PIEZORESISTANCE OF CARBON FIBERS

D.B. Fischbach & K. Komaki
Department of Mining, Metallurgical & Ceramic Engineering FB-10, University of Washington, Seattle, Wash. 98195

A few studies on the change of electrical resistance R of carbon fibers with applied stress have been reported (1-3) for fibers from PAN, using resistance bridge techniques. Resistivities ρ were confirmed to be high and found to be noisey; R increased with tensile strain, except for the highest modulus fibers where it decreased; changes were largely reversible; and the results were explained in terms of contact resistances within the substructure, with emphasis on ρ increases (2). The piezoresistance characteristics are being further investigated as part of a study, by both electrical and dynamic mechanical (torsion pendulum) techniques, of the micromechanical behavior of carbon fibers. Preliminary results of an initial survey of the behavior of fibers from rayon and anisotropic (mesophase) pitch as well as PAN are described.

Individual fibers, ~5 cm long, were attached with glue and silver paint to a micrometer head/calibrated flexure spring tensile stressing device. The resistance was measured with a precision potentiometer and high impedance null detector/amplifier feeding a recorder. Initially, the current thru the fiber was kept very low, $\leq 0.5\ \mu A$, to minimize possible localized heating effects. Tests still in progress indicate that Ohm's law is obeyed for currents up to 15-20 μA (current densities to ~40 A/cm^2) for both stressed and unstressed fibers; but noise levels tend to increase greatly above ~15 A/cm^2, and there is increasing risk of irreversible R changes at higher levels. Measurements have been made on PAN-based fibers (Hercules A-S, HT-S, HM-S) and fibers from rayon (T-11 thru T-100) and anisotropic pitch (AP-27 - AP-53) from Union Carbide. SEM cross section area measurements on fibers from the same batch, and batch elastic modulus values E from the suppliers were used to compute nominal tensile strains ϵ from the measured loads.

The results are shown in Fig. 1 where the percent change in resistance is plotted against tensile strain and the numbers by the curves are E in Mpsi. The low-strain behavior is qualitatively similar for the three fiber types, and consistent with that reported for fibers ex-PAN (1-3): The slope S is positive for fibers with low E (and HTT), decreases with increasing graphitization and becomes negative for the most graphitic high E fibers. However, for fibers ex- hot stretched rayon, and anisotropic pitch, with $E \gtrsim 50$ Mpsi $dS/d\epsilon > 0$ and $S > 0$ for $\epsilon > 0.2\%$. The strain gage equa., $S = d/d\epsilon(\Delta R/R_0) = (1 + 2\nu) + d/d\epsilon(\Delta\rho/\rho_o)$, relates the piezoresistance to separate geometrical (elongation plus Poisson contraction) and resistivity terms. Poisson ratio values in the range $0.15 \lesssim \nu \lesssim 0.4$ have been reported for fibers (4,5). Then at low strains $\Delta\rho < 0$ for $S < 1.3$ to 1.8 depending on fiber type. In Fig. 1, $S \simeq 1.3$ for the ex-rayon 50 Mpsi fiber and $\simeq 1.8$ for the 35 Mpsi ex-PAN fiber. However, in the more graphitic fibers $\Delta\rho$ reverses sign with increasing ϵ and can develop high plus values at high strain levels.

Resistivity changes thus appear to dominate the piezoresistance behavior, and their origins must be sought primarily in the fibrillar substructure of the fibers. Tensile straightening of stacked layer-ribbon microfibrils may contribute directly to the resistivity decrease; but the influence of strain-sensitive internal contact resistances in a fibrillar series/parallel network seems more important (2). Dynamic torsional stiffness increases with tensile stress in graphitized fibers (6), suggesting increased coupling between adjacent fibrils due to straightening and Poisson contraction. This would also reduce parallel contact resistances, decreasing ρ. However, high tensile stresses will tend to open series contacts between fibril ends and may account for the resistivity increase at higher strains. Shorter continuous fibril lengths might be expected for fibers from anisotropic pitch and hot-stretched rayon than for ex-PAN fibers.

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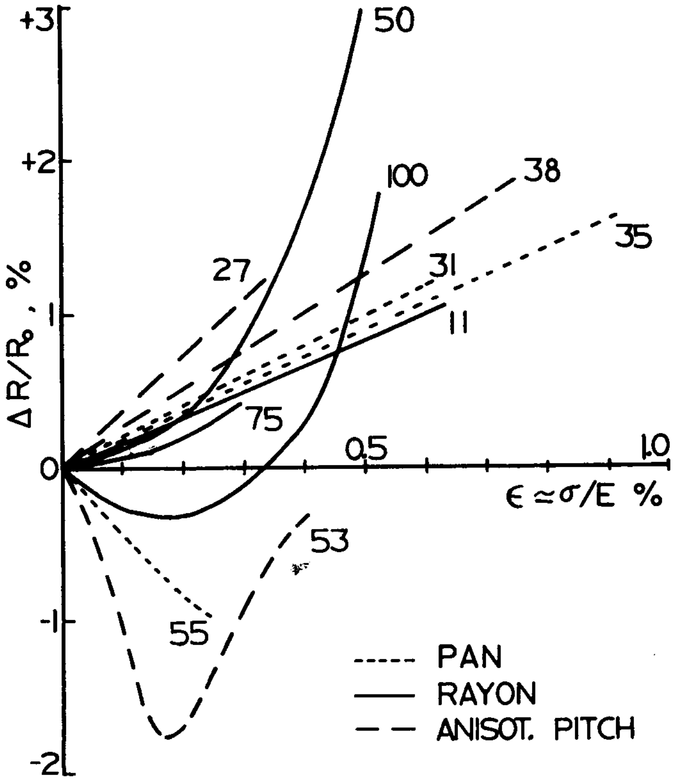

Fig. 1. Resistance change as a function of tensile strain for some representative carbon fibers.