TENSILE STRENGTH OF CARBONS WITH DIFFERENT TEXTURES

F. G. Emmerich
School of Materials, University of Leeds, Leeds LS2 9JT, UK (Present address)
Dept. de Física, Univ. Federal do Esp. Santo, 29060-900 Vitória-ES, Brazil (Permanent address)

Introduction

According to Brocklehurst [1], the fracture of polycrystalline graphite suggests a Griffith type behaviour [2,3] with a weak-link mechanism involved, but the complexity of the process has presented difficulties in obtaining simple relationships between the external failure stress, the basic physical properties of graphite, and the microstructural features.

An important point concerning the fracture and strength of solids is the statistics of flaws. As pointed out by Orowan [4], any statistical treatment of the brittle strength, must take into account the individual natural history of the flaws in the material considered.

Since Burchell [5] in a recent work on the fracture of polygranular graphites provided an accurate quantitative image analysis to determine the statistical distribution of pore sizes present in the materials, his data will be used in connection with the Griffith theory to determine a mean effective (or apparent) surface energy for the polygranular graphites. A special attention to identify the most critical flaws of the materials will be paid in this analysis. The results obtained here could be useful to preview the tensile strength of other polycrystalline graphitic materials.

Materials

The polygranular graphites (H-451, IG-110, AXF-5Q) studied by Burchell [5] were medium, fine and ultrafine-grained graphites with bulk density of (1.78 ± 0.03) gcm^{-3} [5] and Young's modulus of (11.0 ± 0.7) GPa (manufacturers data). In his study it was also included for comparison a coarse-textured graphite (AGX) with bulk density of 1.684 gcm^{-3} [5] and Young's modulus of 7.0-11.0 GPa (manufacturer data).

Results and Discussion

The Griffith condition [2,3,6] for the tensile strength (σ_{TS}) of a brittle isotropic material in a state of plane stress is given by:

$$\sigma_{TS} = (2E\gamma/\pi c)^{1/2} \quad (1)$$

where E is the Young's modulus, γ is the surface energy and c is the half-length of the critical flaw. For polycrystalline graphites the corresponding expression for a state of plane strain hardly differ from eqn (1) since the square of their Poisson's ratio is much less than unity.

According to eqn (1), if a body contains flaws of different sizes, then it will be the larger flaws that controls the strength. This is well emphasised by Davidge [7]. Moreover, as observed by Griffith [2,3], the flaw orientation in relation to the applied tension have to be taken into account.

It will be assumed that the flaws are distributed randomly in the materials. Consequently the effect of the flaws orientation is simplified because for a given flaws statistics, the presence of flaws of particular lengths 2c can be assumed to exist in all directions, including the direction perpendicular to the applied tension.

It will be assumed that the most critical flaws are related with the larger pores of the materials, because the regions of high-stress concentration are at their boundaries. This is in accord with the observation that in the fracture of polycrystalline graphite there is a preferred crack path through pores and that the critical crack density is first reached in regions of high-stress concentration near the larger pores [1].

Since the scatter of brittle strength measurements indicates that the number of the dangerous flaws cannot be very large [4], the critical flaw size (2c) will be taken equal to the length of the flaw situated at 99.9% of the log-normal distribution, that is, only 0.1% of the flaws may have length above 2c. The values of 2c for the analysed materials were directly obtained from the figures of pore size breadth distributions [5] and are shown in Table 1, together with the experimental values of tensile strength.

With the values of σ_{TS} , 2c and Young's modulus (11 GPa), it can be calculated from eqn (1) the effective (or apparent) surface energy of the materials, which are shown in Table 1. The three polygranular graphites

present similar surface energies, with a mean value $\gamma_{app.} = 6.4\ Jm^{-2}$.

By using the above mean value of $\gamma_{app.}$ in eqn (1), it is possible to determine the theoretical tensile strength of the polygranular graphites as a function of $(2c)^{-1/2}$, which is a straight line that passes through the origin (Fig. 1). The crude use of the Griffith theory (with the considered flaws and the same apparent surface energy) seems to account for the experimental behaviour of tensile strength of the three polygranular graphites.

