THE EFFECT OF POROSITY ON THE BLUNT INDENTATION FRACTURE OF GRAPHITE

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Introduction

Engineering graphites are increasingly used in situations where they are subjected to highly concentrated contact stresses.; for example there are situations envisaged within a British AGR reactor where the core graphite could be subjected to highly localised stresses.

This work follows on from an earlier study [1] of the effect of graphite texture on blunt indentation fracture which demonstrated changes in fracture morphology with different microstructures. Figure 1 shows the transition from largely elastic behaviour with an extremely fine textured graphite, A, to largely "plastic" behaviour with a coarse textured graphite, C, while graphite B shows a combination of the two types of fracture.

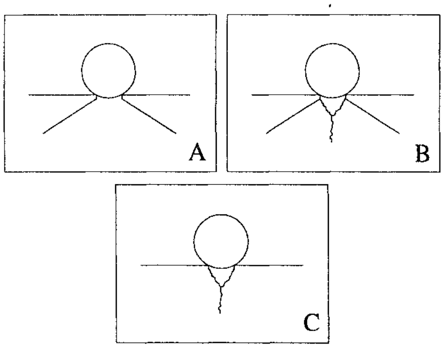

Figure 1. Schematic of indentation fracture of graphite with different textures [1], (spherical tungsten carbide indenter of diameter 6mm was used).
A, Poco ZXF, B, EY306, C, IM1-24.

The fracture in Figure 1A is a classical Hertzian type of failure while the deformation in Figure 1C is caused by shear stresses [1]. However the effect of the differing extents of porosity in the graphites could not be ascertained with these materials. Consequently, further work with new materials was initiated, which is presented here.

Experimental

Two approaches have been used in order to investigate the effect of porosity. A moulded moderator graphite, IM1-24, was thermally oxidised in CO_2 to increase the extent of the porosity. This provided a material with a range of porosities from 18-40%.

For the second approach three extruded graphites (supplied by UCAR) were used with identical solid microstructures, but with different extents of porosity (14-25%) introduced by controlled impregnation.

Bonded interface samples were produced [2] by polishing pieces of the UCAR graphite down to a sub micron finish, then bonding them together. Indentations were then made on the join using a 6mm tungsten carbide sphere, after which the samples were separated using a solvent allowing the damage zone to be viewed. Indentation cycles and tests to failure were also carried out on conventional unbonded samples for both IM1-24 and UCAR graphites.

Results and Discussion

Figure 2 shows the damage zone created by a 1kN load cycle for the three UCAR graphites. It is immediately apparent that both the intensity and the size of the damage zone change dramatically depending on the extent of porosity in the graphite. Graphite D shows a large well developed damage zone, while in the lower porosity graphite F, the damage is barely visible.

The damage appears to occur in a well defined drop shaped region below the surface, and is similar to the damage seen in polycrystalline ceramics [3] as well as in previous work on graphite (see Figure 1c) [1]. This corresponds to the distribution of shear stresses beneath a Hertzian indenter, hence it seems likely that the damage is largely due to shear. Further weight is given to this hypothesis as the fracture surfaces exhibit characteristic shear morphology.

In graphites E and F, the greatest intensity of damage is some distance beneath the surface. This may be due to an expected region of hydrostatic compression just below the surface, preventing significant damage in this region. Consequently it is possible that the maximum shear stress is a significant distance below the surface.

