on each case, the strength retention rate was determined. The tensile test was defined as n = 3 for the test pieces virgin and 2000 hours of exposure, and as n = 1 for 1000 hours of exposure. According to the ASTM D3039, this testing was carried out by using a universal testing machine (made by INSTRON, Inc.) and the AG-X plus (Shimadzu Corporation).

(5) Arrhenius law

If a characteristic value of a resin material attains a threshold level while it changes at Temperature T, Time t at the deterioration time is considered to conform to Expression (1) of the Arrhenius law, given Time t is lifetime.

$$t = Ae^{-E/RT} \quad \cdots\cdots (1)$$

$$\ln t = \ln A - E/RT \quad \cdots\cdots (2)$$

Where, A is a frequency factor, E is activation energy, and R is a gas constant. Based on changes in strength characteristics of respective exposure temperatures, we tried to predict long-term changes in material strength corresponding to the practical environmental temperature of the one-directional CFRP.

3 Result and Discussion

3.1 Strength Retention Rate of a One-Directional CFRP after Long-Term Accelerated Thermal Exposure

Fig. 2 to Fig. 5 show Tensile Strength σ at each exposure temperature and each fiber direction angle. In order to examine characteristic changes from an early stage of testing, the strength retention rate at each direction angle is shown on the assumption that the virgin tensile breakdown strength is 100%.

For the CFRP at the fiber direction angle of 0°,

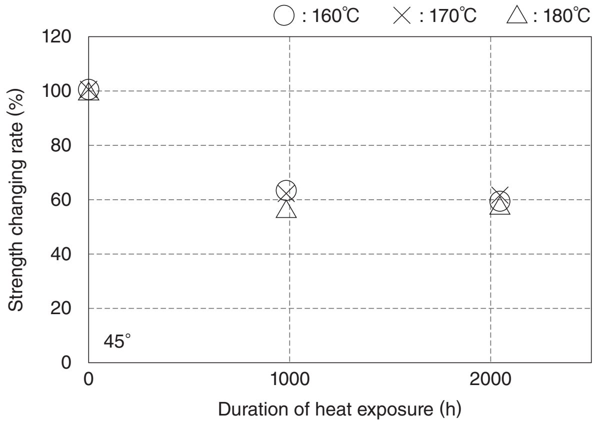

Fig. 4 **Strength Changing Rate of One-Directional CFRP at Fiber Direction Angle 45°**

The strength changing rate at the fiber direction angle of 45° is shown under the conditions of 0 hour (virgin), 1000 hours, and 2000 hours of heat exposure and at 160℃, 170℃, and 180℃, respectively.

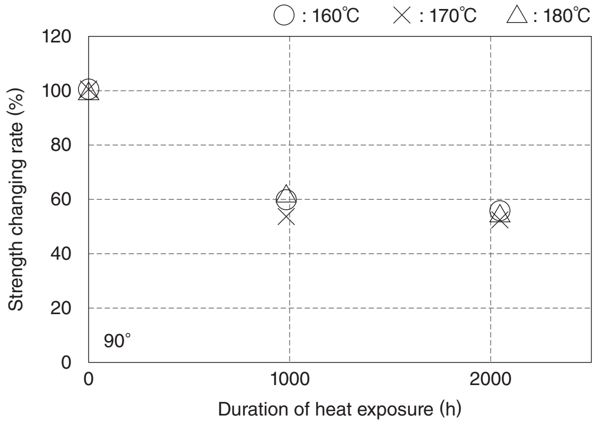

Fig. 5 **Strength Changing Rate of One-Directional CFRP at Fiber Direction Angle 90°**

The strength changing rate at the fiber direction angle of 90° is shown under the conditions of 0 hour (virgin), 1000 hours, and 2000 hours of heat exposure and at 160℃, 170℃, and 180℃, respectively.

