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FRICTION AND WEAR PROPERTIES OF HIGH MODULUS PITCH-BASED CARBON FIBER REINFORCED PLASTICS WITH SIC NANOPARTICLES

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Summary: *The flexural, friction, and wear properties of high modulus pitch-based* Carbon fiber reinforced polymer matrix composites *(CFRP) with 130 nm β-SiC-nanoparticles were investigated. The flexural strengths of the nanoparticle filled CFRP were higher than that of unfilled CFRP. Especially, the large enhancement was observed in 2 vol% nanoparticle filled CFRP. The matrix peeling and wear scar was not observed for 2 vol% SiC-nanoparticle filled CFRP. The friction coefficient of 2 vol% nanoparticle filled CFRP was the higher than that of unfilled and 1, 5, and 10 vol% nanoparticle filled CFRP.*

1 INTRODUCTION

Carbon fiber reinforced polymer matrix composites (CFRP) show great potential for application in structural components, and it have become a dominant material in the aerospace, automotive and sporting goods industries.

Extensive research and development in CFRP led to remarkable improvements in the performance of the system, which exhibits excellent in-plane properties.

Another critical drawback in structural composites is the presence of matrix-rich regions formed in the surfaces and gaps between the laminates. These regions are difficult to reinforce/functionalize with traditional micro-scale reinforcement. Various nano-scale materials have been explored for selective reinforcement of matrix-rich regions. There is a possibility that nano-structure does not damage the fiber and is less impact on the original fiber volume fractions. The result that were different from the case of adding the material of micro-scale can be expected.

The surface of CFRP have resin layer, so friction and wear properties are not good because it is soft. To apply the CFRP in sliding parts, it is necessary to reinforce the surfaces.

There is a lot of papers investigated the friction and wear properties of the polymer material with nanoparticle. However, there is little papers examined the friction and wear properties of CFRP with nanoparticle. The silicon carbide (SiC) is widely used as sliding member because the new Mohs hardness scale of SiC is 13, which makes it the third hardest element on earth behind diamond (15) and boron carbide (14).

By adding SiC-nanoparticle in a CFRP to form hybrid composites may create materials possessing the new functional properties of the CFRP.

In the present work, the flexural, friction, and wear properties of high modulus pitch-based CFRP with SiC-nanoparticle were investigated.

2 EXPERIMENTAL PROCEDURE

2.1 Material

CFRP laminate was produced using cyanate matrix based unidirectional CFRP prepreg material K13C/EX-1515 (fiber: K13C, matrix: EX-1515). K13C carbon fiber was a high modulus pitch-based carbon fiber (Tensile modulus: 900 GPa, Tensile strength: 3.8 GPa, Density: 2.20 g/cm^3). K13C/EX-1515 prepreg was supplied from TenCate Advanced Composites USA, Inc.

The 130 nm β-SiC-nanoparticle (Average particle diameter: 130 nm, Density: 3.22 g/cm^3) was used as reinforcement. The SiC-nanoparticle was supplied by Nanostructured & Amorphous Materials, Inc. The shape of SiC-nanoparticle is spherical.

2.2 Molding procedure of CFRP

The prepreg sheets were cut into the appropriate size and fiber orientation (lengthwise 300 mm - crosswise 150 mm (fiber direction is lengthwise direction)).

Appropriate amounts of SiC-nanoparticle were added into the both sides of prepreg sheets using a dry method. Four different volume fractions of SiC nanoparticle (V_S = 1, 2, 5 and 10 vol%) were used for the inclusion.

The sheets were placed on the vacuum molding board. CFRP laminates were made using hand lay-up and vacuum bagging technique (no bleeder). Fiber orientation and layers of the composites were set to $[0]_8$. The nominal fiber volume fractions of the composites were 53.1 vol%. The prepreg sheets were pressed in 0.490 MPa and cured in 120 °C for 4 h and 135 °C for 2 h (heating rate was 1 °C/min) by an autoclave (Ashida Mfg. Co., Ltd., ACA Series) in the laboratory.

2.3 Flexural test

The rectangular straight side flexural test specimen with dimensions of 100 mm in length, 10 mm in width and ≈1 mm in thickness was used.

