Mechanical Properties of Carbon Fiber Braided Composites with CNT

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SUMMARY

The effect of incorporation of Carbon nano fiber (CNF) on the mechanical properties of the braided composites was investigated. The tensile test and the in-situ observation were performed for evaluation of the mechanical property and the crack initiation and propagation.

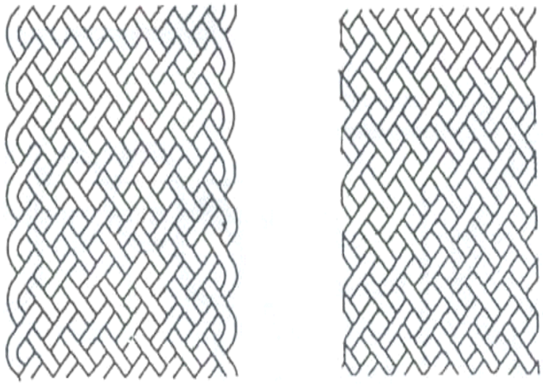
Keywords: Carbon nano fiber, Braided composite, Mechanical performance

Introduction

Various forms of textile composites, which were reinforced with woven, knitted and braided fabric preforms, have been considered through much of modern composites history. Among them, braided fabrics can provide continuous fiber arrangement in any direction and can bear the axial loads with all the bundles. The braided fabrics can realize thick, hollow, solid or irregular cross sections and can be easily manufactured in a 2D and a 3D form; for example flat bar, tube, square rod, I-shaped beam and so on, in an automated manner. Thus, braided fabrics have been expected to be an excellent preforms for the reinforcements of composite materials [1-5].

One of the features of the braided fabric is the continuity of all fiber bundles diagonally oriented. Therefore the braided fabric reinforced composites have superior mechanical properties. Other characteristic is capability of changing the braiding angle. Also the fiber bundle called the Middle End Fiber (MEF) can be inserted into the braiding fibers along the longitudinal direction [6]. Moreover, various kinds of braiding fiber and MEF with different mechanical properties can be used simultaneously. From these features, mechanical properties of braided composites can be designed according to the requirement.
The schematic drawing of braided fabric is shown in Fig. 1(a). For the braided composite, continuity of fiber bundle is significant factor. For example, flat braided fabric without the continuity of fiber bundle at the edge, can be assumed to be bias woven fabric. Braided composite, in which each side of the specimen was cut, is called Cut specimen as shown in Fig.1(b), and braided composite with continuous fiber bundle is called Non-cut specimen as shown in Fig.1(a). In the previous research, the effect of continuity of fiber bundle at the edge on mechanical properties of braided composite was investigated [7]. The tensile strength of Non-cut specimen was higher than Cut

specimen. The dominant fracture aspect was multiple fractures of filaments, so that fiber strength was exerted by the fiber continuity. In Cut specimen, the initial fracture was interfacial fracture around the fiber bundles at the crossing part between fiber bundles.



(a) (b)

Fig.1. Schematic drawing of flat braided fabric.
(a) Non-cut (b) Cut

Meanwhile, for polymer composite, the addition of micro-scale fillers to polymers often increases its strength, but decreases the toughness since the fillers or agglomerates may induce stress concentration, which initiates cracks and make them become larger than the critical crack size that causes failure. Therefore, it is a good way to reinforce the polymers with nano-particles in order to increase the fracture toughness and the mechanical properties of the polymers because well-dispersed nano-particles are much smaller than the critical crack size to initiate failure. Thus, they provide an avenue for simultaneously toughening and strengthening polymers [8]. Nano-particle reinforced polymer composites have been widely studied and some researchers already reported the improvement of the fracture toughness of polymers. Carbon Nano Tube (CNT) are graphitic sheets rolled into seamless tubes, are a new nanoscale materials discovered by Iijima [9]. Various methods have been proposed for evaluation of the properties for carbon nanotubes and currently receiving much attention due to their interesting properties. CNT have shown a high potential to improve the mechanical properties of polymers as well as electrical properties [10, 11, 12]. Gojny et al. [13] reported that double walled CNT (DWCNT) could increase both tensile strength and fracture toughness. Florian et al. [14] studied the influence of different carbon nanotubes on the tensile properties as well as fracture toughness and explained the contribution of nano-mechanical mechanisms to enhancement of the fracture toughness. In textile composite, interlaminar strength was improved by using CNT in plain weave composites [15].

