Nanocellulose

A sustainable nanomaterial derived from wood pulp with applications in composites, food, cosmetics and pigments

Found in plants, bacteria and algae, cellulose is the most abundant natural substance on earth, but its mechanical properties are anything but common. It is both strong and flexible, making it a suitable base for an exciting new class of materials: nanocellulose. Nanocellulose promises to improve everyday materials such as paints, packaging, cosmetic bases and pigments, food modifiers, sensors, and biomedical devices. The Sustainable Nano-Biocomposites lab in the chemical engineering department at McMaster University is working to make this promise a reality. The lab is characterizing the material, studying its properties, inventing new forms and developing processing methods. Through its efforts, nanocellulose materials have the potential to replace current technologies that are based on non-renewable resources while offering better performance.
Research Program

Research in the Sustainable Nano-Biocomposites lab focuses on unresolved scientific issues regarding the design of new nanocellulose composites, including how to improve the compatibility of nanocellulose with other composite components and how to thoroughly measure its physical, chemical and mechanical properties.

The lab works with two types of cellulose nanoparticles: nanofibrillated cellulose (NFC), which can be considered “spaghetti-like;” and nanocrystalline cellulose (NCC), which is more “rice-like”. Although these particles are nanometers in dimension, they retain the biocompatibility, non-toxicity and stability of cellulose. As a result of their size, they possess unique optical and mechanical properties. For example, their long aspect-ratio makes them ideal to use as strengthening agents in gels, foams and plastics. Nanocellulose can also be used to make brightly-colored iridescent coatings that are similar to butterfly wings and beetle shells.

Impact

The lab is committed to a vigorous course of research and works to disseminate its finding to the broader community. Work by the lab’s founder, Emily Cranston, has already played a noteworthy role in shaping the science of nanocellulose. Published in leading journals, a complete list of citations can be found at: http://chemeng.mcmaster.ca/cranston.html. Highlights of her research findings include:

- Extensive characterization of nanocellulose
- Patterned, aligned and oriented nanocellulose surfaces
- Multilayer films containing NCC and polyelectrolytes
- Surface functionalization of NCC
- Nanocellulose reinforced hydrogels
- Mechanical properties of nanocellulose based on buckling mechanics
- Adhesion and surface forces between cellulose and other polymers

The iridescent colors of a butterfly are mimicked by a nanocellulose coating developed in the Sustainable Nano-Biocomposites lab at McMaster University.

From tree to nanoparticle

While it can be used to coat paper and hardwood flooring, nanocellulose has potential applications in many other products.
More Surface is Better Surface

One advantage of using nanocellulose is that a small amount has a very large surface area, assuming the nanoparticles remain well dispersed. To ensure this dispersion, the lab is working to optimize the surface interactions between host materials and nanocellulose. This work has led to a number of key findings.

When nanocellulose is produced, it forms a stable colloidal suspensions (in water and in some organic solvents), and the particles are charged and hydrophilic. Its surface properties can be tailored to enhance compatibility and dispersability in a number of ways:

A) changing the surface charge (from negative to positive) or changing the charge density;
B) attaching polymers or small molecules to the surface through chemical bonds; or
C) coating the nanoparticles with polyelectrolytes or surfactants.

The exact surface modification needed depends on the intended application but there are many possible options.

To better understand and improve compatibility for future applications the Sustainable Nano-Biocomposites lab is now investigating the adhesion and forces between nanocellulose and various composite components using an atomic force microscope. By gluing a small particle of an important material onto a sensitive spring the researchers can probe how materials interact in various environments. Additional research will study how nanocellulose coatings wrinkle when compressed in order to determine stiffness, strength and cracking tendencies. The combination of these techniques will help to decipher the link between chemistry, materials structure and overall performance.

Three ways of tailoring the surface properties of nanocellulose

- Fibre-like, microns long × 5 nm cross section
- Flexible
- Amorphous and crystalline regions
- Gels easily

- Needle-shaped, 100 nm to 200 nm × 10 nm
- Highly crystalline
- Strong (E=150 GPa)
- Forms liquid crystal suspensions
Industrial Context

Given the challenges facing the forestry industry, research into nanocellulose is timely. As traditional products such as newsprint decline, nanocellulose offers a replacement market for pulp producers. Several companies are already moving in this direction. Notably, Domtar recently announced that it will begin producing nanocrystalline cellulose (NCC) at its demonstration plant in Windsor, Quebec. However, the commercial success of nanocellulose depends upon the development of markets for this sustainable material.

The Sustainable Nano-Biocomposites lab is committed to helping Canada’s forestry sector seize this opportunity. The lab’s research program aims to overcome the limiting factors in nanocellulose adoption, including: compatibility between natural and synthetic components, reproducible manufacturing, standardizing nanometrology and handling procedures, and evaluating potential toxicity, biodegradability and shelf-life.

Leadership

The Sustainable Nano-Biocomposites lab was founded by Emily D. Cranston, assistant professor of chemical engineering. She has more than a decade of experience designing high-performance materials to replace those that are based on non-renewable resources by using biological components. In the lab, Cranston leads a team of post-doctoral fellows and graduate students who are working on various aspects of the nanocellulose challenge.

Lab Capabilities

- Atomic force microscopy
- Electron microscopy
- Polarized-light microscopy
- Elemental analysis
- Zeta potential
- Thermal analysis
- Dynamic light scattering
- Surface plasmon resonance
- Quartz-crystal microbalance

Lab Expertise

- Surface and corrosion science
- Fibre technology
- Soft matter and polymers
- Colloid/physical chemistry
- Nanotribology
- Surface forces
- Nanomaterials
- Biomimetics
- Pulp and paper

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