ON THE MECHANICAL CHARACTERISTICS OF COMMERCIAL CARBON FIBERS

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Introduction

The use of carbon fibers in composites is the most successful commercial application of solid carbons within the past few decades. Notwithstanding their success, questions remain regarding how to tailor and optimize their properties. Addressing these questions is important in order to develop improved composites and new applications for carbon fibers [1].

Being a vertically integrated supplier of advanced composites, Hexcel is unique in its ability to apply decades of technology to address every single aspect of the carbon fiber and composite production process. This study examines some key aspects known to impact the performance of carbon fibers. A more comprehensive assessment of structure-property relationships will be given elsewhere [2].

Experimental

Commercial fibers were produced from various precursors (polyacrylonitrile, rayon, mesophase and isotropic pitches,

carbon whiskers, which are tougher (because of their multiple yet small crack nucleation sites or steps).

Figure 1 also shows contours of constant Young's modulus of elasticity, E. In commercial fibers, toughness is seen to be gained at the expense of E. This is why commercial fibers are termed HS (for high strength) or HM (for high modulus), with a more ideal combination of properties being displayed by short graphite whiskers. Figure 1 thus suggests that optimum HS-HM fiber properties are attainable, but they might require important changes in fiber manufacturing conditions.

Given the impact that flaws and structural discontinuities have in determining fiber properties, relatively little has been published on relating surface area and porosity characteristics to ultimate fiber performance. Surface areas of carbon fibers are reported to be low (< 10 m^2/g) when tested by external fluid probing methods like gas sorption or mercury porosimetry. Yet typical fibers are rich in elongated (needle-like) but "closed" pores, as determined by small-angle X-ray scattering (SAXS), or by the ratio R_{ac}, as illustrated in Figure 3. If R_{ac} is low (say < 0.2, as expected in theory [13]), the planes of weakness within it will act as effective crack stoppers, but the toughness will be low due to the high concentration of planes of weakness or pores. Conversely, if $R_{ac} > 0.2$, the material will behave as a continuum and would exhibit brittle fracture upon crack propagation. The fact that the toughness of many commercial fibers is lower than might be anticipated from their R_{ac} values is likely to be due to external and internal flaws introduced in the fibers during their manufacturing processes.

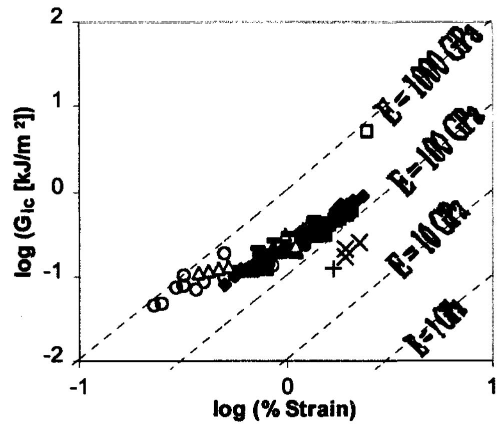

Figure 1. Toughness (G_{Ic}) vs. % strain for commercial carbon fibers [4,8]. Precursors: filled symbols, PAN; open symbols = pitch; crosses, rayon; hyphens, vapor-grown; grey square = graphite whiskers [9]. Contours represent lines of constant Young's modulus of elasticity.

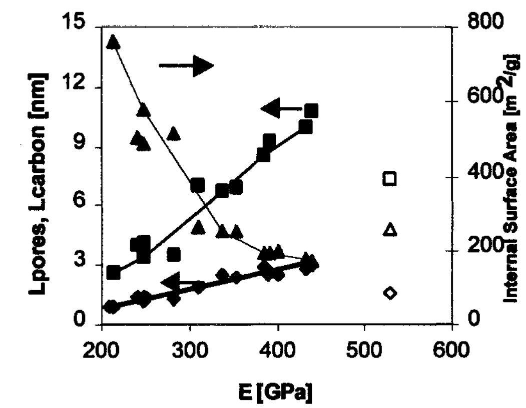

Figure 2. Relationship between Young's modulus (E) and physical parameters (surface area and pore structure) of a commercial carbon fiber. Adapted from Refs. 10 and 11. Symbols: ♦, L_{pores}; ■, L_{carbon}; ▲, surface area; closed symbols = fibers subjected to various heat treatments; open symbols = commercial product.

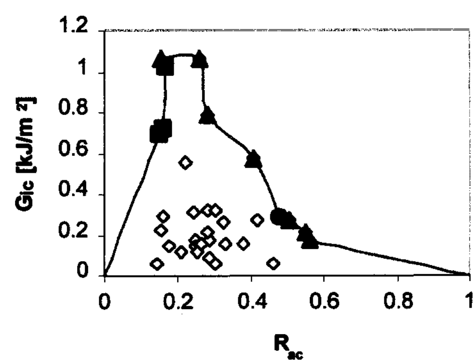

Figure 3. Toughness (G_{Ic}) vs. R_{ac} for PAN-based commercial carbon fibers. Symbols: ■, Hexcel; ▲, Toray; ●, Toho; ◊, others.

References

1. Abraham T. Carbon/graphite fibers: highlighting new applications. Norwalk CT: BCC Inc. 1993: 1-91.
2. Hartman et al., in preparation.
3. Edie DD. The effect of processing on the structure and properties of carbon fibers. Carbon 1998;36(4):345-362.
4. Peebles LH. Carbon Fibers. Boca Raton, FL: CRC Press, 1995.
5. McIntyre JE, Denton MJ. Fibers, manufacture. In: Kroschwitz JI, editor-in-chief. Encyclopedia of polymer science and engineering, 2nd ed., vol 6. New York, NY: Wiley. 1986:802-839.
6. ASTM Standard Test Method D4018. Properties of continuous filament carbon and graphite fiber tows. Conshohocken, PA: ASTM, 1993.
7. Sibilia JP. A guide to materials characterization and chemical analysis, 2nd ed. New York, NY: VCH Publishers, 1996.
8. Starr T., Lovell DR, Carbon and high performance fibers directory, 6th ed. New York: Chapman & Hall, 1995.
9. Bacon R. Carbon fibers from rayon precursors. In: Walker Jr. PL, Thrower PA, editors. Chemistry and physics of carbon, vol 25. New York, NY: Dekker, 1973:1-102.
10. Jain MK, Abhiraman AS. Conversion of acrylonitrile-based precursor fibers to carbon fibers. J Mater Sci 1987;22(1):278-300.
11. Reynolds WN. Structure and physical properties of carbon fibers. In: Walker Jr. PL, Thrower PA, editors. Chemistry and physics of carbon, vol 11. New York, NY: Dekker, 1973:1-67.
12. Pittman, Jr. CU, Jiang W, Yue ZR, Leon y Leon CA. Surface area and pore size distribution of microporous carbon fibers prepared by electrochemical oxidation. Carbon 1999;37(1):85-96.
13. Gordon JE. The new science of strong materials, 2nd ed. Middlesex, UK: Penguin Books, 1976.