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Polymer Nanocomposites for the Real World: Achieving Well-Dispersed Nanoplatelets, Nanotubes, and Nanoparticles by Solid-State Shear Pulverization

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A major stumbling block impeding widespread application of polymer nanocomposites concerns the inability of conventional process methods, e.g., melt processing, to yield well-dispersed nanofillers in many hybrid systems. We have addressed this issue by employing a novel, continuous process called solid-state shear pulverization (SSSP) that involves the use of a modified twin-screw melt extruder. Unlike melt extrusion, the industrially scalable SSSP process is done at temperatures below the melt transition temperature of semi-crystalline polymers or the glass transition temperature of amorphous polymers. The material being processed via SSSP is subjected to high shear and compressive forces, leading to multiple fragmentation and fusion steps and dispersion that is not hindered by thermodynamics limitations encountered during melt processing. Here we demonstrate that SSSP can be used to produce substantially higher levels of exfoliation of nanofiller sheets, e.g. silicate platelets from montmorillonite clay, as well as dispersion of multiwall carbon nanotubes and nanoparticles, than may be achieved by conventional melt processing. We also demonstrate that SSSP can be used for producing nanocomposites from a variety of polymers, including polypropylene, polyethylene, poly(ethylene terephhalate), poly(methyl methacrylate), poly(2-vinyl pyridine), and thermoplastic starch. Achievement of dispersion is characterized by various techniques, including transmission electron microscopy, x-ray scattering, conductivity, and physical aging (enthalpy relaxation). The stability of the nanofiller dispersion to subsequent melt processing of the product from SSSP is shown via in situ x-ray characterization during shear flow and ex situ x-ray characterization during static annealing. Improvements in macroscopic properties, including modulus, thermal stability, and conductivity, accompanying nanofiller dispersion have also been quantified.