MATRIX CARBON CHARACTERISTICS IN RELATION TO THE STRENGTH OF PITCH BASED CARBON-CARBON COMPOSITES

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Introduction

Carbon-carbon (C/C) composites are mainly used as structural materials and their successful application requires a combination of strength and stiffness. It is well established that there is a good correlation between the stiffness exhibited by pitch carbon based matrix composites and the preferred orientation of the carbon basal layers parallel to the fibre surfaces [1]. It is also known that the strength of porous carbons is influenced by the porosity, the pore shape, the size of the critical flaws present at failure and the nature of the material. Although, strength-pore structure relationships have been developed for materials such as electrodes and metallurgical cokes [2], similar relationships are not available for C/C composites However, for two dimensional (2D) composites it has been found [3] that the presence of cracks oriented perpendicularly to the cloth layers are important in relation to flexural strength.

The objective of this study was to investigate further the influence of cracks oriented perpendicularly to the fibre layers on the flexural strength of the materials and the association of such cracks with the nature of the carbon matrix precursor.

Experimental

A series of 2D composites was prepared from a 2/2 twill weave carbon fabric made from high-modulus PAN fibre and four coal-tar pitches, A, B, C and D, differing in quinoline insolubles (QI) content. The QI insolubles content of the pitches was A: 11.5%, B: 6.5%, C: 5.3% and D: 2.6%. An image analysis technique was developed for the characterisation of the porous structure of the composites and the measurement of cracks oriented perpendicularly to the fibre layers. Perpendicular cracks are regarded as cracks lying within an angle ±45° to a plane perpendicular to the plane of the fibre layers. Cracks with an area larger than 500 μm^2 only are included, smaller cracks being deemed to be too small to influence significantly the strength of the composites. The total porosity of the composites was determined by liquid and gas displacement methods and the mechanical properties by the three point bend test.

Results and Discussion

Image analysis data for the perpendicular cracks for densified composites are presented in Table 1. It can be seen that the porosity of the perpendicular cracks tends to decrease with decreasing pitch QI content. The number of cracks per mm^2 also follow a similar trend. The breadth of the pores appears to be roughly constant throughout while the area and the length show possible decreasing trends.

Table 2 shows that both the flexural modulus (FM) and flexural strength (FS) of the composites tend to be higher with low QI pitch content. Previously it was shown [4] that an increased amount of preferred orientation of the carbon matrix could account for the modulus increase while microscopic investigation suggested that the presence of cracks oriented perpendicularly to the fibre layers may be associated with the flexural strength of the composites.

Total porosity data are also presented in Table 2. It can be seen that the total porosity of the composites tends to increase with decreasing pitch QI content. It is noteworthing that the composites based on the low QI pitch (D) have better flexural strength despite having higher total porosity. So, suitably oriented defects i.e. perpendicular cracks appear to govern the strength of the composite rather than the total volume porosity. The flexural strength of the composites studied will then be influenced by change in the size or number of perpendicular cracks present in the material.

The high QI pitch composite (A) exhibits the highest mean number of cracks per mm^2 with the largest mean area and longest length, and its poor strength may be explained on the basis of these characteristics. On the other hand, the low QI pitch composite (D) is associated with the lowest mean number of voids per mm^2, the smallest mean area and the shortest length and high strength. It can also be seen that of all the geometric parameters obtained for the perpendicular cracks, the variation of the mean length is in good agreement and consistent with the variation of the flexural strength of the composites. Thus the variation of the mean crack length could possibly be used as an index for predicting the flexural strength of the composites.

However, the mean length criterion for predicting the strength of the composite may be truly meaningful only if its value results from the presence of a large number of long cracks rather than to the presence of an even larger number of shorter cracks.

Figure 1 shows the variation of the percentage of the number of perpendicular cracks longer than 80 μm with the type of pitch used for the fabrication of the composites. Comparison of the results in Figure 1 and Table 1 shows that the higher mean length values are associated with presence of longer cracks.

Conclusions

An image analysis technique was used to quantify cracks oriented perpendicularly to the fibre layers of 2D composites. The variation of the porosity due to this type of crack and their mean length follow the same trend as that of the flexural strength of the composites. Lower QI pitch content is associated with lower porosity due to perpendicular cracks, shorter mean length and higher flexural strength. The variation of the mean crack length is related to the variation of the longer cracks and a relationship clearly exists between the longer perpendicular cracks and the flexural strength of 2D C/C composites.

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References

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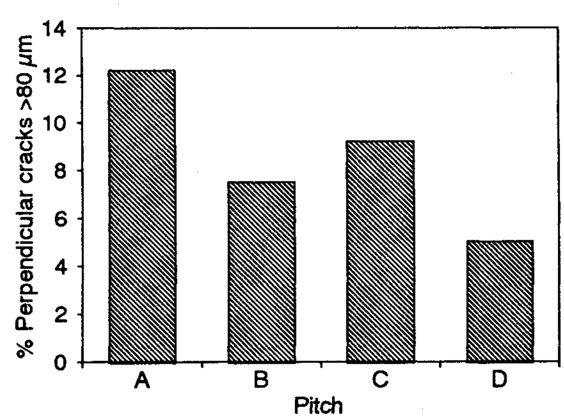

Figure 1 Variation of perpendicular cracks with QI insolubles.

Table 1 Data for perpendicular cracks >500 μm^2.

Mean parameter	Composite			
	A	B	C	D
Porosity, vol %	1.1	0.8	0.9	0.7
No of pores/mm^2	10	7	8	7
Area, μm^2	1140	1080	1120	1010
Breadth, μm	27.0	27.4	27.7	27.3
Length, μm	58.6	54.9	55.6	51.8

Table 2 Mechanical properties of composites.

Composite	FS, MPa	FM, GPa	Total porosity, vol %
A	106	79	10.3
B	122	93	11.1
C	119	92	10.7
D	137	91	12.1