Highly oriented poly(vinyl alcohol) fibers modified with nanodiamonds: from effective structural modification to high tensile strength and modulus

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The morphological features and properties of the highly oriented poly(vinyl alcohol) fibers modified with nanodiamond and nanodiamond soot of detonation synthesis were investigated by wide-angle (WAXS) and small-angle (SAXS) X-ray scattering techniques, as well as by electron microscopy and mechanical testing methods. Applying those techniques yields the essential information on particle distribution within the matrix polymer, the effectiveness of modification and the relation of those features to the mechanical properties of the fibers, and as a result, their application opportunities. The effectiveness of modification can be defined as the ratio of gross quantity of the filler being introduced into the matrix to its volume fraction with particle sizes being in ~1-100 nm range. Measurements of the absolute intensity of SAXS suggested that in our case this ratio is unity for gross concentration of the filler varied from 0.5 to 3 vol.%. Thus it was shown, that the introduced nanodiamond soot particles were dispersed within the polymer matrix without aggregation, but with nanoparticles forming cloud-like structures. The nanodiamond soot treated with high-power ultrasonication was found to be more effective as to the modification of the mechanical properties of the oriented fibers in comparison to untreated soot and nanodiamond. The maximum increase in the longitudinal elastic modulus (from 30 GPa up to 45 GPa) and in the energy at break (from 3 J/g up to 6 J/g) was obtained for the fibers modified with the nanodiamond soot already at small (1 vol.%) soot content, that is technologically attractive. The increase in mechanical properties cannot be attributed to the molecular orientation within the fibrils, which was the same for all fibers regardless of the nanofiller content (as was proven by WAXS). Neither can these effects be interpreted in terms of additional cross-linking.

The measured values of the adhesive strength (in the ED-20 epoxy matrix) of poly(vinyl alcohol) fibers modified with the nanodiamond soot in amount of 1% by volume, were remarkably higher than that of the unmodified fibers. Maximum adhesive strength values of the modified fibers (42 MPa) were comparable to the adhesive strength value of the reference sample - steel wire (57 MPa) in the same epoxy matrix.

The obtained results suggest this kind of fibers to be a promising reinforcing component for the other types of polymer materials.