In this study, the effect of Vapor grown carbon nano fiber (VGCF)[16] on the mechanical properties and fracture behavior of the braided composites was investigated. Braided composites with and without the fiber continuity were examined. Tensile test and the in-situ observation, Scanning Electron Microscope (SEM) observation were performed in order to investigate the effects of VGCF content on the fracture aspects after tensile test.

Specimens and experiments

Flat braided fabrics were fabricated by using Carbon fiber (HTS40: 7μm, 12000 fillaments, TOHO TENAX Co.,Ltd.). The tensile modulus and strength of HTS40 is 240GPa and 4200MPa. Epoxy resin (JER828: Japan Epoxy Resins Co.,Ltd.) was used as matrix resin, and vapor grown carbon fiber (VGCF^{TM} ; SHOWA DENKO) was used as carbon nano fibers. Diameter and length of the VGCF were 100~150 nm and 10~20 μm.

First, the braided fabric was braided using a flat braiding machine with 25-carrier and the braiding angle was 30 degree. Secondary, VGCF was added to the epoxy resin and the blended materials were stirred for 15 minutes by the mixer. VGCF contents were varied from 0, 1 and 2wt%. Braided fabrics were impregnated with the matrix resin with VGCF by vacuum assist. Braided fabrics impregnated with the matrix resin were molded by hand lay-up method. The curing and post curing conditions were 80C° for 3 hour and 120C° for 6 hour.

Two kinds of specimens were prepared. One was the normal braided specimen called "Non-cut specimen", and the other was "Cut specimen" in which each side of the Noncut specimen was cut. For the tensile tests, the specimens were cut in the length of 250 mm and the aluminum tabs of 50 mm in length were attached on the specimens, and the span length was 150 mm. The tensile tests were performed by using an Instron Universal Testing Instrument (Type 4206) and the cross head speed was 1 mm/min at room temperature. The strain value was obtained from a strain gauge attached on the center of the each specimen.

In-situ observation by means of replica method during the tensile test was conducted in order to examine the effect of VGCF on onset and progress of initial fracture at edge during tensile test. Fig.2 shows schematic drawing of replica observation method. This method is based on the chemical reaction for methyl acetate with acetyl cellulose. The procedure is as follows; previously, the edge of the specimen was polished in fine quality. The testing machine was periodically stopped and then, methyl acetate was applied onto the polished surface. At once, acetyl cellulose film was put on. As a result, the micro damage was replicated onto the film. After that, the micro damage initiation and propagation on the film was observed with optical microscopy. Moreover, the fracture surface after tensile test was observed by using SEM (S-4700; Hitachi Co..Ltd.).

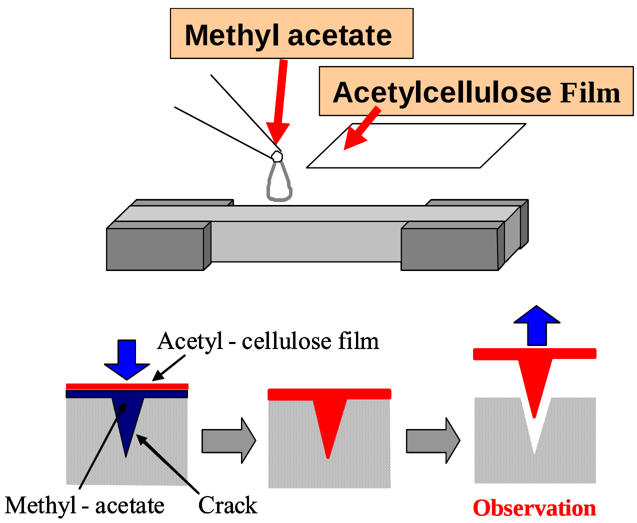


Fig.2 Replica method

Results

Fig.3 shows the stress-strain curves of the specimens. The stress was increased lineally and then stress-strain curves showed non-linear behavior regardless of continuity of braiding fiber bundle at the edge.

Relationship between tensile modulus and VGCF contents was shown in Fig.4. In spite of the continuity of fiber bundle at the edge, tensile moduli were constant in every specimen. Fig.5 shows relationship between tensile strength and VGCF contents for Non-cut and Cut specimens. The strength of the specimen was increased with increase in VGCF content regardless of the continuity of braiding fiber bundle at the edge. Especially, improvement ratio of Cut specimen with VGCF contents of 2wt% compared to that with 0wt% was 35%.

