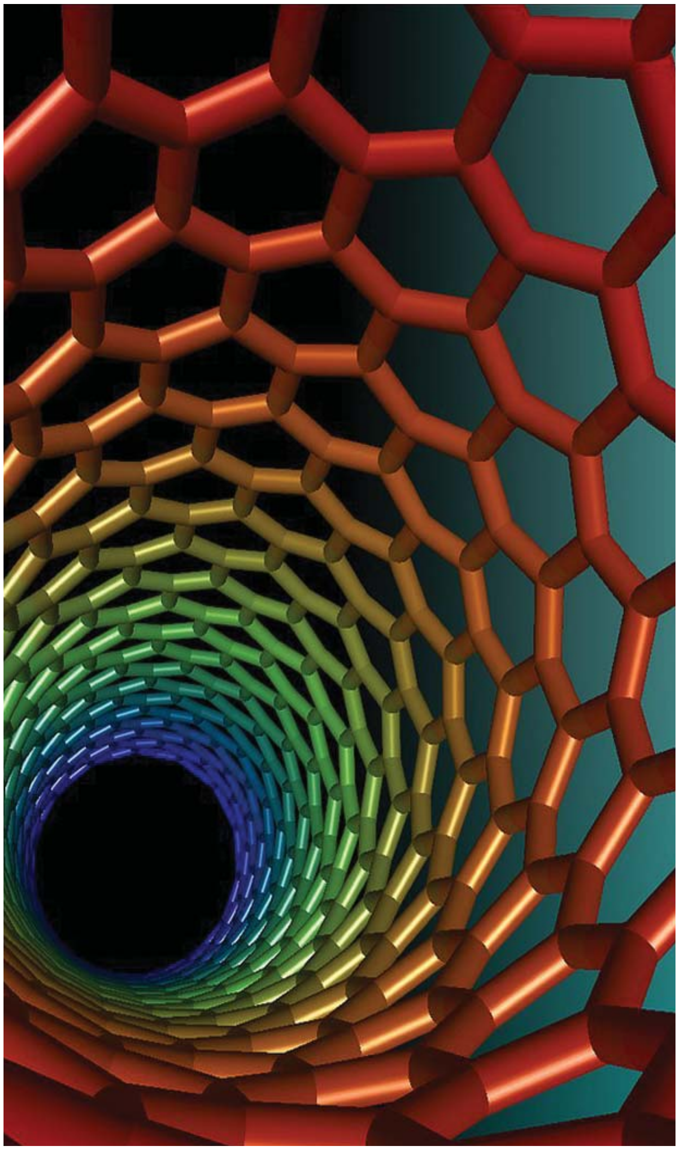
Small World… Big Results

Nanotechnology and forest products are teaming up to create the "Material of the 21st Century" – Coated Paper and Paperboard.

By Phil Jones and Ted Wegner



Nature has utilized nanostructures since the earth began to cool 4.5 billion years ago and has blessed us with a rich legacy of examples to stimulate our imaginations. These structures range from the micro and nanostructures of minerals to the intricate molecular mechanisms of life. While it is now possible for us to manufacture structures that do not occur in nature, we remain strongly guided by the immense variety of those that do. Some of the most important applications of biotechnology are likely to be the tuning-up of useful cellular machinery that Nature has not yet had time to evolve to its most efficient form and to modify functioning and material properties of sustainable and renewable biological materials for specialized human uses.

We have been doing something similar for a century and a half with organic molecules—dyes, for example, or synthetic fibers—and Japanese metallurgists were inventing new microstructures over a much longer history to create edged tools and weapons of legendary quality. Those involved at the time were not aware of the nanoscale origins of their products, but they were producing them just the same.

Some of the most important developments in nanotechnology are occurring at the interface between biological and inorganic systems. The current emphasis of the new branch of science known as "nanotechnology" is the development of macro-scale materials with nanoscale structures and functionality. The distinctive feature of nanoscience is the increased understanding and technical control of nanoscale structure and functionality. This is not about new materials but about new processes, new forms, and new functionalities for old materials.

