Carbon Nanotube Enhanced Functional Carbon Fibers from Renewable Resources

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Lignin, a low-cost, abundant and melt spinnable precursor, was selected as an alternative for automotive carbon fibers; however, meeting the target mechanical properties has been challenging. The physical properties of lignin carbon fibers, specifically the tunable electrical and thermal transport, are suitable for high temperature functional applications such as furnace insulation, heating elements and electrical conductors. Carbon fiber mats from lignin precursors can be produced at a fraction of the cost of conventional amorphous and graphitic fiber materials. Pyrolysis of lignin precursors yields microstructures with near perfect turbostratic disorder and controllable degrees of graphitic order. In addition to kinetic evaluations of the conversion of the biopolymer into a high carbon content structure, we have investigated alternative approaches to control the oxidative stabilization and microstructural evolution resulting from pyrolysis and heat treatment. To expand the range of physical properties that are possible from lignin carbon fibers and circumvent some of the limitations associated with the completely random arrangement of crystallites, we examine the functionality of carbon nanotubes (CNT) bound in the carbonaceous matrix. In order to maintain low material and processing costs, this study only considers CNTs produced at ORNL using scalable synthesis. CNTs are mechanically dispersed into the biopolymer precursor prior to compounding above the lignin's glass transition temperature. The lignin + 1wt% CNT compound is melt processed into a continuous bundle of fibers. The biopolymer compound is converted into LCF via conventional thermal methods. Microstructural evaluations revealed that the CNT are aligned by melt spinning and bound in the carbonaceous matrix after pyrolysis. Mechanical property measurements revealed that compounding and melt processing lignin with CNTs produces significant increases in tensile strength (over 40%) over the pure lignin carbon fiber. This is indicative of a strong physical bond between the nanomaterials and the matrix along with enhanced microstructural alignment. We systematically varied the carbon structure from mostly amorphous to fully graphitic. Most interestingly is that incorporating a relatively small fraction of CNT consistently doubles the electrical conductivity in all carbonization conditions we examined. Incorporating 1wt% CNT into lignin carbon fibers increases the cost of the fibers from $3/lb to slightly over $6/lb which is acceptable for many functional applications. This technology is designed to be scalable and further reductions in cost could be expected with large scale production.