Nanotechnology Applications in Forest Products: Current Trends

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Abstract

Over the past several decades, a significant world-wide research effort has been made in the application of nanotechnology to forest products. Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. Nanotechnology research roadmaps have been developed and applied to forest products globally. Many of the applications being developed provide great potential for improved forest products that offer improved material properties for a variety of consumer products. In considering nanotechnology and forest products, we can apply nanomaterials to forest products in the form of coatings, biocides and modified resins or we can derive nanomaterials from wood. Nanomaterials derived from renewable biomaterials like wood, especially cellulose and lignin will undoubtedly play a large role in future nanotechnology research efforts. Research focus areas for nanotechnology applications in forest products include: polymer composites and nanoreinforced materials; self-assembly and biomimetics; cell wall nanostructure; nanotechnology for sensors, processing and process control; and analytical methods for nanostructure characterization. High profile nanotechnology applications in forest products include optically transparent cellulose nanofiber paper and optically transparent cellulose nanocomposites for flexible electronic displays. Future needs of nanotechnology in forest products include the ability to have scalable nano-manufacturing by adapting conventional manufacturing processes or developing novel process equipment. It appears that we may be on the cusp of significant commercial applications of novel nanotechnology applications in forest products.

Keywords: nanotechnology, research, forest products, cellulose nanofibrils, applications

Introduction

Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. Nanotechnology research and development (R&D) in the U.S. is high priority research across all segments of science and engineering since the enactment of the National Nanotechnology Initiative (NNI) in 2001. The forest products industry in the U.S. developed a nanotechnology research roadmap in 2005 and more recently in 2010, recognized the study of cellulose-based nanomaterials as a signature research initiative. Nanotechnology research roadmaps have been developed and applied to forest products globally. Research focus areas for nanotechnology applications in forest products include: polymer composites and nanoreinforced materials; self-assembly and biomimetics; cell wall nanostructure; nanotechnology for sensors, processing and process control; and analytical methods for nanostructure characterization.

Nanotechnology Applications in Forest Products

At first glance, applications of nanotechnology in forest products might appear to be a relatively new development, but in actual fact, nanoscale materials have been used in the production of sized and coated paper for over a century. Colloidal materials which are systems consisting of a mechanical mixture of particles between 1 nm and 1000 nm dispersed in a continuous medium, usually water, are commonly used in paper chemicals, as well as in paints and coatings to protect wood. The terminologies used to describe nanomaterials become important because the term nanotechnology was first coined in 1974. Even though the term nanotechnology is relatively new, we have been in fact utilizing nanomaterials in production of man-made materials for many centuries and a number of good examples can be found in the popular scientific media including glazings for pottery, carbon nanofiber reinforced steel, emulsions for food, etc.

In considering nanotechnology and forest products, nanomaterials can be applied to forest products in the form of coatings, biocides and modified resins or nanomaterials can be derived from wood. Nanomaterials derived from renewable biomaterials like wood, especially cellulose and lignin will undoubtedly play a large role in future nanotechnology research efforts. High profile nanotechnology applications in forest products include optically transparent cellulose nanofiber paper and optically transparent cellulose nanocomposites for flexible LED displays. Wood protection applications have been a significant focus of nanotechnology including the utilization of nanobiocides and nanocarrier delivery systems in wood preservatives. Wood coating applications of nanotechnology are now becoming common in the consumer marketplace where coatings with improved scratch and abrasion resistance, hydrophobicity, ultraviolet light blocking and dust free surfaces are touted by commercial manufacturers.

Cellulose Nanomaterials

Cellulose nanomaterials are a large focus of research across the world as evidenced by six comprehensive literature reviews appearing in the peer reviewed literature in 2010 and 2011 [1-6]. Cellulose nanofibers (CNF) are prepared in four different forms: 1) bacterial cellulose nanofibers, 2) cellulose nanofibers by electrospinning, 3) micro- or nano-fibrillated cellulose plant cell fibers, and 4) nanorods or cellulose nanocrystals. Processing techniques have a significant impact on the adhesion properties of the resulting cellulose nanofibers in composite material applications. The behavior of cellulose surfaces in polymers as well as their interaction with different chemicals is of great importance in their current and future applications in nanocomposites. The mechanical performance of nanocomposites, for instance, is dependent on the degree of dispersion of the fibers in the matrix polymer and the nature and intensity of fiber-polymer adhesion interactions. Challenges in the scale-up of producing commercial quantities of cellulose nanofibrils for materials applications include: scalable processing methodologies, adequate methods to dry the fibrils and maintain the nanoscale dimensions, and reduction in energy requirements and production costs.

Cellulose nanomaterial applications that appear to be close to commercial production include: cellulose nanopaper, paper and paperboard coatings, aerogels and foams from nanofibrillated cellulose, bacterial cellulose for clothing, artificial veins and bone scaffolding, as well as spray dried cellulose nanofibrils as a pharmaceutical excipient. Barriers to the commercialization of CNF are based on large scale supply availability. So far, only modest investment has been made in scale up processes from lab to pilot scale. Certain applications will require large quantities of CNF to evaluate in larger scale, real world manufacturing processes. There is a lack of significant, coordinated effort among research organizations (academia, government, industry) and potential customers in transitioning CNF technologies into the marketplace. Also, there are uncertainties in CNF pricing under commercial production conditions, potential safety issues and regulations. One positive step that is currently underway is the development of ISO cellulose nanomaterial standards.

Future Needs of Nanotechnology in Forest Products

Future needs of nanotechnology in forest products include the ability to have scalable nano-manufacturing by adapting conventional manufacturing processes or developing novel process equipment. For example, a goal might be to adopt papermaking processes where we currently self-assemble wood cells on the micron and millimeter length scale at 100 kilometers per hour. Novel composite manufacturing processes will need to be developed for automobiles, adhesives, ballistic applications, coatings, biomedical applications as well as drug delivery. Concerns, challenges and opportunities of nanotechnology in forest products will include addressing consumer perception issues of sustainability as well as health risks. There may be market opportunities to improve existing products with nanotechnology such as the development of intelligent packaging.

It appears that we may be on the cusp of significant commercial applications of novel nanotechnology applications in forest products. The current applications of nanomaterials in wood protection and wood coatings as well as the near to market potential for some cellulose nanofibril material applications is an exciting development in the forest products industry. Perhaps the future is now?

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