At its fundamental level, wood is made up of nano-dimensional cellulose nanocrystalline fibrils that have extremely high strength—approximately 25% the strength of carbon nanotubes. Because of this, plus our emerging ability to manipulate cell wall nano- dimensional architecture and functionality, the abundance of lignocellulosic materials, and our emerging ability to self-assemble nanodimensional materials into macro-scale materials and products, we can expect that forest products will emerge as "the material of the 21st Century" just as steel was in the 19th Century and plastics in the 20th Century.

NANOTECHNOLOGY

A nanometer (nm) is one billionth of a meter, which is approximately the size of an atom. Above 100 nm, bulk properties rule. From one nanometer up to 100 nm, quantum mechanics rules and very interesting things can happen. These are the dimensions of proteins, viruses and other biological molecules. The United States and many other countries are spending billions of dollars per year on nanotechnology research, development and deployment and have built many new facilities with state-of-the-art analytical and test equipment. It is anticipated that substantial developments will result and some people believe that we are at the start of the next industrial revolution. In this new industrial revolution, we will use materials much more efficiently and effectively, creating currently unheard of multi-functional materials and products that are sustainable, renewable, and recyclable[1].

Nanoprobe IV Atomic Force Microscope. The United States and many other countries are spending billions of dollars per year on nanotechnology research, development and deployment and have built many new facilities with state-of-the-art analytical and test equipment.

A variety of natural materials with nano-dimensional architectures, such as seashells, bone and teeth are being successfully studied and most of their unique properties are being shown to originate from nanoscale structures and bonding. In the case of seashells it has been shown that only 2% protein holds together the calcium carbonate platelets and results in a very strong material[2]. In the case of seashells, such as abalone, the nano-action is taking place with the proteins between calcium carbonate plates that are 400 to 500 nm thick. The stacking of these plates leads to a photonic structure, or optical band gap, that does not allow light to pass and thus gives the inside of the shell the silvery metallic appearance[3]. Understanding how nature achieves this efficient use of binder will allow the development of higher performance, more cost-effective coatings.

In the case of bones and teeth, mineral platelets around 20 to 30 nm thick are bonded together to provide an extremely tough structure. Platelets 30 nm and thinner have been shown to have close to theoretical strength, as any defects at that scale, will have no effect on crack propagation. Because of their small size, unique properties, and extremely high surface areas, small amounts of nano-dimensional materials can create large changes in macroscopic material properties and will provide significant opportunities for paper coatings. In the past, coatings have been developed through diligent formulation guided by "bulk" measurements such as rheology, pore structure, light interactions and electron microscopy. We now have the tools to see and manipulate these building blocks and to use the understanding at the nano-scale to guide the development of higher performance coatings.

NEW TOOLS

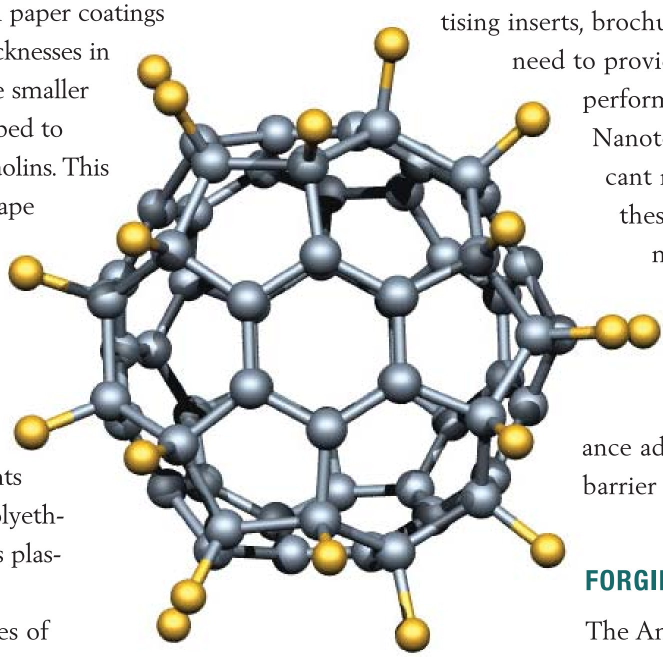
Until this fairly recent development and availability of new analytical tools such as atomic force microscopy and new computational data manipulation and storage capabilities, wood and paper were considered to be highly complex and very difficult materials to effectively study. We now have the opportunity to study wood and paper in new ways and to develop a number of high-strength and lighter weight materials. This opportunity includes the ability to make wood intrinsically stronger, resistant to biological decay, and more stable to the effects of water and weathering. In addition, the fundamentals of pulping and papermaking are governed by nanoscale interactions and we anticipate substantial benefits in process efficiency and product properties from the use of nanotechnologies.

