

TRIBOLOGICAL STUDY OF PAN/PITCH, PAN/CVI AND PITCH/RESIN/CVI CARBON-CARBON COMPOSITES

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The present study compares low and high energy tribological behavior among three different carbon/carbon composites designated "E", "A" and "TL". Under low energy condition, all composites have exhibited steady-state friction coefficients, except for "TL" which has a much larger starting bump. Weight losses of all composites increase with sliding distance and eventually approach some stable values. The "TL" composite at each sliding distance has a larger weight loss than the other two. Under the high energy condition, the three composites generally have much larger friction and wear than the respective ones under the low energy condition. Under the low energy condition, composites E and A behave quite similarly and both have lower friction and wear than TL. Under the high energy condition, composite E apparently performs better than the other two composites in terms of weight loss. It is shown that the nature of debris film is critical to the tribological behavior of all three materials.

1. INTRODUCTION

Due to their light weight, excellent thermal and mechanical properties, and self-lubricating capability, carbon/carbon (C/C) composites have emerged as a strong friction material [1-3]. Many military aircrafts (fighters), such as the U.S. F-14, F-15, F-16, F-18 and French Mirage 2000, as well as commercial aircrafts such as 747, Airbus, Concorde, Canadair Challenger and Gulfstream III, have employed C/C composites as brake disk materials.

Major C/C composites currently used for aircraft brake disks are either PAN-based fiber (fabric laminates)-reinforced chemical vapor infiltrated (CVI) matrix or mesophase pitch-based fiber (chopped yarns)-reinforced phenolic resin char/CVI hybrid matrix composites. These two types of C/C are different in processing and properties and each has its own advantages.

The present work is an attempt to compare tribological behavior under two different energy conditions among PAN/pitch, PAN/CVI and pitch/resin/CVI C/C composites.

2. MATERIALS AND METHODS

As listed in Table 1, the three C/C composites used in this study were fabricated by different techniques. The 2D (two-dimensional) PAN/pitch (designated "TL") composite was fabricated using woven high modulus PAN-based fiber preforms which were pressure-infiltrated and densified with molten pitch as matrix. The 2D PAN/CVI (designated "E") composite was fabricated from stacked dry PAN-based fiber laminates which were infiltrated/densified by CVI. The 2D pitch/resin /CVI (designated "A") hybrid matrix composite was fabricated from carbonized mesophase pitch fiber/phenolic resin prepregs which were subsequently densified by CVI.

Table 1.
Three C/C composites tested in this study

Designation	Formula	Flexural strength (MPa)	Density (g/cm ³)
TL	PAN/pitch	91	1.55
E	PAN/CVI	92	1.76
A	pitch/resin/CVI	53	1.74

Wear tests were conducted in air using a homemade disk-on-disk sliding wear tester (Fig. 1). A load of 1.7 MPa and two fixed rotor speeds (70 rpm and 2000 rpm), were used for all tests. The specimens for tests were machined into samples having dimensions of 25mm O.D. x 10mm I.D. and mechanically polished to a level of #1200 grit paper, followed by ultrasonic cleaning and drying. Sliding torques, which were used to calculate friction coefficients, were recorded during each test using an AST-BH dynamometer (SATO, Japan). A NIKON FM2 camera was used to examine as-polished and worn surfaces of each composite.

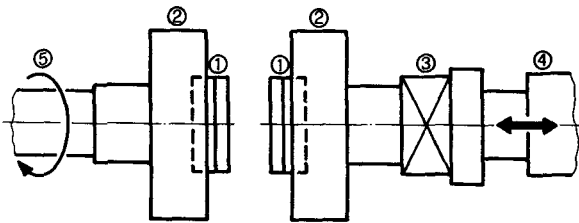


Fig.1. Schematic of the wear tester 1. specimen 2. holder 3. dynamometer 4. loading system 5. rotating shaft.

3. RESULTS AND DISCUSSION

Figure 2 shows typical curves of variation in friction coefficients with sliding distance for the three composites under two different speeds (70 rpm and 2000 rpm) and the same load (1.7 MPa) (note: many tests have been run for each composite and the curves shown are typical ones). Under low energy condition (70 rpm) all composites had friction coefficient values in the range of 0.15-0.30 after a starting "bump". The composite "TL" had a much larger bump (up to 0.6) and higher steady-state friction coefficient than the other two. Under the high energy condition (2000 rpm), the friction coefficients (between 0.4 and 0.8) of all composites were much larger than those under the low energy condition after twenty some meters. The composite "A" had a low value (0.1) before a transition occurred at about 25m, after which the friction coefficient

rose to an average of 0.8. Composites "E" and "TL" had starting bumps of about 0.6 and 0.8 respectively, after which the coefficients decreased with sliding distance to lower stable values (close to 0.4 and 0.6 respectively).

