Mechanical Properties of Spun Type Carbon/ Carbon Composites at High Temperature

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Introduction

The ablative materials exposed to high temperature are often fabricated from carbon/phenolic(C/P), carbon/carbon(C/C) composites. These materials serve as thermal insulation in rocket motor components by absorbing energy through material degradation [1-3].

To utilize fully the potential of ablative materials in structural application, it is necessary to have a complete and accurate description of their high-temperature mechanical properties [4].

The aim of the present study is to understand the high-temperature mechanical behavior between polymer composites reinforced with spun yarn type carbon fabrics and filament yarn type carbon fabrics. The present paper reports the high-temperature mechanical behavior of C/C composites because the transformation polymer matrix into carbon occurs during the pyrolysis of C/P composite at high temperature.

Experimental

- Materials and Composites

Stabilized staple PAN fibers (Pyron®, Zoltek Co., USA) were used as precursor fiber to prepare spun carbon yarns for fabricating spun carbon reinforcements. The length of the staple fiber is 102 mm in average. The stabilized staple PAN fibers were converted into the stabilized PAN spun yarns using a semi-worsted spinning method.

The stabilized PAN spun yarns were woven into a fabric form with an eight harness satin texture. The woven spun yarn type fabrics were proprietarily heat-treated up to 1100℃ with a purging N_2 gas in a batch-type carbonization furnace and then successfully converted into spun yarn type carbon fabrics. Resol-type phenolic resin (KC-98®, Kangnam Chemical Co., Korea) was used as matrix for the composites in this work. The resin contents of spun C/P prepregs were about 36 wt%. The resin contents of spun C/P composites obtained after a compression molding with vacuum bagging technique were about 32 wt%.
The polymer composite plates to perform the mechanical test at high temperature were carbonized in a high-temperature furnace up to 1000℃ for one hour. The C/P plates were converted into C/C plates without further densification process.

- Mechanical Tests at High Temperature
Tensile specimens were designed as a dog-bone type with a double step to diminish locally occasional failure. The compressive specimens were shaped to fit the special fixture designed to apply a compression load to the specimen under tensile mode. The mechanical tests at high temperature were performed using a Universal Testing Machine (Instron Model 4496) equipped with an indirect heating system of copper grips and a chamber with a water-cooling system, as shown Figure 1. The graphite heater was located at the distance of 10 mm from the specimen and the heating zone was limited within a gauge length. The heating rate was varied to be about 10 to 150℃/s. A steady argon gas flows at a low rate was supplied during testing. An optical pyrometer was used to measure the temperature above 1000℃ at the lateral center of specimens. The crosshead speed at high temperature was 10 mm/min. Test temperatures of 1000℃, 1500℃, and 2000℃ were used.

Results and Discussion

- High-Temperature Tensile Strength
The high-temperature tensile strengths of undensified C/C composites are presented in Figure 2. It is found that the high-temperature tensile strength of two types of the C/C composites increases with increasing test temperature, indicating an increase of 4~12% for spun C/C and an increase of 18~34% for filament C/C, respectively. This may be due to removal of microstructural flaws such as micro-cracks, inclusion and micro-pores with the increase of test temperature. The spun C/C composite shows higher tensile property than the filament C/C one at high temperature. From an inspection of the fracture patterns of two types of the C/C composites after high-temperature tensile test, it has been found that a fracture mode of spun C/C composite is changed from brittle fracture to interlaminar shear fracture after

carbonization. This behavior may be resulted from the relatively weak interfacial property after carbonization. On the other hand, filament C/C composite shows a completely brittle fracture mode before and after carbonization in comparison with spun C/C composite. This behavior may be due to the low tensile strength because there is no sufficient energy absorption by delamination, as described elsewhere [5]. This fracture study agrees with the result of high-temperature tensile tests.

- High-temperature compressive strength

The high-temperature compressive strengths of two types of the C/C composites are presented in Figure 3. It is found that the compressive strength of filament C/C composites is not changed significantly up to 1000℃. Above 1000℃, it decreases with increasing test temperature. However, the high-temperature compressive strength of spun C/C does not change significantly with increasing test temperature. It is found that the spun C/C composite has good dimensional stability with varying test temperature. This may be due to a reinforcing effect of the protruded fiber between the layers as reported earlier [6]. Consequently, it indicates that the spun C/C composite has better good dimensional stability than the filament C/C one up to 1500℃. The failure pattern of filament C/C composite is observed to be the brittle fracture below 1500℃, but to be a mixed mode of brittle fracture and partial interlaminar shear fracture above 1500℃. This failure behavior agrees with the results of high-temperature compressive strength.

