EVALUATION OF MODE Ⅰ, Ⅱ INTERLAMINAR FRACTURE TOUGHNESS FOR A FILAMENT WOUND CARBON/EPOXY COMPOSITE UNDER LOW AND HIGH TEMPERATURE

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Abstract

This study was conducted to evaluate the temperature effect of Mode Ⅰ, Ⅱ interlaminar fracture toughness for filament wound Carbon/Epoxy composite applied to pressure vessel. Mode Ⅰ was evaluated by specimens of Double Cantilever Beam(DCB), and Mode Ⅱ was tested by specimens of Mixed Mode Bending(MMB). Specimens were manufactured by filament wound method used to make pressure vessel with diameter of 1,700mm and had three different types of helical part(±10°), dome part(±27°) and bonded part(±10°/±27°) with FM73 adhesive, respectively. Temperature environment was -30 ℃, room temperature and 60 ℃. It was found that fracture toughness of Mode Ⅰ, toughness had a high value in the order of -30 ℃, 60 ℃ and room temperature, and fracture toughness of Mode Ⅱ was high according to priority of room temperature, -30 ℃ and 60 ℃.

1. Introduction

Composites known as a lightweight material with high specific stiffness and strength have been widely used in various applications in mechanical fields such as ground transportation, ships and aerospace. Recently, composites have been increasingly used in aerospace for the airplanes, rockets and missile in order to increase flight distance by lightening the weight for flight. Resins in a chemical matrix are greatly influenced by temperature. Therefore, the mechanical properties of composites must be evaluated at both low and high temperatures, before such materials can be used in the aerospace field where there is frequent and variable exposure to low and high temperatures. Composites have different mechanical properties depending on the manufacturing method. Studies of interlaminar fracture toughness of laminate composites made by the autoclave method have been conducted, but studies on composites made by filament winding method have not been reported[1, 2, 3]. This study is intended to evaluate interlaminar fracture toughness of composites made by the filament winding method. The temperatures for the evaluation were -30℃, 20℃ and 60℃.

2. Test specimens

The specimens had diameters of 1,700mm and were manufactured with T700 grade carbon fiber. The manufacturing method was the same as composite pressure vessel, in which the winding angles were the helical part, the dome part and the adhesive part. At adhesive part helical part and dome part were assembled with FM73 adhesive. Figure 1 shows the configuration of a composite pressure vessel.

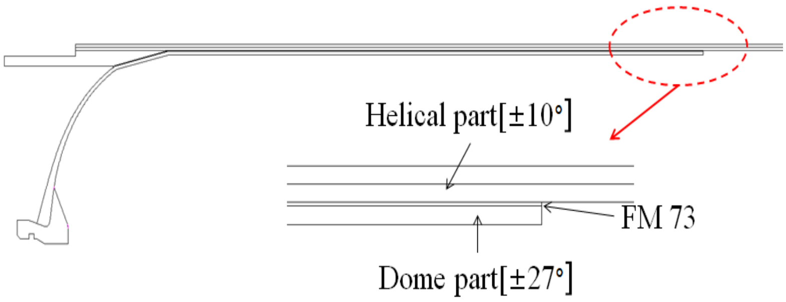


Figure 1. Configuration of a composite pressure vessel

The shape of specimens was based on ASTM D5528 and ASTM D6671[4, 5]. The width was 25mm, the total length 150mm, and the initial crack length 50mm which was made with releasing film. The specimens of Mode I and the hinges were bonded with epoxy adhesive. The specimens of Mode II of the adhesive part were cut to a total length of 125mm because it was difficult to induce crack on middle surface. Figure 2 shows the manufacturing process of the specimens. Figure 3 (a) shows the shape of Mode I specimen and (b) shows the shape of Mode II specimen.

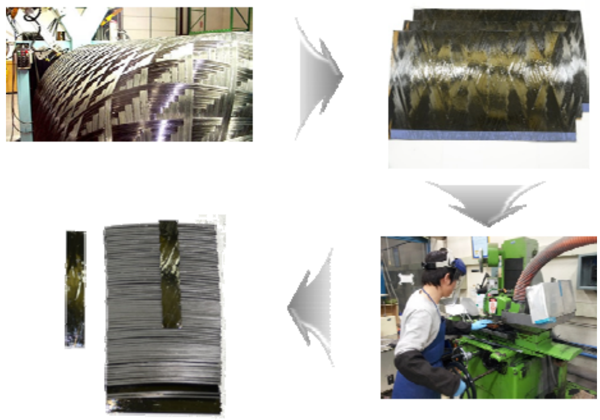


Figure 2. Manufacturing process of specimens

(a) (b)

Figure 3. Shape of specimens (a) Mode I (b) Mode II

3. Test instrument and method

An Instron 5848 Micro Tester was used in this test and atmospheres of -30℃, 20℃ and 60℃ was made by an environment chamber. The test speed was 1mm/min, the speed was based on ASTM. Figure 4 (a) shows the Instron 5848 Micro Tester and (b) shows the environment chamber.