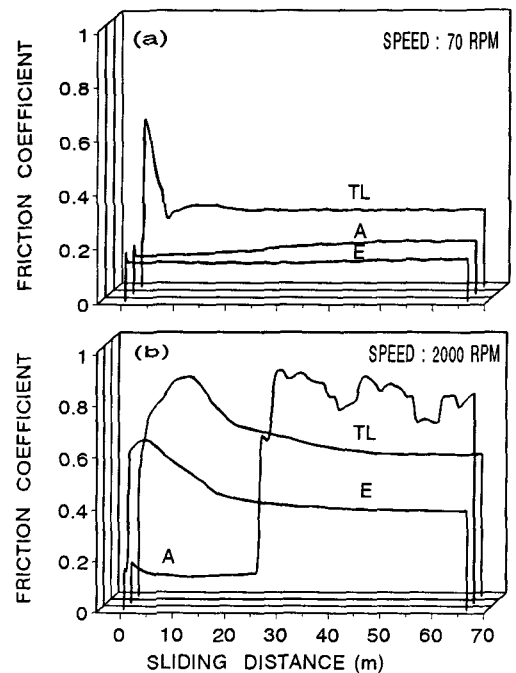


Fig. 2. Friction coefficient variation with sliding distance.

Figure 3(a) shows weight losses of the three composites under the same load (1.7 MPa) and the low speed (70 rpm) against sliding distance. The first thing worth noting is that the weight loss of composite "TL" was at all times higher by about an order of magnitude than those of the other two composites. As shown in Figure 3(b), under the high energy condition (2000 rpm), all the composites had higher weight losses than under the low energy condition. Among the three composites, the composite "TL" had a larger weight loss than the other two all the way up to 66 meters. Composite "A" showed a very low weight loss in the first few meters which was comparable to that under the low energy condition. During the transition (20-30m), a quick wear of "A" started to take place and the wear rate

of that, between 33m and 66m, became nearly the same as that of "TL". The wear rate of "E" kept decreasing and had the smallest weight loss among the three composites after 33 meters. Obviously, the lowest steady state friction coefficient has caused "E" to have the lowest wear.

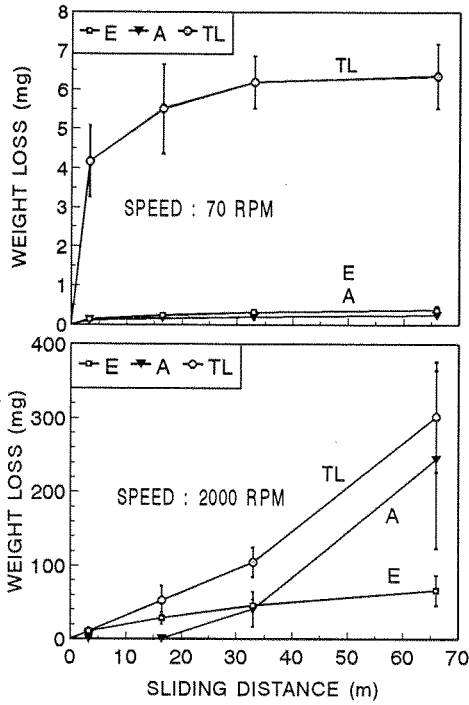


Fig. 3. Weight loss variation with sliding distance.

Surface morphology of as-polished and worn surfaces of the three composites under the low energy condition is shown in Fig. 4. After wear, smooth and thin debris films were found over the worn surfaces of the composites "A" and "E". On the worn surface of "TL", however, a quite thick layer of debris was formed to cover the whole surface and the original (as-polished) microstructure was overshadowed. This quick wear in the beginning was reflected in the unique friction curve of the composite (Fig.2). The height of the first bump in the friction coefficient of "TL" was three times as large as those of the other two composites and it took a much longer time for the friction to get stabilized. As described in more detail elsewhere [5], the quick formation of a powdery debris layer on the worn surface might

be responsible for the unique friction and wear behavior of this composite. After thirty some meters (a wear-in process) the wear rate of "TL" had dropped to a level comparable to the other two. Under the present low energy condition, all the composites had reasonably low friction coefficients and their wear rates all dropped sharply after a few minutes of sliding when a lubricative debris film was more or less developed.

