MECHANICAL PROPERTY OF CARBON NANOTUBE COMPOSITE USING SPUN YARN REINFORCEMENT

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1. Introduction

Carbon fibers, which have high specific strength and stiffness, are the main stream of reinforcement of composites used for light-weight structural components. Carbon nanotubes (CNT) are expected to exceed the mechanical properties of carbon fibers. Growing continuous CNT, however, has limitation so far, and thus it is difficult to use CNT as structural components. In order to resolve the problem, spinning of CNTs have been investigated [1-2]. However, the basic mechanical properties of CNT spun yarn have not been clarified yet.

In this study, tensile tests of CNT spun yarn were conducted and stress-strain curves were obtained to investigate the mechanical behavior of CNT spun yarn for future applications of CNT spun yarn for reinforcement of composite. Fracture mechanism of CNT spun yarn was discussed from SEM observation of facture portions. Then, composite specimens using CNT spun yarns were fabricated, and tensile tests were conducted. Stress-strain curves of CNT composites were obtained, and SEM observation of facture surface was conducted.

2. Materials

Multi walled carbon nanotube (MWNT) was prepared by Inoue et al [3]. MWNTs were grown on a quartz glass plate with chemical vapor deposition (CM-CVD method), and drawn into yarn by pulling out. MWNTs were contracted by Van der Waals' force during drawing process. Figure 1 shows a schematic of drawing a MWNT spun yarn and Fig.2 shows a SEM image of a MWNT spun yarn. The MWNT length was around 1.2mm and the diameter was 50 nm. The yarn diameter was about 45 μm. Twist angle α is defined as the angle of CNT of the outmost layer to the longitudinal direction of a spun yarn. Room temperature cured epoxy was used for composite specimens.

3. Tensile Test of MWNT Spun Yarn

Specimens for tensile tests were prepared as shown in Fig.3. The both ends of spun yarn were glued onto a paper mount with a slight tensile force. The gauge length was 40mm. After the specimen was gripped, the paper mount was cut and tensile tests were conducted at 1mm/min of the cross head speed. Displacement was measured by a noncontact extensometer. Figure 4 shows typical stress-strain curves of tensile tests. Each lot showed different stress-strain behavior because the twist angle had strong influence on it.

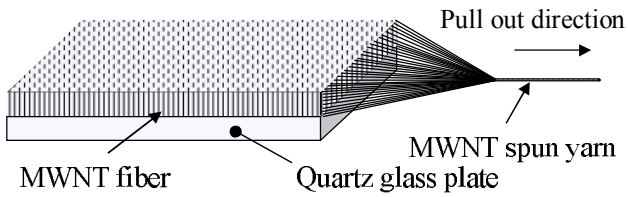


Fig.1. MWNT spun yarn

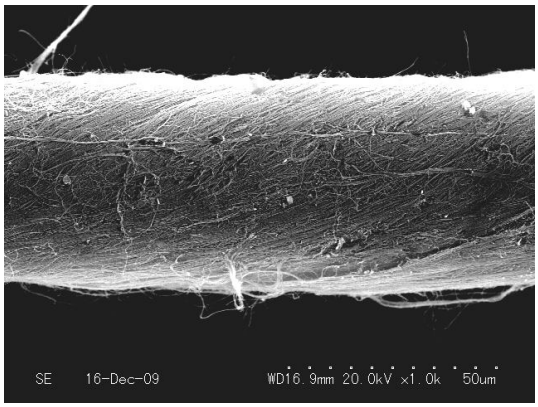


Fig.2. SEM image of MWNT spun yarn

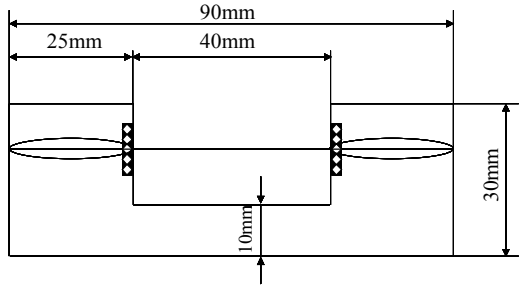


Fig.3. Tensile specimen of MWNT spun yarn

A yarn with α=21° had high strength but small elongation, whereas a yarn with α=40° had low strength but large elongation. A yarn with α=25° showed intermediate behavior between with α=21° and 40°. Figures 5 and 6 show the variations of Young's modulus and tensile strength with twist angle. They strongly depended on the twist angle. They had the maximum values around 20°~25°. The greater the angle of MWNT spun yarn, the more decrease strength and Young's modulus.