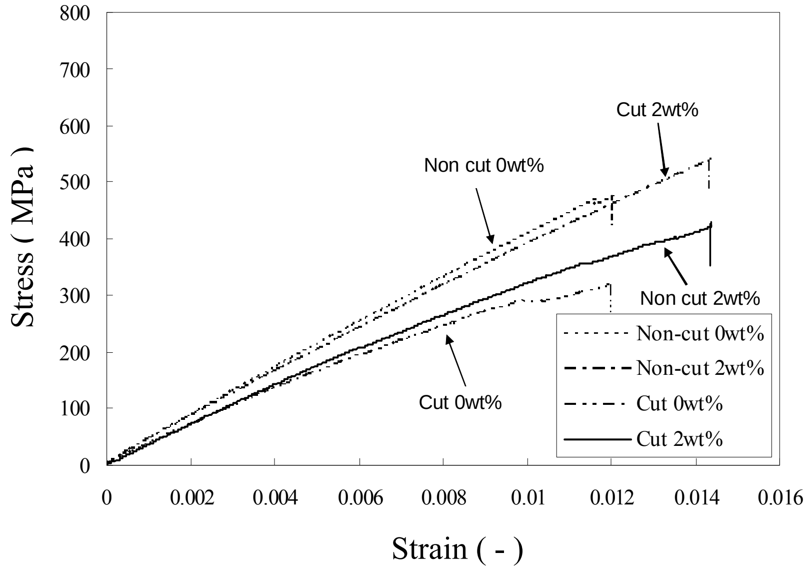


Fig.3 Stress-Strain curves from tensile test

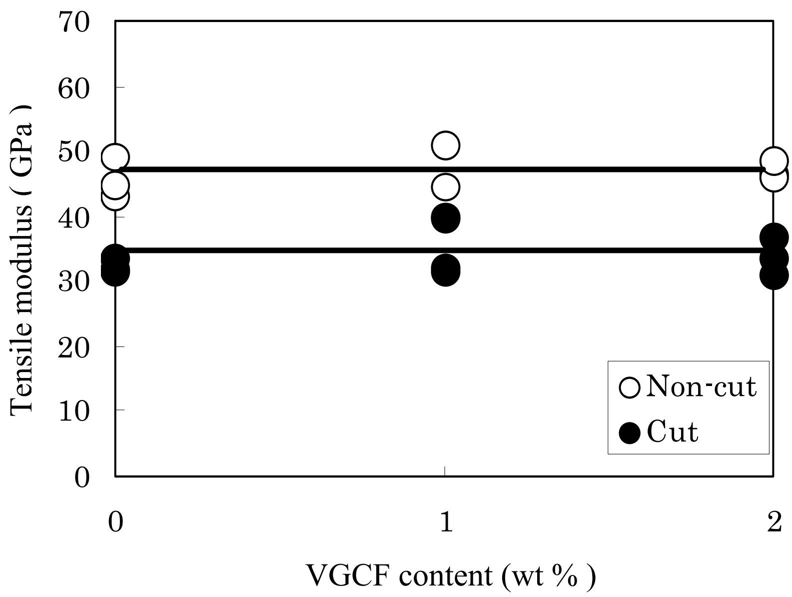


Fig.4 Tensile modulus of improvement with increasing VGCF content

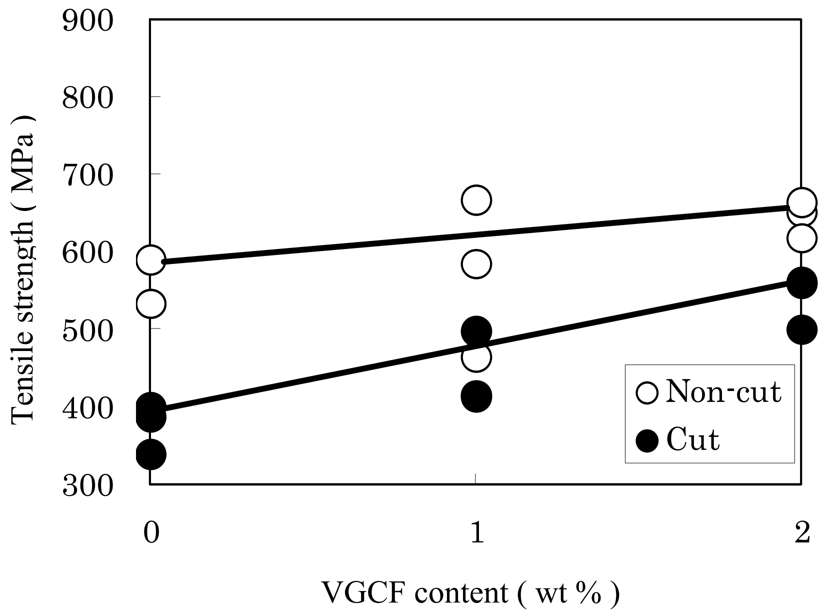


Fig.5 Tensile strength of improvement with increasing CNT content

Fig.6 shows appearance of fractured specimen after tensile test. The crack was propagated along braiding fiber bundle regardless of VGCF contents. In addition, especially for the Cut specimen, the pull-out of fiber bundles was observed at the fiber bundle crossing part of the edge. Incorporation of VGCF largely affected to the strength of the composite in the case of Cut specimen. As mentioned above, the initial fracture of Cut specimen is interfacial fracture between fiber bundle and the fracture is progressed around fiber bundle. Therefore, it was considered that the initiation and/or propagation of interfacial fracture between fiber bundles were restrained by the VGCF. Therefore, in-situ observation during the tensile test was conducted in order to examine onset and progress of initial fracture at edge.

