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The size and rate dependence of the large deformation response of polystyrene nanofibers

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ABSTRACT

The intertwined effects of macromolecular length scale and specimen size on the large deformation response of individual polystyrene (PS) nanofibers were investigated. Glassy PS fibers with diameters of 150–5000 nm were electrospun from seven monodisperse PS powders with molecular weights between 13,000 and 9,000,000 g/mol. Individual nanofibers were tested using a MEMS-based microscale testing platform under an optical microscope over six decades of strain rate ranging from 0.0003 to 200 per second. The uniaxial stress–strain response demonstrated not only unusual but also repeatable postyielding behavior including strain-softening, necking, and strain-hardening, unlike the brittle behavior of bulk PS. The aforementioned deformation mechanisms were exclusive to specific combinations of specimen size and molecular weight (molecular dimensions). Extremely low and high molecular weights resulted in glassy or craze-assisted brittle failure, whereas intermediate molecular weight sustained stable necking leading to ductilities exceeding 100%, and strain hardening that increased the fiber strength by 200% compared with bulk PS. A size dependent brittle-to-ductile transition occurred within the intermediate molecular weight regime wherein thin fibers showed pronounced strain-hardening behavior and 100–300% increase in failure strength which was reduced with increasing fiber diameter until brittle failure ensued. In addition, experiments over six decades of strain rate showed that nanofibers of specific combinations of molecular weight and diameter can sustain stable necking at localized strain rates reaching 25,000 per second, thereby resulting in rate-independent elongation and drastically improved capacity for energy dissipation.