NANO-PAPER COATINGS

We have already seen the emergence of a number of nanomaterials for use in the paper industry. Most familiar, are various retention aid systems which use nano-sized components to interact with the "fines" (nano-components) present in the wet end. In paper coatings, we are seeing the use of nano-dimensional (<100nm) binders ranging from latexes through starches and core-shell materials. These newer binders are offering higher stiffness, improved blocking, better blister resistance and opportunities for enhanced functionality. As an example, the most commonly used latexes are between 1200 and 1600 Angstroms (120 to 160 nm) in diameter and were empirically developed several decades ago when the commodity kaolins dominantly used in paper coatings were comprised of platelets of thicknesses in this range. We are at a point where smaller diameter binders are being developed to match the much thinner crystal kaolins. This represents a new era of particle shape engineered minerals. These thin crystal kaolins are showing useful improvements in coating strength performance[4]. Another example includes the development of enhanced barrier coating materials using nano-dimensional components with a view to replace wax and polyethylene-coated paperboard as well as plastic-based packaging.

Optical and print performances of paper and paperboard coatings depend on how the components are assembled and how the pore structures develop. Many additives have been created that modify the consolidation and other processes to control the migration and assembly of components during dewatering and especially drying, when surface tension forces can influence significantly the final structures. One of the challenges is changing the paradigm of the need for low viscosity. As you move to the increased use of nano-dimensional building blocks, the increased surface area and increased number of particles make dispersion and stabilization more challenging. However, this is exactly where nanotechnology is blazing a trail, looking at the more efficient use of materials by addressing issues such as dispersion, stabilization and assembly. There are a number of research centers outside the paper industry studying "self assembly" of structures and we are working to identify and make contact with key researchers at these centers in order to harness their findings in our industry. Most notable is George Whitesides at Harvard University, who sees paper as an economic, sustainable material that deserves wider appreciation.

In short, nanotechnology offers the opportunity to transform the design and production of coated paper and paperboard materials and it plays well to market needs. Paper is used predominantly in catalogs, magazines, advertising inserts, brochures and copy paper where we need to provide improvements in application performance with lower weights. Nanotechnology could play a significant role in delivering solutions to these challenges by providing new mechanisms for delivering optical performance and higher strength interactions. Similarly, paperboard will benefit from these performance advantages as well as improved barrier coating properties.



"Little" Enginnering.
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FORGING AHEAD

The American Forest and Paper Association (AF&PA) and their Agenda 2020 Technology Alliance program have set up a task group that has developed a nanotechnology roadmap outlining many of the potential opportunities (www.nanotechforest.org). More recently, a Consultative Board for Advancing Nanotechnology (CBAN) for Forest Products has been established as a way for the industry to interact with the major federal government agencies having nanotechnology programs through the National Nanotechnology Initiative.