Flexural tests of the CFRP specimens were performed using a universal testing machine (Shimadzu, Autograph AG-series) with a load cell of 100kN and conducted under three-point bending (the diameter of support point 6mm and the diameter of load point 12mm) with a span length, L of 50 mm. The crosshead speed of 5 mm/min was applied.

2.4 Friction and wear test

The rectangular straight side friction and wear test specimen with dimensions of 30 mm in length, 30 mm in width and ≈1 mm in thickness was used.

Friction and wear tests of CFRP specimens were performed using a ball-on-disk type friction tester (RHESCA, Friction player, FPR-2000). Ball material is SUJ-2 (Bearing steel abrasion ball, spherical diameter: 4.76 mm). Ball was cleaned by acetone. The specimens was cleaned by hexane, then they were kept for more than 24 hours in the laboratory environment at room temperature. The load of 1 N, linear velocity of 4 cm/s, radius of gyration of 4 mm, rotational speed of 95.5 rpm, rev up of 3000 rotation, and sliding distance of 75 mm (30min) were used as the test condition. Five specimens were tested for all CFRP specimens.

3 RESULTS AND DISCUSSION

3.1 Flexural property

Figure 1 shows typical load-deflection (P-δ) curve for nanoparticle filled and unfilled CFRP specimen. The load was almost linearly proportional to the deflection at the beginning of loading (linear deformation region). Subsequently, a transition from linear to nonlinear deformation occurred with an increase in applied load until the load reached its maximum. Afterwards, the load decreased gradually with an increase in deflection until fracture occurred.

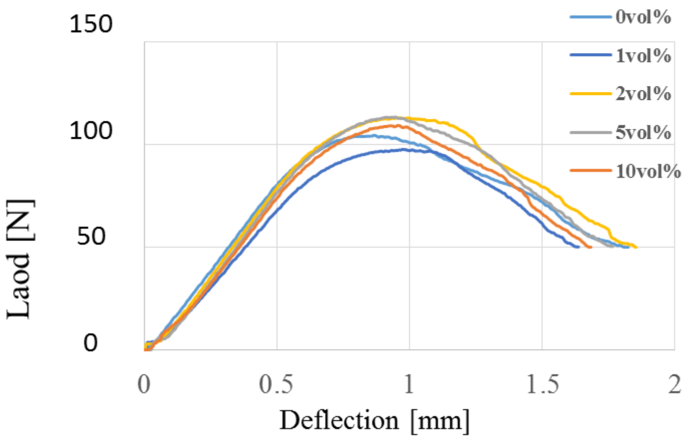


Figure 1 Load-deflection curve for nanoparticle filled and unfilled CFRP specimen.

The flexural stress, σ for the three point bending test was calculated using a simple beam theory equation given by

$$\sigma = \frac{3PL}{2bh^2} \tag{1}$$

where, P, b and h are the applied load, width and thickness of the CFRP specimens, respectively. The flexural strength, σ_f of the CFRP specimens are calculated using maximum load, P_{max}.

Figure 2 shows the relation between the flexural strength and the volume fraction of nanoparticle.

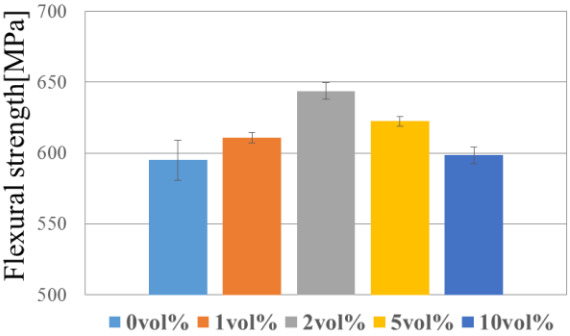


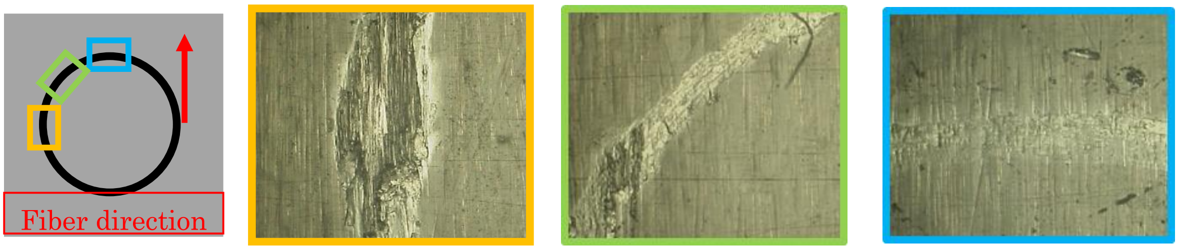
Figure 2 Flexural strength for nanoparticle filled and unfilled CFRP specimen.

