THE FORMATION OF SURFACE FILMS ON CARBON-CARBON COMPOSITES IN RESPONSE TO SURFACE STRESSES AND BLUNT INDENTATION

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Introduction

Although carbon-carbon composites exploit the high tensile strength and stiffness of the carbon fibre reinforcement, in complex stress fields it is necessary to take account of the response of the material to shear and compressive stresses. This is particularly relevant to load bearing surfaces. The main civil application of carbon-carbon composites is in aircraft brakes. Here, the response of the load bearing faces of tenons which transmit the braking torque are of interest, since these load bearing faces are known to wear in some cases during the life of the disc. This paper reports a study of surface damage to load bearing faces of tenons and assessment of blunt indentation as a tool to investigate the formation of surface films under compressive and shear stresses.

Experimental

The carbon-carbon composite used in this study was a PAN/CVI aircraft brake material. The term "witness mark" is used to denote an area of the composite surface which has developed increased optical reflectivity in response to loading. This is commonly observed on the load bearing faces of tenons on ex-service discs, including highly worn faces. In order to elucidate the morphology of the surface film and the form of any sub-surface damage, the surfaces and cross sections were examined by optical and electron optical microscopy.

Blunt Indentation Method

Blunt indentation was chosen as a tool to investigate the formation of surface films as it produces a combination of compression and shear under the indenter. Blunt indentation was carried out by forcing a 6mm diameter tungsten carbide sphere into the surface of the composite[1]. Outputs from a load cell and an LVDT were recorded on a computer every $^{1}/_{10}{}^{th}$ of a second. The effect on film formation of peak load and number of cycles was investigated.

Results and Discussion

Wear of Tenons at Load Bearing Surfaces

Figure 1 shows a section of a tenon after a service conditions test, which involves mainly compressive stresses but with some shear. It clearly shows subsurface damage at depths of between 20 and 100 μm below the surface (a). A thin, smooth surface film can also be seen which appears to be made up of very fine particles (b). An area where the surface film is missing can be seen (c), and its appearance suggests that the film has been detached from the substrate. If this inference is correct, a cyclic process of film formation and spallation is a possible mechanism by which tenon wear may occur.

Blunt Indentation Method

Figure 2 shows the effect of 1 cycle to a peak load of 2 kN. The composite typically failed at approximately 2.5 kN by cracking between the plies of the composite allowing a transverse expansion to accommodate the indenter. It is clear that film formation has occurred preferentially over some areas of the surface. These areas correspond to regions of continuous fibre reinforcement parallel to the surface and regions of low fibre density. The effects of increasing the peak indentation load were to increase the depth of the indent and the disruption of the structure of the composite, and to increase the coherency of the film produced. However, the latter effect was only slight over the range of loads studied. Increasing the number of loading cycles progressively improved the quality (reflectivity and coherency) of the film produced. This form of contact area polishing is similar to that observed on nuclear graphites where the film is attributed to the smearing of the graphite over the surface by basal plane shear[1]. An example of a load displacement trace from a cyclic indentation test is shown in figure 3. For clarity only the 1st, 3rd and 5th cycles are shown. Each loading cycle consisted of loading to 1 kN and unloading to zero load. The curves have been smoothed using a ten point rolling average method. From the traces it is clear that the composite responds in a largely pseudo-plastic manner, particularly on the 1st cycle, and that the depth of the indentation does not significantly increase with increasing cycles. The elastic response of the material was calculated from the curves using equation 1, where B is the area under the loading curve and A is the area within the hysteresis loop. This equation is valid for all cases except where A=0. Table 1 shows the results of mathematical analysis of the curves. It is clear that the material becomes more elastic in response to an increasing number of cycles, and it seems likely that near perfect elasticity will be achieved after a large number of cycles.

$$\% \text{ Elastic recovery} = \left(1 - \frac{A}{B}\right) \times 100 \qquad 1^{[2]}.$$

Conclusions

The load bearing faces of tenons in carbon-carbon composite aircraft brake discs show subsurface damage and an incomplete surface film. This suggests a cyclic wear mechanism of film formation and spallation. Loading of the surface of the composite by blunt indentation shows preferential film formation in regions of continuous fibre reinforcement parallel to the surface, and regions of low fibre density. Cyclic loading using a blunt indenter shows that the response of the composite is mainly pseudo-plastic, but that the proportion of elastic recovery increases with increasing number of loading cycles.

Acknowledgements

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References

[1] M. Hartley and B. McEnaney, *Proceedings "Carbon 96", Univerity of Newcastle upon Tyne, UK*, p. 210, (1996).
[2] M. Hartley and B. McEnaney, *Abs. An Open Discussion On Current Issues In Nuclear Graphite And Carbon Topics*, Meeting of the British Carbon Group, (1996).

Table 1 : Analysis of load vs displacement curves for cyclic blunt indentation shown in figure 3

	Cycle 1	Cycle 3	Cycle 5
Loading curve area / Nm	0.177	0.052	0.075
Loop area / Nm	0.085	0.030	0.028
% Elastic recovery	27	42	63

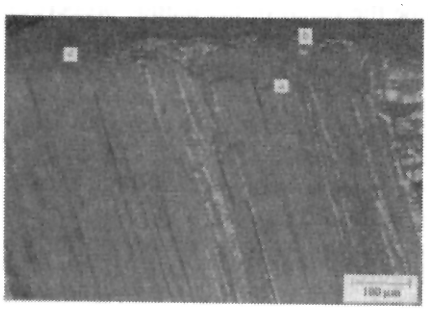

Figure 1 : Optical micrograph of a tenon exhibiting film formation

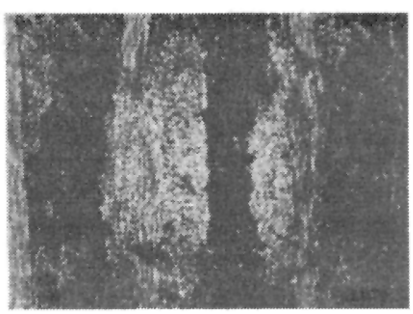

Figure 2 : Optical micrograph of a typical indentation

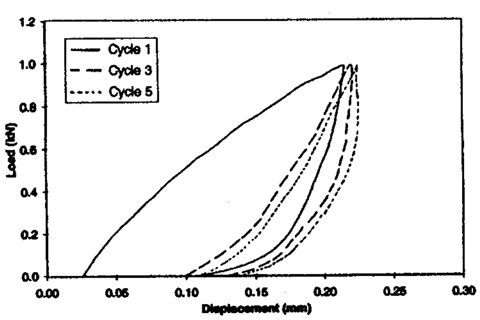

Figure 3 : Load vs displacement curves for cyclic indentation