At our first CBAN meeting we encountered a very high level of interest from a number of agencies such as National Institute of Standards and Technology (NIST), the Environmental Protection Agency (EPA), Department of Energy (DOE), the United States Department of Agriculture (USDA), and the Forest Service. The image of wood as a renewable source of material that is also a sink for carbon dioxide is of great interest. We discussed forest products being part of a biorefinery where, like oil, wood would be converted into energy and chemicals as well as materials' building blocks such as nano-dimensional crystalline fibrils and nano-dimensional self-assembled architectures.

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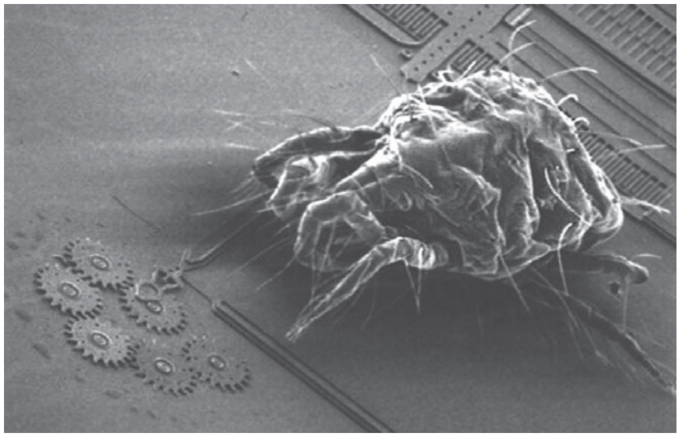
The AF&PA Agenda 2020 nanotechnology task group, which has representation from industry, academia, and federal departments and agencies has identified six theme areas for further study that are thought to be the key to re-inventing the forest products industry. The six areas are:

- Achieving lighter weight, higher strength materials
- Producing nanocrystalline fibrils from wood
- Controlling water/moisture interactions with cellulose
- Producing hyper-performance nanocomposites
- Capturing the photonic and piezo-electric properties of lignocelluloses
- Reducing energy usage and reducing capital costs in processing wood and paper to products.

Each of these areas is to be translated into fundamental cross-cutting science themes at a proposed workshop at NIST.

The plan is to meet with key representatives of government agencies as well as representatives of taskforces from the chemical, pharmaceutical and semiconductor industries and extend their already funded programs to include forest products. The government agencies as well as other industries are already engaged in Nanotechnology programs that have similar aspirations as the forest products industry and we have the opportunity to pool resources to accelerate these developments.



Another World. SEM (scanning electron microscope) image of a dust mite approaching a gear train. The gear train is microscopic in dimension, each gear tooth is smaller than a human red blood cell. The gear train is connected to a microscopic motor and acts much like the transmission in your car, but it is so small that you can not see it without the aid of advanced scientific microscopes. This device is an example of real things being made with nanotechnology.

Much of the above may be a surprise to many readers, but it is important to carry the message forward to a wider audience that forest products represent a vital part of our future as "the material of the 21st Century." In particular, the industry needs to remain engaged and be active in these endeavors. ■

References

1. "The USA National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel", USA President's Council of Advisors on Science and Technology, May 2005.
2. Whaley. S. R., English, D.S., Hu, E.L., Barbara, P., Belcher, A.M., "Selection of polypeptides with semiconductor binding specificity for directed nanocrystal assembly" Vol 405 Nature 465-468, 2000.
3. Vukusic, P., Hallam, B., and Noyes, J., "Brilliant Whiteness in Ultrathin Beetle Scales", Vol 315 Science, 19 January 2007.
4. Husband, J.C., Preston, J.S., Gate, L.F., Blair, D., and Creaton, P., "Factors Affecting the Printing Strength of Kaolin-based Paper Coatings", 2007 TAPPI Coating Conference Proceedings, April 2007. Norman, D. A. "Emotional Design."

Phil Jones is Director Technical Marketing & New Ventures at Imerys Pigments in Roswell, Georgia. He can be reached at: pjones@imerys.com. Ted Wegner is the Assistant Director at the U.S. Forest Products Laboratory in Madison, Wisconsin.