EFFECT OF GRAPHITIZATION TEMPERATURE ON MECHANICAL AND TRIBOLOGICAL BEHAVIOR OF A PAN-PHENOLIC RESIN-BASED CARBON-CARBON COMPOSITE

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Introduction

An earlier study [1] indicated that the bending properties of a PAN/phenolic-based carbon/carbon (C/C) composite processed at a conventionally low carbonization rate of 1°C/min and at an ultrahigh carbonization rate of 1000°C/min were comparable. Furthermore, the composite carbonized at 1000°C/min had much higher fracture energy than that carbonized at 1°C/min. The sharp increase in carbonization rate can be very economically beneficial to the C/C industry. Reported in the present study is the effect of graphitization temperature on mechanical and tribological properties of the same PAN-phenolic type composite fabricated at the same, high carbonization rate of 1000°C/min.

Experimental

The reinforcing fiber and matrix phenolic resin used for the preparation of the present PAN/phenolic-based C/C composite are a randomly oriented chopped (4.5 mm) PAN-based carbon fiber (Torayca T700SC, 12K, Toray Co., Japan) and a powdery phenolic resin (RM-18389, Texxco, Taiwan), respectively. A resole-type phenolic resin (PF-650, Chang Chun Petrochemical Industry, Taiwan) was used as impregnating resin.

The chopped carbon fibers (55 vol%) were first mixed with the matrix phenolic powder (45 vol%) in a mode to form a 110 mm × 110 mm composite, followed by hot pressing, curing, and post-curing.

Carbonization was conducted by heating the post-cured composite under a nitrogen atmosphere to 1100°C at a heating rate of 1000°C/min. The nitrogen gas was introduced continuously into the furnace at a constant flow rate of 0.6 L/min. The carbonized composite was subsequently graphitized in a helium-purged graphitization furnace. To study the effect of graphitization temperature on properties of the composite, three different graphitization temperatures, 1700, 1900, and 2100°C, were used for the study. Samples prepared from these three graphitization temperatures were designated "G17", "G19" and "G21", respectively.

The porous graphitized composite was then densified by re-impregnation with the impregnating resin, followed curing, post-curing and carbonization. To improve the density and properties of the composite, four such densification/carbonization cycles were applied.

The flexural strength and modulus of the composite were measured by three-point bending test based on ASTM D790 method with the span-to-depth ratio of 16. Samples for this test were in a size of 50 mm × 10 mm × 2.2 mm. A Shimadzu AGS-500D universal tester (Shimadzu Corp., Kyoto, Japan) was operated at a crosshead speed of 1 mm/min with a support span of 40 mm. All the bending test data shown in this paper are the average of five samples.

A simulated-stop wear test was conducted on the composite with a normal pressure of 1.0 MPa and 1200 rpm (equivalent to an average linear speed of 1.1 m/s) in an environment with a humidity level of 45-65%. A homemade disk-on-disk sliding wear tester was used for the test. Prior to testing, all samples were mechanical polished to #1200 grit level, followed by ultrasonic cleaning to remove debris on surface. Prior to each subsequent test, the samples were allowed to cool to room temperature. The coefficient of friction (COF), μ, was determined using the equation, $\mu=M/rF_n$, where M is the torque, F_n the normal force and r the average radius of the sample. The simulated-stop wear test was repeated 40 times under each condition.

Results and Discussion

The flexural strength and flexural modulus values of composite samples processed from different graphitization temperatures are demonstrated in Figs. 1 and 2, respectively. As indicated in Fig. 1, the composite processed from higher graphitization temperature exhibited higher flexural strength and flexural modulus values. For example, the flexural strength and flexural modulus of the composite graphitized at 2100°C (65.9 MPa and 27.1 GPa, respectively) were respectively higher than those of the composite graphitized at 1700°C (59.3 MPa and 23.8 GPa, respectively) by 111.1% and 115.1%. The flexural strength and flexural modulus of the composite graphitized at 1900°C (62.7 MPa and 25.6 GPa, respectively) were in between. The highest flexural strength and flexural modulus values of the composite graphitized at 2100°C were directly reflected in its highest bulk density (1.49 g/cm^3) and lowest porosity level (8.3%).

As indicated in Fig. 3, the average COF values of composite samples graphitized at 1900 and 2100°C were similar (0.38), which were higher than that graphitized at 1700°C (0.36). The relatively low COF depicted in the composite graphitized at 1700°C was also reflected in its relatively long stopping time (176.2 s), compared to those samples graphitized at 1900°C (172.9 s) and 2100°C (174.1 s), as shown in Fig. 4.

The weight loss values of composite samples processed from different graphitization temperatures were shown in Fig. 5. As indicated in the figure, the average weight

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losses of composite samples graphitized at 1700 and 1900°C were similar (5.1 and 5.2 mg, respectively). The average weight loss of the composite graphitized at 2100°C (7.3 mg), however, was significantly larger.