Conclusions

The high-temperature tensile strength of two different types of the C/C composites slightly increases with increasing the test temperature. The spun C/C composite shows higher tensile property than the filament C/C one at high temperature. The high-temperature compressive strength of the spun C/C composite remains almost constant with increasing test temperature up to about 1000℃ and then gradually decreases. The spun C/C composite has good dimensional stability at high temperatures up to 1500℃.

References

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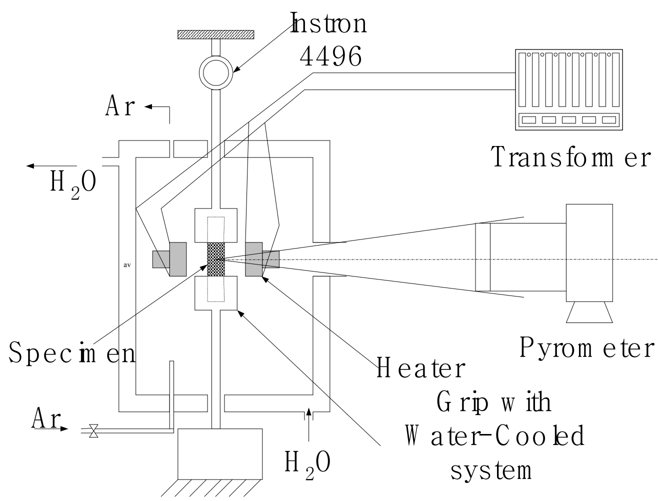

Figure 1. A schematic of a universal testing machine equipped with indirect heating system.

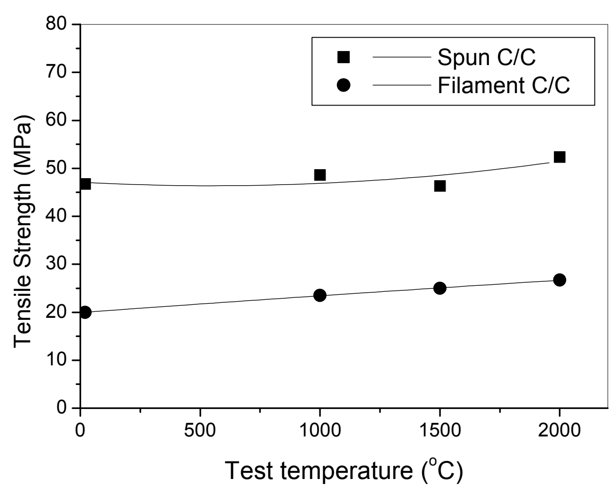

Figure 2. Tensile strengths of two different types of the C/C composites as a function of test temperature.

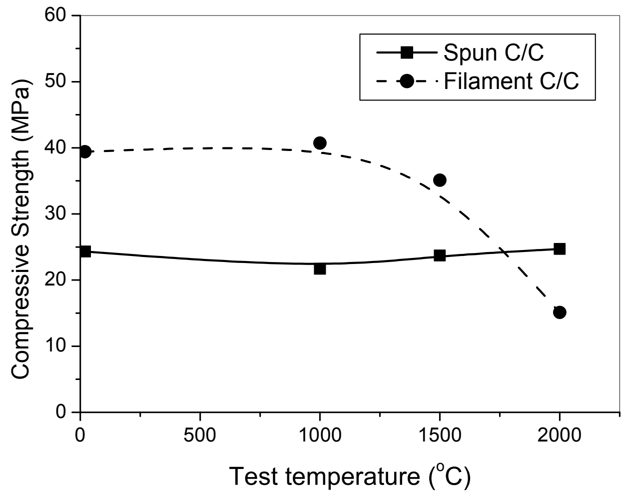

Figure 3. Compressive strengths of two different types of C/C composites as a function of test temperature.