Tensile test was stopped at arbitrary stress point at around 150MPa, 215MPa, 280MPa, in situ observation was performed. Fig.7(a) shows photograph of replicated film and the schematic drawing for the specimen with VGCF content of 0wt%. Initial crack was interfacial fracture between fiber bundles and occurred at 160 MPa. This crack was propagated between fiber bundles at 218MPa and other cracks occurred around other fiber bundles. Furthermore these cracks were propagated around fiber bundle at 274MPa. Fig.7(b) shows photograph and schematic drawing for the specimen with VGCF content of 2wt%. Any fractures were not observed at 137MPa and two cracks occurred between fiber bundles at 214MPa. Two cracks were propagated and connected at 296MPa. However, the crack was not propagated around fiber bundle and the progress of the crack was restrained compared with that of 0wt%.

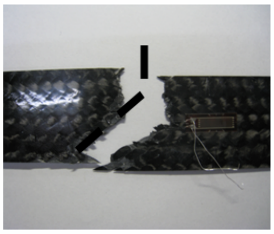
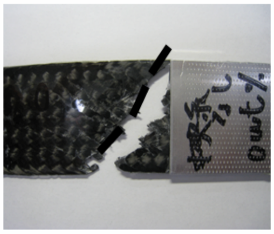
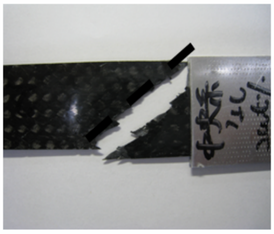
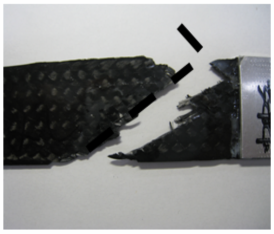
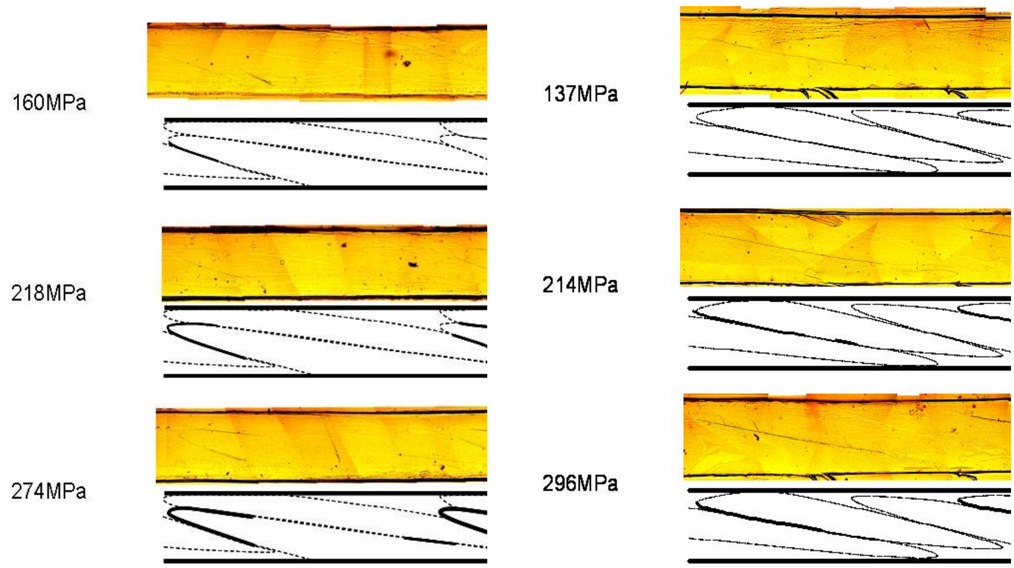
	Cut	Non cut
VGCF 0wt%		
VGCF 2wt%		

