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Nonlinear Behavior Of Carbon Filaments In Bending*

W. S. Williams and D. Steffens**

Union Carbide Corporation
Carbon Products Division
Parma Technical Center
Parma, Ohio 44130

ABSTRACT

The bending behavior of 7-micron-diameter carbon filaments at room temperature has been studied using the Sinclair loop test.[1] A loop is formed in a vertical plane and the loop diameter is measured for each of several loads applied to the free end. The initial regions of the stress-strain curves for such deformation give values of Young's modulus in agreement with those determined in tensile tests. However, all carbon fibers tested showed nonlinear behavior at higher strains. The nonlinear region is essentially reversible and similar in shape to that produced by a stranded, high modulus stainless steel wire. We propose that the nonlinearity observed for both stranded wire and carbon filaments results from slippage of subunits (strands or microfibrils) past each other when the stress becomes high enough to overcome "friction" (cross-linking in the case of carbon). Since the onset of nonlinearity is at approximately the same strain (0.5%) for all carbon filaments independent of modulus, the following relations holds: $Y \cong 5 \times 10^{-3} E$, where E is Young's modulus and Y is a "yield stress" for the observed nonlinear though reversible deformation. Carbon filaments break in tension at approximately this same strain. Hence, $\sigma_t \cong Y$, where σ_t is the tensile strength. A theory of brittle fracture in glass and bcc metals which includes these relations has been advanced by Marsh.[2] We suggest that this theory also describes fracture in carbon fibers: in tension, a flaw-free carbon fiber breaks because of local stress concentrations which develop when some cross-linkages fail. This type of internal damage is the analog of plastic flow in glass.

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**Now at Massachusetts Institute of Technology.

1. D. Sinclair, J. Appl. Phys. 21, 380 (1950).
2. D. M. Marsh, Proc. Roy. Soc. A 282, 33 (1964).