Mechanical classification of carbon fibers from Raman and x-ray scattering

J. L. Niedziela, A. J. Miskowiec, J. J. Langford, R. J. Kapsimalis
Nuclear Nonproliferation Divison
Oak Ridge National Laboratory, Oak Ridge, TN 37831

Carbon fiber mechanical properties, in particular bulk modulus and tensile strength, originate from the nanoscale arrangement of graphitic domains, but the precise mechanism for the differences in macroscopic properties remain uncertain. We have investigated a selection of commercial carbon fiber samples covering a broad range of mechanical properties and production methods using non-destructive testing methods, including Raman spectroscopy and x-ray scattering. X-ray scattering accesses static structural elements on a length scale of 10-1000 nm, while Raman scattering probes vibrational dynamics of a sample volume on the order of microns, consequently the techniques provide complementary information. The scattering measurements combine to indicate significant correlation among several nanoscale observables and macroscopic mechanical properties. In particular, the interlayer lattice spacing in the carbon crystal matrix and the average size of both in- and out-of-plane graphitic domains measured by x-ray scattering are strongly correlated with the bulk modulus and tensile strength, and these quantities are directly correlated to Raman spectral details known to arise from disorder and strain in the carbon fiber matrix. For the graphitic domain size, the correlation to tensile strength and bulk modulus is strong enough that it can be considered a surrogate quantity across the evaluated range of mechanical properties. The interlayer lattice spacing and the graphitic domain size are intrinsically related to details of the carbon fiber production process, consequently this work reveals that a clear separation between carbon fibers of different classes is discernible from these nondestructive tools.