Figure 6 shows a SEM image of a fracture portion of a MWNT spun yarn. Similar fracture morphology was observed for each specimen.

In the fracture portion, pullouts of MWNT fibers and fiber bundles were observed. This implies that slippage among MWNT fibers is probably the reason of the tensile fracture.

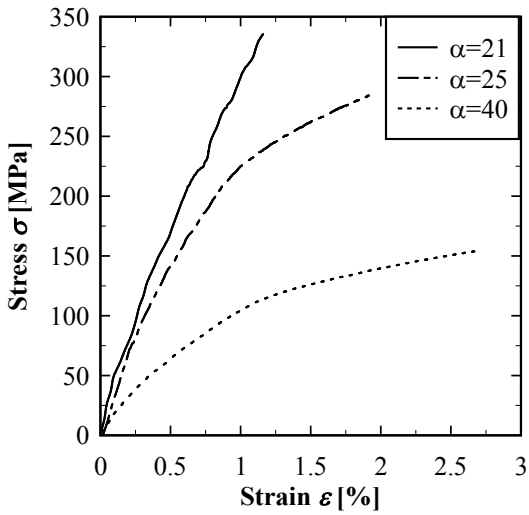
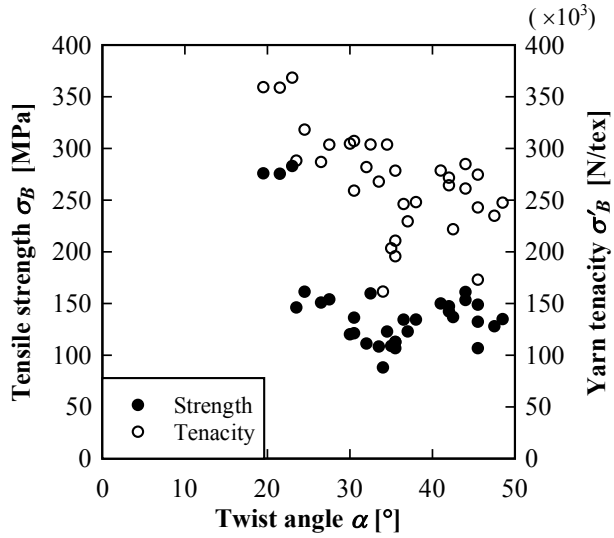
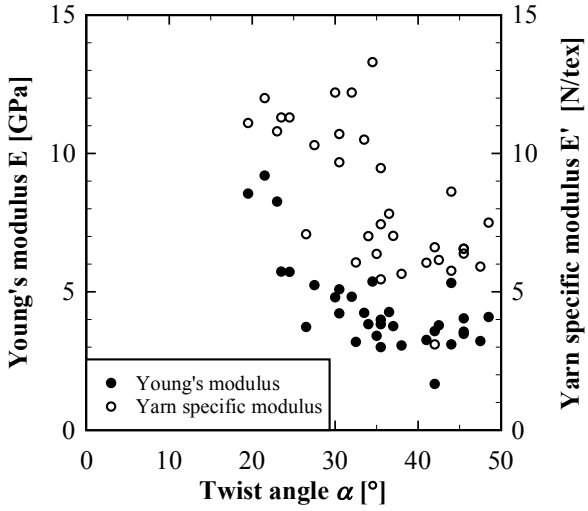


Fig.4. Typical stress-strain curves of MWNT spun yarn



(a) Tensile strength



(b) Young's modulus

Fig.5. Effect of twist angle on mechanical properties

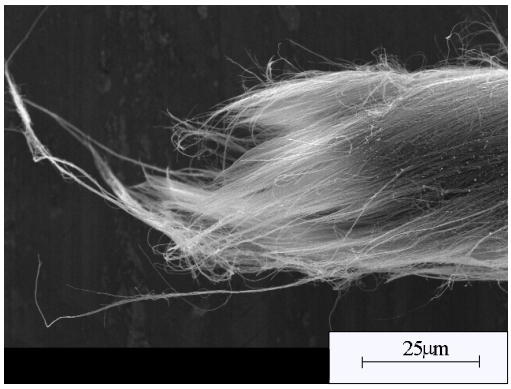


Fig.6. SEM image of fracture portion of MWNT spun yarn

3. Tensile Test of MWNTs Composite

Composite specimens using MWNT spun yarns were fabricated by using pultrusion [4] as shown in Fig.7. The epoxy matrix was cured at room temperature for 24 hour and postcured at 80°C for 3 hour. Figure 8 was an optical micro scope image of the composite cross section. The volume content of MWNT spun yarn was about 8%.