For SiC nanoparticle filled CFRP specimens, the maximum flexural strength were observed around 2 vol% nanoparticle volume content, and the flexural strength decreased with increasing the volume fraction of nanoparticle.

This may lead to the generation of interlaminar crack for the nanoparticle filled and unfilled CFRP. For the 1, 5, and 10 vol% nanoparticle filled and unfilled (0 vol%) CFRP, the interlaminar crack was observed at the interface among layers. However, the interlaminar crack was not be observed for the 2 vol% nanoparticle filled CFRP. The interface strength of fiber/matrix might be improved.

3.2 Friction and wear property[1]

Figure 3 shows typical wear test results for the nanoparticle unfilled CFRP specimen (0 vol%). The sliding direction relative to fiber direction are (a) of 0 ˚, (b) of 45 ˚, and (c) of 90 ˚, respectively.



(a) 0 ˚ (b) 45 ˚ (c) 90 ˚

Figure 3 Typical wear test results for the nanoparticle unfilled CFRP specimen (0 vol%).

For nanoparticle unfilled CFRP specimen, it was observed that the wear form differed in 0 ˚, 45 ˚, and 90 ˚. For the 0 ˚ sliding direction, the matrix was peeled off, and then the fiber was exposed. For the 90 ˚ sliding direction, however, the wear scar was observed and the matrix peeling was not observed. The transitional region from the matrix peeling to the wear scar was observed for the 45 ˚ sliding direction. It found that the wear mode differ greatly by the sliding direction relative to fiber direction. The wear modes for 1, 5, and 10 vol% SiC-nanoparticle filled CFRP specimen were almost similar to those for unfilled CFRP specimen. For 2 vol% SiC-nanoparticle filled CFRP specimen, the matrix peeling and wear scar was not observed.

The wear resistance might be improved by adding SiC nanoparticle.

Figure 4 shows the coefficient of friction for nanoparticle filled and unfilled CFRP specimen.

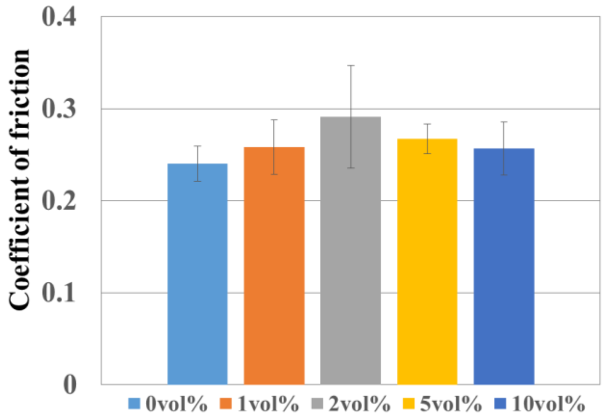


Figure 4 Coefficient of friction for nanoparticle filled and unfilled CFRP specimen.

The maximum coefficient of friction were observed around 2 vol% SiC-nanoparticle volume content, and the coefficient of friction decreased with increasing the volume fraction of nanoparticle.

4 CONCLISIONS

The flexural, friction, and wear tests of high modulus pitch-based CFRP with 130nm β-SiC-nanoparticle were performed. The results are briefly summarized.

(1) The maximum flexural strength were observed around 2 vol% SiC-nanoparticle volume content, and the flexural strength decreased with increasing the volume fraction of nanoparticle.

(2) The matrix peeling and wear scar was not observed for the 2 vol% SiC-nanoparticle filled CFRP.

(3) The maximum coefficient of friction were observed around 2 vol% SiC-nanoparticle volume content, and the coefficient of friction decreased with increasing the volume fraction of nanoparticle.

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