Effects of Number of Plies on Mechanical Behaviors of Thin Glass Fiber Reinforced Plastic Composites

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1. Introduction

Glass fiber reinforced plastic (GFRP) composites, which are commonly used as dielectric layers in printed circuit boards, contain only one or two layers of fabric so that the thickness is getting thinner to under 100 μm. Accordingly, their mechanical behaviors have become more complex with structural complexity and heterogeneity. Therefore, it is necessary to understand the complex mechanisms of the mechanical behaviors of the composites under various loading conditions to design the appropriate physical properties. For instance, there is a clear structural difference in existence of a matrix layer between the fabric layers between the single-ply and the two-ply composites while a number of plies do not affect for the mechanical behavior for relatively thick composites [1].

In this study, mechanical behaviors of the single-ply and the two-ply composites were measured and analyzed based on digital image correlation (DIC) method. First, tensile moduli of composites at room temperature to 260 °C were measured. During uniaxial tensile test, accurate strain of stretched specimen was measured using sprayed speckle patterns by image correlation method. Also, bending test was conducted to determine the mechanically weak positions of the composites. To analyze the results of mechanical tests, cross-sectional strain distribution was visualized by micro-DIC method [2]. Different mechanical behaviors of the single-ply and the two-ply composites were validated by quasi-static strain mapping under tensile and bent condition.

2. Experimental

Three types of the GFRP composites were used in our study as described in Table 1. Each type of the composites was classified with the number of plies and fiber contents. Volume fraction of the composites were measured by the matrix burn-off method based on ASTM [3]. Matrix was burnt off at 650 °C in a muffle furnace, and remained particles were removed by sonication for 10 seconds.

Uniaxial tensile tests were progressed using a universal testing machine (Shimazdu AGS-X STD). Commercial ceramic spray was used to form the speckle patterns on the surface of the specimens for accurate measurement of strain. The loading velocity was 7.5 μm/s and the specimen dimension was as follows; grip distance = 40 mm, total distance = 70 mm and width = 10 mm.

Cross-sectional strain distributions of the thin GFRP composites were mapped by micro-DIC method to analyze the differences between the single-ply and the two-ply composites. Specimens were ground and polished to obtain the smooth cross-sections using 3 types of abrasive paper; P1200, P2400, and P4000. The cross-sections of specimens were ground for 4 minutes using P1200 and P2400, and 8 minutes using P4000 in order. Micro-patterns for the image correlation method were generated using a commercial water-based diamond polishing suspension. The suspension solution was spin-coated on the cross-sections of the specimens for 40 seconds at 500 rpm. Then, remained solvent was fast-dried at 140 °C for 4 minutes. DIC analysis was progressed with the images captured by an optical microscope (Keyence VHX-1000) by commercial software (ARAMIS professional, GOM mbH, Germany). High temperature environment for quasi-static strain mapping was created using a glycerol platform, which has a high boiling point of 290 °C.

	Thickness	# of ply	Fiber contents
Type A	101 μm	2	21.7±0.2 %
Type B	25 μm	1	18.5±0.1 %
Type C	67 μm	2	35.9±0.5 %

Table 1 Description of the three types of the GFRP composites

3. Results and discussion

Fig. 1 shows the results of the uniaxial tensile tests of the GFRP composites at room temperature to 260 °C. At room temperature, tensile modulus of the type C composites was distinctly higher than other types because modulus depends on the volume fraction of the glass fiber, which is much stiffer than the matrix layer. However, at high temperature, modulus of the type B decreased linearly depending on temperature while other types suffered significant modulus drop around 150 °C. Thus, the single-ply composites were stiffer than the two-ply composites at high temperature for same volume fraction of the glass fiber.

Fig. 2 shows the locations of fracture at the surfaces of the single-ply and the two-ply composites under a harsh single bending with the radius of 3 mm. Fracture occurred regularly in warp direction, but the appearance was different between the single-ply and the two-ply composites. The single-ply composites showed two cracks for each cycle while the two-ply composites showed one crack for each cycle.

Then, the cross-sectional strain distributions were analyzed using micro-DIC method to figure out the different mechanisms of tensile and bending behavior between the single-ply and the two-ply composites. Softening effect of the matrix between two plies of glass fiber at high temperature was determined.

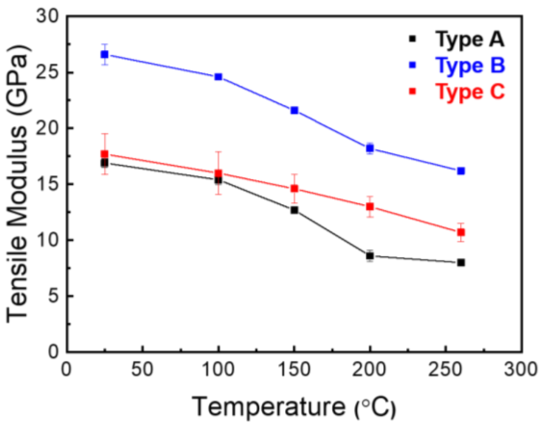

Fig.1 Tensile modulus of the three types of the GFRP composites at different temperatures 25 to 260 °C

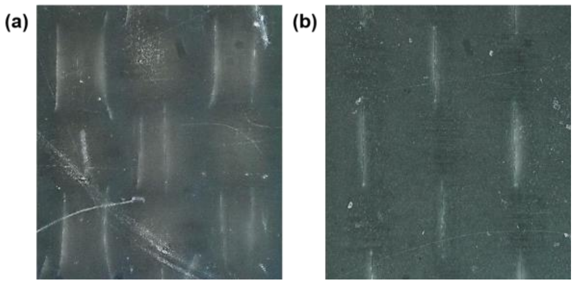

Fig.2 Top surface views of the GFRP composites after single bending with radius of 3 mm
(a) single-ply (b) two-ply

4. Conclusions

Mechanical behaviors of the single-ply and the two-ply GFRP composites were analyzed and compared. Tensile moduli of composites at various temperatures were measured by uniaxial tensile tests. Difference in decreasing rate of tensile modulus depending on temperature between the single-ply and the two-ply composites was measured. Also, the locations of the cracks were observed under bending loading condition. The mechanisms of different mechanical behaviors depending on the number of plies were determined by micro-DIC method. Thermal softening of matrix layer between the glass fabric and stress concentration under bending loading condition were visualized by cross-sectional strain mapping. This study is expected to suggest a guide line for designing the properties of the thin GFRP composites for appropriate applications.

References

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