Specimens for tensile tests were prepared by glueing both ends on a paper mount (Fig.9). The specimen shape was the same as that for spun yarn, but the gauge length was changed from 40mm to 15mm.

The tensile test conditions were the same as those for spun yarn. Figure 10 shows the stress-strain curves of epoxy composites fabricated by using the pultrusion method. The stress-strain curves of the composite were almost linear whereas that of spun yarn was nonlinear. Maximum strength and Young's modulus were 194MPa and 22GPa, respectively. Average strength of MWNT composite was 167MPa. The average strength was about three times as high as the resin strength, and Young's modulus was about ten times as high as the resin modulus.

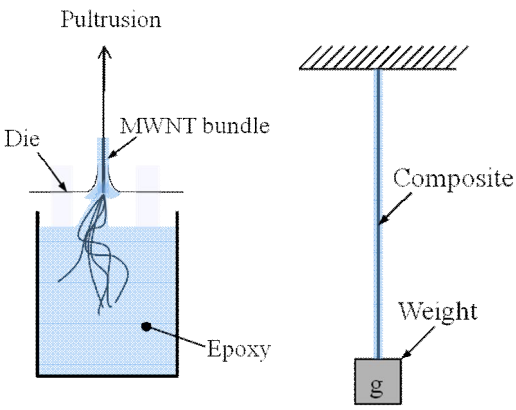


Fig.7. Pultrusion process of MWNT spun yarn composite

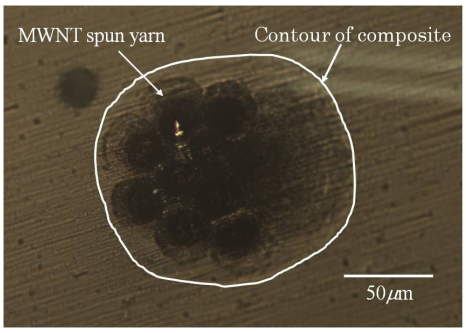


Fig.8. Optical microscopic image of cross section of MWNT spun yarn

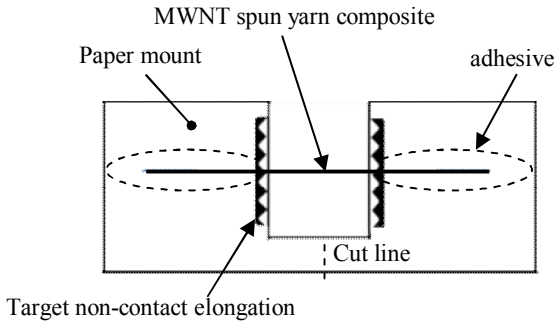


Fig.9. Specimen of MWNT spun yarn composite

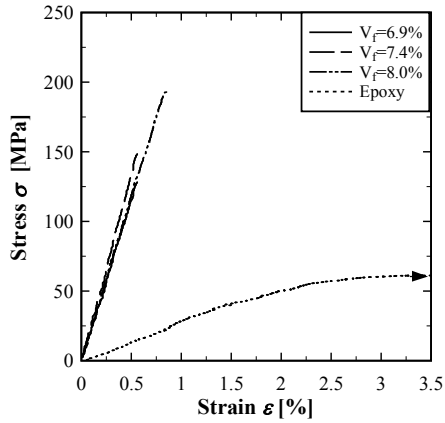


Fig.10. Stress-strain curves of MWNT composite and epoxy

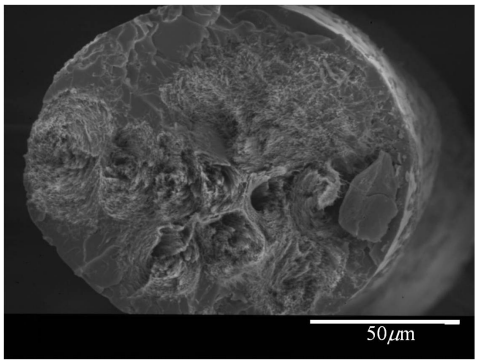


Fig.11. SEM image of fracture surface of MWNT spun yarn

5. Conclusions

Tensile tests of MWNT spun yarn and MWNT composite were conducted. As a result, it was found that tensile strength and Young's modulus of spun yarn were influenced by twist angle. Tensile strength

and Young's modulus of spun yarn showed maximum values around 20°, and fracture of MWNT spun yarn is probably dominated by slippage among MWNTs.

MWNT spun yarn reinforcement effectively enhanced the mechanical properties of epoxy. Average strength was about three times as high as the resin strength, and Young's modulus was about ten times as high as the resin modulus.

References

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