Introduction to the Special Issue on Nanocellulose Composites

Cellulose nanomaterials (CNs) are at the convergence of nanotechnology and bio-sourced material trends and are currently of considerable interest. CNs are a new class of nano-scale, cellulose-based building blocks extracted from trees and plants as well as certain animals, bacteria, and algae. CNs are not a single material type but a family of materials with different characteristics, which largely result from differences in source and preparation methodology. Here we focus on plant- and tree-derived CNs.

CNs derived from trees and other plants are renewable and environmentally sustainable, have the potential to be produced in large volumes, and are projected to be less expensive than many other nanomaterials. They also have an impressive strength-to-weight ratio and, in their unmodified state, have so far shown few environmental, health, and safety concerns (*Cellulose nanomaterials - A path towards commercialization workshop report, Washington D.C., 2014*). Not just very fine fibers, their unique combination of characteristics (e.g., very high surface area, transparency, ability to self-order in solution) offer new opportunities for bio-based materials, many of which are only beginning to be explored. Consequently, although derived from trees and other plants, CNs may very well be used in applications far different from which these materials have historically been used.

Such breadth of opportunity creates challenges in trying to compile a useful issue from this rapidly growing technology area with such varied perspectives. Therefore, in this special issue, we focus specifically on the use of CNs in composite materials. We offer a snapshot of the current state-of-the-art and future direction of a portion of the emerging and very dynamic field of nanocellulose composites. To better reflect the growing consensus of the need for research more directly supporting nanocellulose composites applications, we solicited overviews in specific application areas for this special issue in addition to novel research manuscripts. In the overviews section, for example, Sabo *et al*. provide examples of a variety of advanced applications that are being explored on nanocellulose-enabled electronics, energy harvesting devices, and smart materials and sensors. They also suggest several other related applications that may be possible. In a very different application area, Stark discusses the performance requirements for packaging films and the effects of CNs on them. She also explores future opportunities for such materials given current trends in packaging. Clemons provides a review and outlook on the relatively recent area of continuous fibers from CNs, both those spun from nanocellulose dispersions as well as in combination with polymers. The wide variety of spinning approaches and motivations for doing so are analyzed.

On the research front, the solicited papers provide cutting-edge discoveries on overcoming the shortcoming in CN-based composites to leverage their applicability in a wide variety of sectors. For example, Orellana *et al*. investigated the feasibility of CNs and polyethylene glycol (PEG) as toughening agents for polylactic acid and polylactic-polyacrylic acid graft copolymer. They observed that both CNs and PEG were effective in toughening the investigated polymer and its grafted blend. In a contrasting research, Joy *et al*. investigated the reinforcing effect of CNs, extracted from Helicteres isora plant, on the mechanical, thermal and morphological properties of polybutylene succinate composites. They observed that CNs showed a promising reinforcing ability by enhancing both tensile and flexural strengths but only up to certain loading concentration beyond which both the strength parameters were observed to decline due to possible agglomeration of CNs. This elucidates that agglomeration of CNs is still problematic when it comes to scalability and mass manufacturing. However, the property enhancement observed by Joy *et al*. at the small volume fractions of CNs is substantial enough for the use of said bionanocomposites in targeted applications. In yet another application area, Tajvidi *et al*. emphasize the practical advantages of using CNs

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in their as-produced, aqueous suspension form for high volume applications. Uses of such as binders for composite materials, paper, and paper coatings are explored. The final manuscript of this issue focuses on employing spin coating technology to form highly oriented CN films. In their work, Jiang *et al.* investigated the structure-property relationships of these films including morphological and surface properties to develop a reference for industrial level CN-based films processing, such as microelectro-mechanical systems (MEMS) device manufacturing. The study provides a new pathway and application direction for CN-based films in MEMS applications.

We hope that this special issue provides the reader with a useful snapshot of a portion of the broad and rapidly evolving area of Nanocellulose Composites as well as a sense of its future direction. We have enjoyed preparing this special issue and would like to thank the staff of the *Journal of Renewable Materials* that made it possible as well as extend our sincere appreciation to all the reviewers for their critiques of the manuscripts submitted for this special issue.

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