almost no changes in strength could be seen at any exposure temperature during the 2000 hours (**Fig. 2**). When the fiber direction angle is 0°, it is considered that the fiber strength is kept predominant and changes in strength are never caused by heat exposure for the duration up to 2000 hours. Accordingly, in order to predict long-term strength changes at a fiber direction angle 0° in terms of the Arrhenius law, it is necessary to continue heat exposure for more time. It should be noted that in the case of fiber direction angles at 15°, 45°, and 90°, a reduction of strength was observed after heat exposure for 1000 hours (**Fig. 3** to **Fig. 5**). In addition,

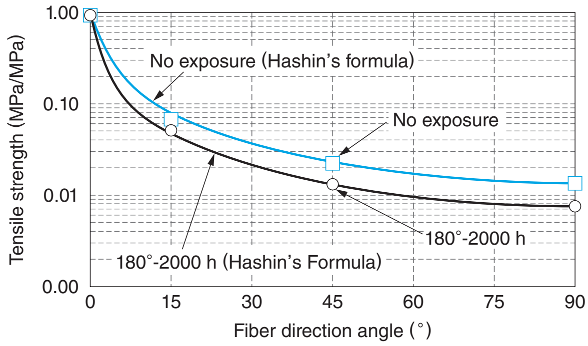

Fig. 6 **Tensile Strength of One-Directional CFRP at Various Fiber Direction Angles**

The test result of "deterioration-free items" and "deteriorated items after 2000 hours of exposure at 180℃" at various fiber direction angles is shown. In addition, shown are the "applied prediction lines by the Hashin's destruction law where values of deterioration-free" and the "applied prediction lines by the Hashin's destruction law where values of deteriorated items after 2000 hours of exposure at 180℃."

the strength retention rate tended to lower as the fiber direction angle was greater. Judging from this result, we can surmise that the reduction of one-directional CFRP strength due to heat exposure is influenced by the reduction of strength in the resin or fiber/resin interface.

At the fiber direction angle of 15°, 45°, and 90°, there was strength reduction after 1000 hours of heat exposure. There was also almost no change in strength due to the exposure temperatures nor the lapse of time from 1000 hours to 2000 hours. This test result implies that the reduction of strength in resin or fiber/resin interface due to heat exposure continues rapidly from a considerably early stage to 1000 hours. After that, such a tendency slows down.

In order to predict long-term strength changes by the Arrhenius law at respective fiber direction angles of 15°, 45°, and 90° based on the aforementioned result, it is necessary to perform an evaluation of long-term heat exposure in the same manner as for the evaluation of strength changes at an early stage of heat exposure and at the fiber direction angle of 0°.

3.2 Estimation of One-Directional CFRP Strength at Each Fiber Direction Angle

To accomplish a more detailed strength prediction on the one-directional CFRP, we made strength presumption by the aid of Hashin's formula[(4)] that is used for characteristic prediction on anisotropic materials. For example, **Fig. 6** shows the tensile strength of one-directional CFRP at various fiber direction angles for virgin test pieces and those after exposure at 180℃ and for 2000 hours. Strength at each fiber direction angle is shown on the assumption that the tensile strength at the fiber direction angle of 0° is 1. Based on this result, the strength of one-directional CFRP has been estimated under the conditions of 2000 hours of exposure at 180℃ and at the fiber direction angle of 0° to 90°.

4 Postscript

After 1000 hours and 2000 hours of the thermal exposure test at 160℃, 170℃, and 180℃, respectively, the tensile strength test was carried out on one-directional CFRP test pieces. The test results indicate that there is no change in strength up to 2000 hours of thermal exposure at the fiber direction angle of 0°, while there is reduction of strength after 1000 hours of thermal exposure at a fiber direction angle of 15°, 45°, or 90°. After further lapse of time, however, there is almost no reduction of strength in terms of time. For one-directional CFRP materials, these test results suggest that resin or fiber/resin interface can give rise to reduction of strength at a considerably early stage of thermal exposure. For the prediction of long-term strength characteristics by applying the Arrhenius law, we consider it necessary to carry out an evaluation of characteristics before 1000 hours and after 2000 hours of thermal exposure test.

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