According to these mechanical and tribological data, it was concluded that, for the current C/C formula, the graphitization temperature of 1900°C would be the most optimal temperature among the three temperatures. The conventionally-used higher temperature for graphitization (usually higher than 2000°C) is not necessary and would not perform better under the current wear test conditions.

References

1. Kuo, H.H., Chern Lin, J.H., and Ju C.P. Effect of carbonization rate on the properties of a PAN/phenolic-based carbon/carbon composite. *Carbon* **43** (2005) 229-239.

Acknowledgement

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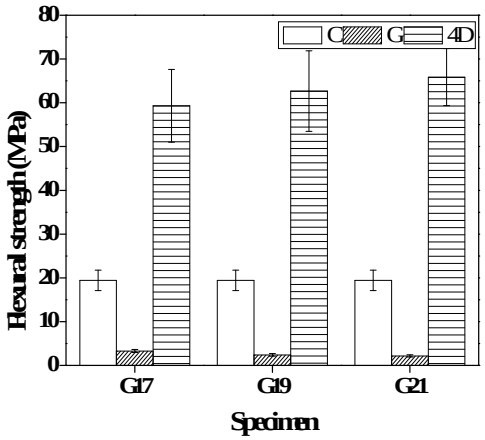

Fig. 1. Flexural strength values of composite samples processed from different graphitization temperatures.

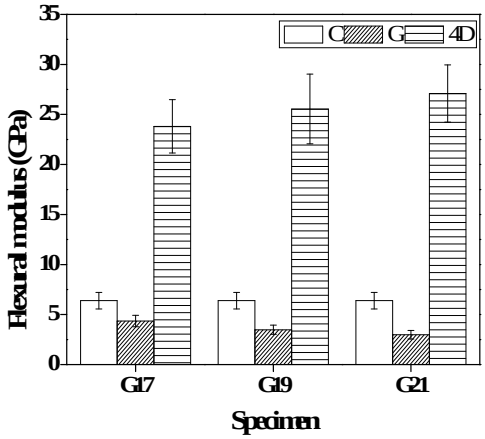

Fig. 2. Flexural modulus values of composite samples processed from different graphitization temperatures.

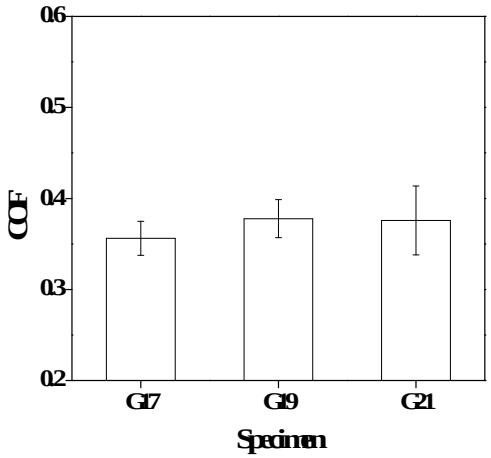

Fig. 3. COF values of composite samples processed from different graphitization temperatures.

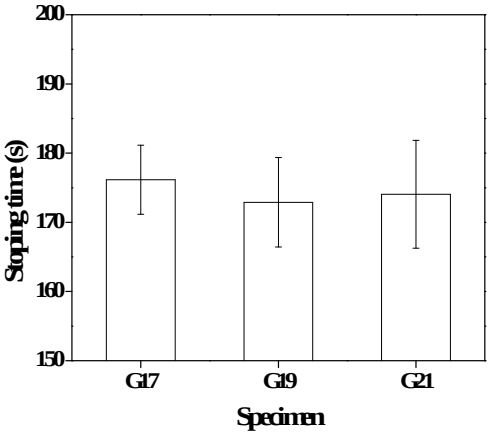

Fig. 4. Stopping time values of composite samples processed from different graphitization temperatures.

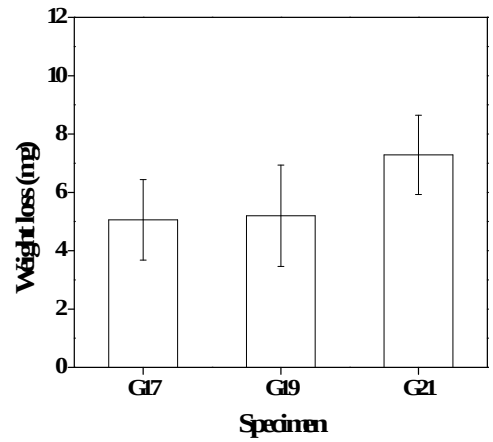

Fig. 5. Weight loss values of composite samples processed from different graphitization temperatures.

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