Sustainable, renewable nanomaterials may replace carbon nanotubes

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Research on cellulose nanocrystals may provide a viable alternative to other reinforcing fibers in commodity fiberthermoplastic composite materials.

Discussions on the use of nanomaterials have focused mainly on carbon nanotubes (CNTs). These have been touted as one of the most promising types of nanomaterials for commercial manufacturing, but most nanomanufacturing processes remain little more than expanded laboratory experiments. Questions of toxicity are still a concern, and accurate dimensional metrology and characterization are problematic. However, a natural nanocrystal-manufacturing process surrounds us. A newly discovered class of nanomaterials, cellulose nanocrystals (CNCs), are created from biomass through a process that has the advantage of already being sustainable and viable in bulk. Moving CNCs into the innovation pipeline requires determination of the basic manufacturing-metrology infrastructure needed to develop production processes.

Biomass surrounds us, from the smallest alga to the largest redwood tree. Cellulose, the world’s most abundant natural, renewable, and biodegradable polymer, occurs as whiskerlike microfibrils that are continuously biosynthesized and deposited in plant material. Natural cellulose fibers abound in plants such as grasses, reeds, stalks, and woody vegetation, and CNCs give strength to these plants. Therefore, the basic raw materials for new nanomaterial breakthroughs are already plentiful in the environment.

Cellulose is harvested from plants for many purposes, including paper manufacturing. Micro-dimensional crystalline-cellulose particles are currently used as an industrial processing aid. These particles are included in pharmaceutical and food products, so their biocompatibility has already been demonstrated. These commercially available cellulose particles are commonly referred to as microcrystalline cellulose and consist of micrometer-sized particles. However, the use of nanometer-sized cellulose particles—or cellulose nanocrystals—is expected to expand because of the advantages that nanoparticles can offer.

The forest-products industry, a $260 billion sector in the US economy, is entering into the realm of nanotechnology with the discovery of cellulose nanocrystals and the ability to purify them in bulk quantities. The National Institute of Standards and Technology (NIST), the US Department of Agriculture (USDA) Forest Products Laboratory, and the American Forest and Paper Association are collaborating in a public-private partnership to study cellulose nanocrystals for use as reinforcing materials.1 Recent research suggests that these agro-based fibers are a viable

Figure 1. High-resolution scanning-electron-microscopy images of freeze-dried cellulose nanocrystals (field of view is 2400nm on a side).
alternative to inorganic/mineral-based reinforcing fibers in commodity fiberthermoplastic composite materials.

CNCs are well known as reinforcing polymers because of their properties, including high strength and aspect ratio, and likely lower cost than other nanoscale reinforcements such as carbon fibers or CNTs. CNCs are composed of tiny crystalline regions that are the strongest component of wood fibers—about ten times stronger than the wood fibers themselves. CNCs typically have high aspect ratios, with diameters of about 10nm or less and lengths of hundreds of nanometers.

Reinforcing fibers are but one application for CNCs, however. Researchers at the US Department of Energy’s Pacific Northwest National Laboratory recently used CNCs as templates to grow unique metal nanoparticles that show promise for use in biosensors, catalysis, and photovoltaics. Examples include a method for producing novel porous titania materials and a simple ‘green’ method for preparing nickel nanoparticles.

At NIST we have successfully viewed cellulose nanocrystals with several microscopy techniques (see Figure 1). We have developed suitable sample-preparation steps and determined the differences between air-dried, aqueous, and freeze-dried material to assess the potential for artifact formation. The cellulose nanocrystals are well-dispersed and oriented randomly.

CNCs may be able to replace CNTs as reinforcing materials for many applications without causing the same safety concerns as CNTs. CNCs have been used as fillers in pharmaceuticals for many years, with no known detrimental biological responses. Literally tons of CNC can be generated each day while producing other viable products, such as glucose (for alternative fuel) and gypsum (for buildings). In addition, the use of lignocellulosic fibers derived from sustainable, annually renewable resources as a reinforcing phase in polymeric-matrix composites would provide positive environmental benefits with respect to ultimate disposability and raw-material use. The value of replacing CNTs with CNC has yet to be determined, but future work to further characterize these crystals and to develop the accurate metrology needed will help demonstrate the promise of this new and exciting material. Perhaps eventually airplanes could once again be composed of wood using sustainable, nanocellulose fiber reinforced composites.

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