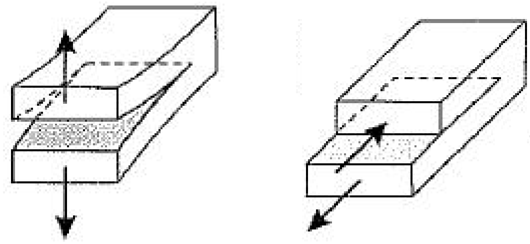
(a) (b)

Figure 4. Test instrument (a) Instron 5848 Micro Tester (b) Environment chamber

4. Evaluation of interlaminar fracture toughness

4.1. Test method for interlaminar fracture toughness

In the Mode I test, crack opening displacement increased when a load was applied at the end of the specimen and a crack grew following the initial crack. For the Mode II test, the load was applied as in a 3-point bending test and a crack grew following the initial crack. Figure 5 (a) gives a sketch of Mode I test and (b) gives a sketch of Mode II test.



(a) (b)

Figure 5. Sketch of Mode test (a) Mode I (b) Mode II

The interlaminar fracture toughness was calculated as Eq. (1), where, a is the delamination length, B is the specimen width, C is the specimen compliance and P is the applied load.

$$G_I = \frac{P^2}{2B}\frac{dC}{da} \tag{1}$$

The interlaminar fracture toughness of Mode II was calculated as Eq. (2) Eq. (2) was applied simple beam theory. Where, a_0 is the initial crack length, L is the half span length and δ is the load-point displacement.

$$G_{II} = \frac{9a^2 P\delta}{2B(2L^3 + 3a_0^3)} \quad (2)$$

4.2.Result of interlaminar fracture toughness test

All results of the Mode I interlaminar fracture toughness test, concerning winding angle and temperature, were verified and displayed a tendency of high level of interlaminar fracture toughness in the order of low temperature, room temperature and high temperature. The specimens of ±10°/FM73/±27° with high strength FM73 bonding layer had the highest interlaminar fracture toughness, while ±10° had the lowest. Figure 6 shows the result of Mode I test.

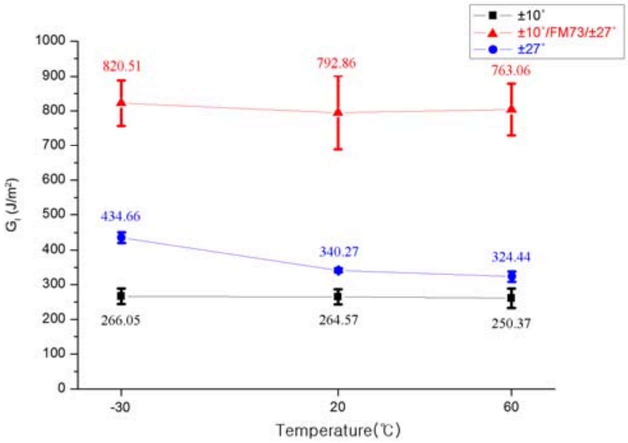


Figure 6. Test result of Mode I interlaminar fracture toughness for specimens

The Mode II interlaminar fracture toughness test also showed the interlaminar fracture toughness to be in the order of low temperature, room temperature and high temperature. Just as the tendencies demonstrated in Mode I, ±10°/FM73/±27° had the highest interlaminar fracture toughness and ±10° had the lowest. Figure 7 shows the result of Mode II test.

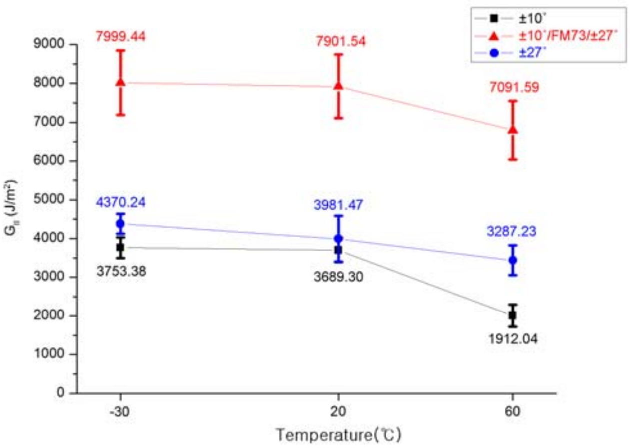


Figure 7. Test result of Mode II interlaminar fracture toughness for specimens

Both results from Mode I and II revealed that as the temperature rose, the interlaminar fracture toughness decreased. This occurred due to the difference in hardness of the resin, which is relevant to the temperature. The ±10°/FM73/±27° had the highest interlaminar fracture toughness because of existence of a bonding layer with FM73, which has a higher strength than resin. As the winding angle increased the interlaminar fracture toughness increased, showing similar tendencies to that of a laminate composite[6, 7].

5. Conclusion

In this paper, the Mode I and II interlaminar fracture toughness of the carbon/epoxy composite constructed in the low and high temperature environment of the filament winding construction method was evaluated. The three types of specimens were ±10°, ±10°/FM73/±27° and ±27° and evaluated under the following three conditions: -30℃, 20℃ and 60℃. The tests revealed the following results.

(1) The interlaminar fracture toughness of the composite of the filament winding showed a difference in interlaminar fracture toughness depending on the winding angle and temperature.
(2) In both Mode I and II, the following tendencies were observed: a decrease in interlaminar fracture toughness due to a rise in temperature and an increase in interlaminar fracture toughness as the winding angle increased.
(3) The specimens of ±10°/FM73/±27°, containing the FM73 bonding later, had the highest interlaminar fracture toughness without regard to the winding angle, due to influence of FM73.

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