This qualitative trend is supported by the mechanical testing of the graphites. The hysteresis in the load deflection curve gives a quantitative measure of the damage occurring in the graphite. A useful way of representing the induced damage is to use the ratio of

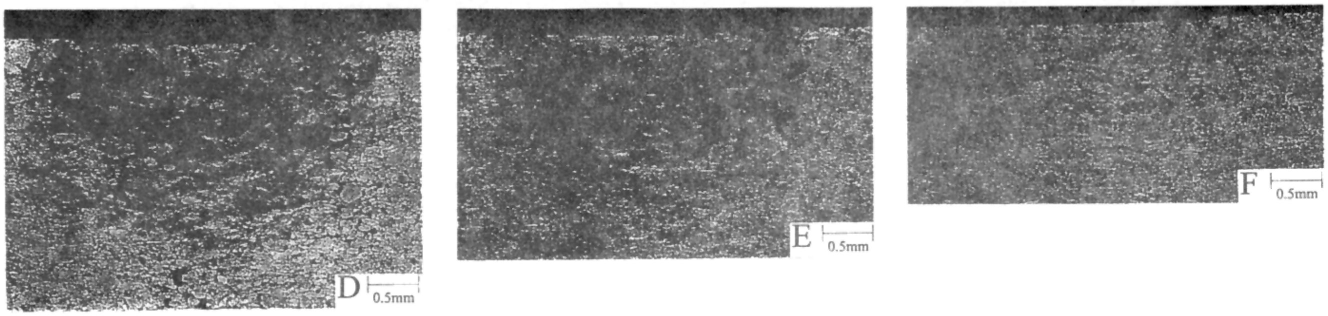

Figure 2. Micrographs showing the damage created in different UCAR graphites by a 1kN indentation cycle with a 6mm diameter tungsten carbide sphere.

loop area, a, to the area under the loading curve, b, (see Figure 3) then multiply by 100 to give a percentage of the total deformation that is permanent. Hence if area a is the same as area b there is no elastic recovery, i.e., all the deformation is permanent, and conversely if there is no hysteresis there is complete elastic recovery. Using the "percentage permanent deformation" calculated in this manner effectively normalises for modulus and strength, allowing a comparison of the two different ways of introducing porosity.

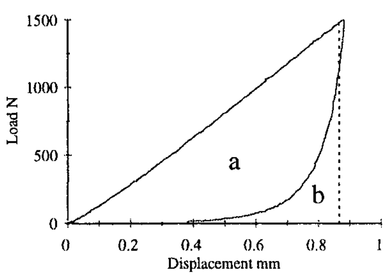

Figure 3. Characteristic hysteresis loop for unoxidised graphite.

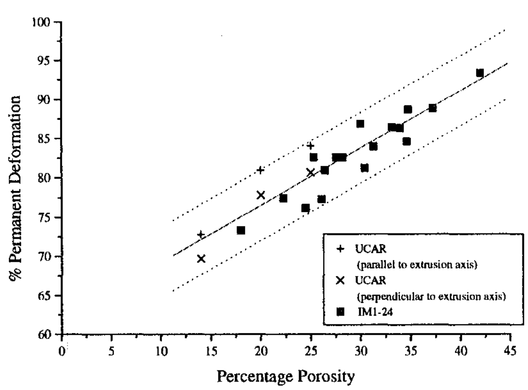

Figure 4. The effect of porosity on the permanent deformation of graphite, for a 1kN indentation cycle.

Figure 4 shows the change in the magnitude of the permanent deformation for the different graphites, with a linear regression line and 95% confidence intervals marked with dotted lines. If we initially consider the UCAR graphite, the degree of damage is greater when indented parallel to the extrusion axis which is consistent with bonded interface results. Comparing IM1-24 and the UCAR graphites, they appear to lie on the same line suggesting that the resistance to indentation damage is dominated by the degree of porosity rather than any difference in structure. It can also be inferred that indentation damage is affected in a similar way by variations in porosity induced either by oxidation or by impregnation.

Conclusion

Comparison of a series of oxidised graphites with a series of impregnated graphites shows that blunt indentation damage is dominated by porosity. Solid microstructure also has an influence on blunt indentation as shown by comparison of indentations parallel and perpendicular to the extrusion axis.

Acknowledgements

The authors would like to thank the EPSRC and Nuclear Electric plc. for their financial support, and UCAR for providing the necessary material.

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