If the data of the AGX coarse-texture graphite ($2c = 1.4 \times 10^{-3}$ m and $\sigma_{rupt.} = (4.4 \pm 1.1)$ MPa [5]) are included in Fig. 1, it is observed that the experimental value differs from the theoretical value by -45%. This difference may be smaller, indeed negligible, if it were used the manufacturer data of tensile strength (6-10 MPa). The manufacturer data of tensile strength might be more representative because for materials with large grain size, as the AGX, larger samples for testing have to be used in order to avoid grain size effects [1].

It should be observed that since the considered flaws may present different radius of curvature and are not atomically sharp, the mean calculated surface energy should really be regarded as an effective (or apparent) surface energy.

The results obtained here for the polycrystalline carbon materials are similar in some extent to those obtained by Griffith for soda lime glass, a truly isotropic amorphous material, using sharp flaws introduced on the glass surface with a glass-cutter's diamond.

An analysis based on an atomistic approach [8] may clarify some aspects discussed here and be useful in the study of the fracture of other materials.

Table 1. Tensile strength, critical flaw-size, and calculated apparent surface energy of the polygranular graphites.

Material	σ_{TS} (MPa)	2c (m)	$\gamma_{app.}$ (Jm^{-2})
H-451	16.0 ± 1.6	3.7×10^{-4}	6.8
IG-110	25.7 ± 1.9	1.4×10^{-4}	6.6
AXF-5Q	65.1 ± 5.5	1.9×10^{-5}	5.7

Acknowledgements

This work was partially supported by the Brazilian agency CAPES.

References

1. Brocklehurst, J.E., in *Chemistry and Physics of Carbon*, Vol 13, ed. P.L. Walker Jr. and P.A. Thrower. Marcel Dekker. New York, 1977, pp. 145-279.
2. Griffith, A.A., *Phil. Trans. Roy. Soc.* 1920, A221, 163-198. (This article has been republished with additional comments in *Trans. ASM.* 1968, 61, 861-906.)
3. Griffith, A.A., in *Proc. of the First Int. Congress of Appl. Mechanics*. ed. C.B. Biezeno and J.M. Burgers. J. Waltman. Delf, 1924, pp. 55-63.
4. Orowan, E., *Rep. Prog. Phys.* 1949, 12, 185-232.
5. Burchell, T.D., *Carbon*. 1996, 34, 297-316.
6. Lawn, B.R., *Fracture of Brittle solids - 2nd ed.* Cambridge University Press. Cambridge, 1993.
7. Davidge, R.W. *Mechanical Behaviour of Ceramics*. Cambridge University Press. Cambridge, 1979.
8. Emmerich, F.G., To be published.

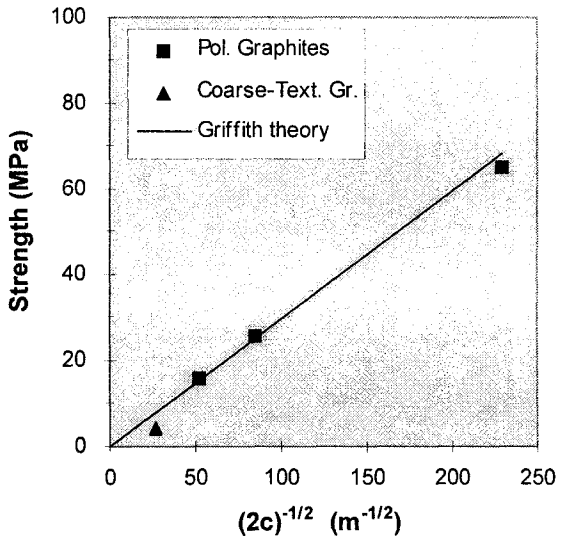

Figure 1. Tensile strength (σ_{TS}) of the graphites as a function of $(2c)^{-1/2}$. The theoretical curve was obtained from eqn (1) with E = 11.0 GPa and $\gamma_{app.} = 6.4\ Jm^{-2}$.