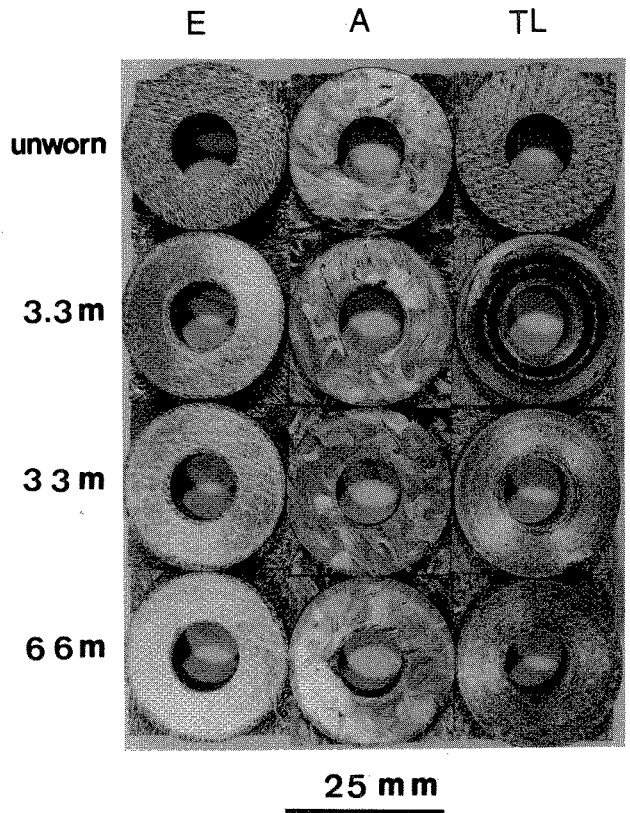


Fig. 4. Morphology of unworn and low energy worn surfaces of the composites at different sliding distance.

Under the high energy condition, the formation of a debris film and the ability for the film to lubricate were also studied. In the first few meters, the worn surfaces of the composites "TL" and "E" were both covered with a powdery debris layer similar to that of "TL" under the low energy condition. For the composite "TL", this powdery debris did not change to a smooth lubricative film within testing distance. Although its friction

coefficient became quite constant (but high) after the beginning bump, the weight loss kept steadily rising and was the largest among the three composites. On the other hand, for the composite "E", a stable lubricative film was developed to cover a part of the surface. This might explain why the composite "E" had reached a stabilization in wear after thirty some meters but "TL" did not. For composite "A", a smooth and thin debris film was formed prior to the transition in friction coefficient. After the transition the worn surface was covered with a powdery debris layer (Fig.5). The reason for this transition is not yet clear. Whatever it might be, this less lubricative debris was mechanically unstable and could not lead to a stable friction coefficient. The wear rate after the transition increased sharply and it did not level off within the testing distance.

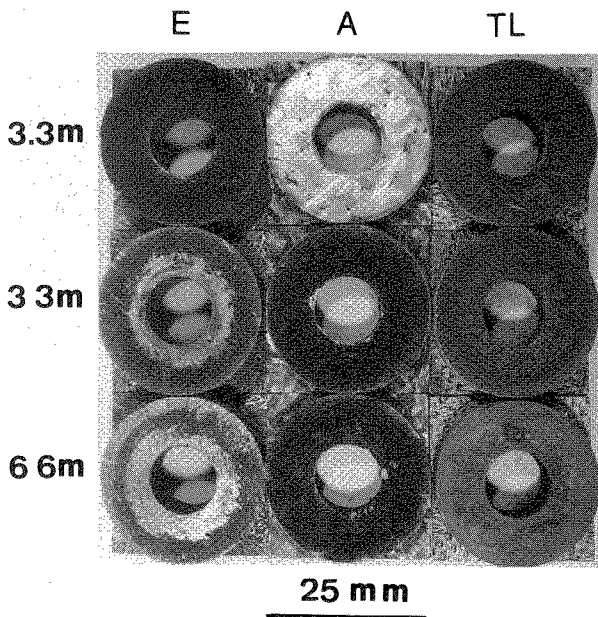


Fig. 5. Morphology of high energy worn surfaces of the composites at different sliding distance.

5. CONCLUSIONS

1. Under the low energy condition all the composites had steady-state friction coefficient

values, except for "TL" which had a much larger bump. Under the high energy condition, generally, the friction coefficients of all the composites were much larger than those under the low energy condition. The composite "A" had a low value before a transition; composites "E" and "TL" had starting bumps.

2. Under the low energy condition, the weight loss of the composite "TL" was at all times higher than those of the other two composites. Under the high energy condition, all the composites had higher weight losses than those under the low energy condition. Among the three composites, the composite "TL", had a larger weight loss than those of the other two all the way up to 66 meters.

3. It is shown that the nature of the debris film is critical to the tribological behavior of all three materials. Formation of a smooth self-lubricative debris film is essential for lowering friction and wear.

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