Fig.6. Fracture aspects of Specimen



(a) (b)

Fig.7. Replica observation for Cut specimen
(a) VGCF content 0 wt% (b) VGCF content 2 wt%

Figs. 8 (a) and (b) show photographs of SEM at fiber bundle crossing part at the edge of Cut specimen with 0wt% and 2wt%. It is found that the brittle crack propagation occurred in the case of 0wt%. On the other hand, pull–out of VGCF was observed at the specimen incorporated with VGCF of 2wt%. According to these results of Figs.7 and 8, crack propagation of interfacial fracture between fiber bundles was restrained by the pull-out of VGCF.

Despite the continuity of fiber bundle at the edge, tensile modulus was constant. It was considered that the modulus depended not on the VGCF content but on the braiding structure, in other words, VGCF was not effective on it because of the much lower volume fraction compared to the reinforcements. Tensile strength of braided composites was improved by incorporating VGCF. The strength of the specimen was increased with increase in VGCF content regardless of the continuity of braiding fiber bundle at the edge. Interfacial delamination at the fiber bundle crossing part was inhibited by VGCF in cut specimen. For the Non-cut specimen, the multiple fractures of filaments were generated. The improvement effects of VGCF on the mechanical properties were higher in Cut specimen with interfacial fracture between fiber bundles compared with Non-cut specimen with multiple filament fracture.

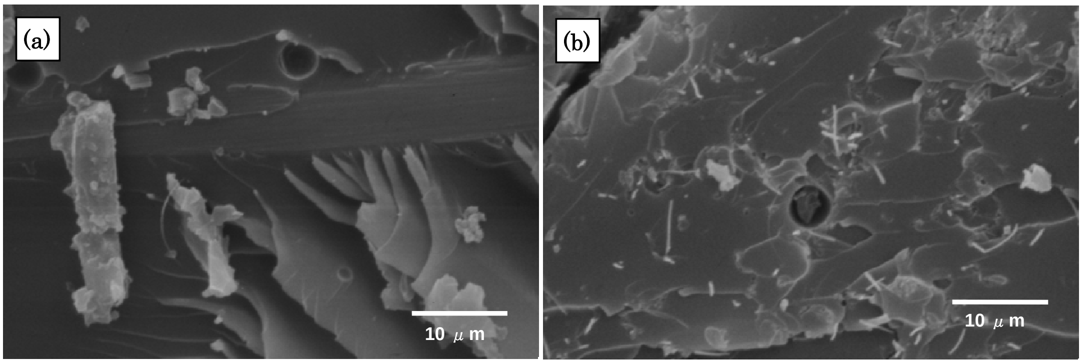


Fig.8. Photographs of SEM at fiber bundle crossing part at the edge
(a) 0 wt% (b) 2 wt%

In the case of Non-cut specimen, the multiple fractures of filaments were generated and this fracture was correspond with the fracture of filament in fiber bundle model. In this case, it is considered that incorporation of VGCF affected the property of the interphase inside of fiber bundle and contributed to the restrain of progress of multiple filament fractures. In the case of Cut-specimen, interfacial fracture between fiber bundles occurred and this fracture was correspond with the fracture of cross resin element in weaving structural model. In this case, the incorporation of VGCF restrained the progress of the interfacial fracture between fiber bundles. Consequently, the incorporation of VGCF was the most effective for the improvement of interfacial properties inside and around fiber bundle.

Conclusion

The effect of incorporating VGCF on the mechanical properties and fracture behavior was investigated on carbon fiber reinforced braided composites with different fracture aspect. Braided composites with and without the continuity of fiber bundle were examined in this study. In spite of the continuity of fiber bundle at the edge, tensile moduli were constant in each specimen. Tensile strength of specimen was increased with increasing VGCF content, especially improvement ratio of Cut specimen with

VGCF contents of 2wt% compared to that with 0wt% was 35%. By in-situ observation and SEM observation, the micro damage propagation between fiber bundles was restrained by pull-out of VGCF. VGCF was the most effective on the interfacial properties inside and around the fiber bundles because of the inhibition of the crack propagation.

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