KEYNOTE

Advanced Wood- and Bio-composites: Enhanced Performance and Sustainability

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Abstract

Use of wood-based-composites technology to create value-added commodities and traditional construction materials is generally accepted worldwide. Engineered wood- and lignocellulosic-composite technologies allow users to add considerable value to a diverse number of wood- and lignocellulosic feedstocks including small-diameter timber, fast plantation-grown timber, agricultural fibre and lignocellulosic residues, exotic-invasive species, recycled lumber, and timber removals of hazardous forest-fuels. Another potential advantage of this type of economic- and materials-development scenario is that developing industrial composite processing technologies will provide producers an ability to use, and to adapt with, an ever-changing quality level of wood and/or other natural lignocellulosic feedstocks. However, the current level of performance of our state-of-the-art engineered composite products sometimes limit broader application into commercial, non-residential and industrial construction markets because of both real and perceived issues related to fire, structural-performance, and service-life. The worldwide research community has recognized this and is currently addressing each of these issues. From a performance standpoint, this developing knowledge has already and will continue to provide the fundamental understanding required to manufacture advanced engineered composites. From a manufacturing and a resource sustainability standpoint, with this evolving fundamental understanding of the relationships between materials, processes, and composite performance properties we now can in some cases, or may soon be able to, recognize the attributes and quality of an array of bio-based materials then adjust the composite manufacturing process to produce high-performance composite products. As this fundamental understanding is developed, we will increasingly be able to produce advanced, high-performance wood- and bio-composites. Then we must use those technologies as tools to help forest and land managers fund efforts to restore damaged eco-systems and which in turn may further promote sustainable forest management practices.

Background

Wood composite technologies (for example, plywood, particleboard, flakeboard, hardboard) have for decades been used to create value-added commodity building and home furnishing products. Simply stated, composite technology is based on breaking woody material down to some smaller element, such as a veneer, particle, flake/strand, or fibre, then reassembling these elements using mastic, such as resin, starch, or natural fibre–fibre hydrogen bonding, into a lumber- or panel-like biocomposite products. More recently, new innovative bio-based composite products based on natural fibres, such as agricultural fibres or residues, or on wood–natural fibre hybrids, have also come on the market and now compete directly with traditional wood composites. Other similar new hybrid products, such as wood- or natural fibre–plastic composites, have recently become popular for decking, siding, roofing, fenestration, and millwork.

In North America, wood-based composites now represent more than 40% of the total materials used in residential construction making them the largest single material type used in residential construction. Wood-based composites are used because they are readily available, light, strong, easily worked, and cost effective. However, to expand into other markets, such as non-residential and commercial construction and consumer goods, they need to achieve enhanced performance, serviceability, durability, and reliability. Users of many of today's wood and wood-composite products commonly refer to the same recurring problems. These common perceptions concern:

- Low strength and stiffness with eventual rheological/creep problems
- Poor durability and water-related problems
- Limited service life
- Limited or poor fire performance
- Wood products harvesting and manufacturing not being viewed as a fully "Green Technology" and thus not being given preference in some "Green" certification programs

Advanced engineered biocomposites are needed to meet the diverse needs of users for high-performance building and commodity products that simultaneously maximize the sustainability of forest resources. This next generation of engineered biocomposites must provide construction materials and building products that far exceed current expectations (such as lower cost, greater adaptability and reliability, lower maintenance, smarter) while opening new markets (such as commercial construction, automotive, aerospace) and reducing effects on the environment (such as energy, air, water, and waste).

Four basic research problems must be addressed as we develop this next generation of composite products:

- Identify and exceed consumer needs for competitively priced products in residential and non-residential/commercial construction, furniture, and transportation systems.
- Develop more robust composite products having recognizably advanced capabilities for performing (that is, strength, durability, and service-life) in adverse environmental or critical-use service conditions.
- Develop advanced, high-performance composites with much higher reliability than current materials that will meet the special needs of the commercial/non-residential construction market.
- Develop new processing technologies that minimize (1) environmental life cycle costs (resource use, energy use, emissions) associated with producing and using composites in various end uses and (2) economic costs of production and use so that new and improved composites are competitive with materials they replace and compatible with the changing raw material sources.

Advanced composite technologies will provide the means to engineer and produce biocomposite materials with enhanced physical and structural performance characteristics using virtually any bio-based material or mixture of bio-based or synthetic materials as constituent materials. Advanced composites will further enhance our ability to meet global needs for improved performance and value-added user products that promote long-term resource sustainability. They will also decrease environmental impacts relative to those of existing products.

Recent advances within the international wood and biocomposites research community are just beginning to lead to a early-stages of a fundamental understanding of the relationships between materials, process, and composite performance properties. This knowledge may lead to new science-based biocomposite processing technologies that will soon allow us to precisely control the composite manufacturing process on-the-fly while also producing high-value-added engineered biocomposite products with reliable and consistent performance properties. This new knowledge is also allowing us to use a diverse array of bio-based raw materials. For example, biocomposite processing technologies are leading to the value-added use of diverse species and an ever-changing quality level of wood and other natural biofibre feedstocks, including small-diameter timber, fast plantation-grown timber, agricultural fibre and biofibre residues, non-desirable exotic–invasive species, burnt timber, and timber removals required to reduce hazardous forest fuel loadings. Once this fundamental understanding is further developed, we will soon be able to use biocomposite technologies as a tool to help forest and land managers restore damaged ecosystems and promote sustainable forest management practices.

Problems or Opportunities

As worldwide demand for timber and lignocellulosic resources grows, sustainable resource management and industrial utilization must collaborate to develop a shared vision for both long-term sustainable management of forest and bio-resources and sustainable, bio-based economic development. As the problems associated with sustaining and enhancing the world's forest and agricultural resources compete with the needs of rapidly increasing populations, the management of our land and its resources becomes a much more complex and important issue. Wood and other lignocellulosic materials are both renewable and if managed properly, can be sustainably produced. Composite wood and natural lignocellulosic products are effective alternatives to non-renewable or non- or less-recyclable mineral- or petrochemical-based materials.

In increasingly more instances, engineered wood- and bio-composites offer an ability to achieve resource sustainability and meet user needs in both developing and in our ever-more affluent societies; each with their growing populations and growing demand for materials. Wood- and bio-composite technologies provide a tool for resource managers to use to add currently unrecognized value to low- or no-value bio-based resources and thereby promote demand for diverse wood- and lignocellulosic-feedstocks including small-diameter timber, fast plantation-grown timber, removals of exotic-invasive species, removals of hazardous forest-fuels, and agricultural residues. At the same time, engineered wood composites can serve as a tool for economic development of rural communities and provide more urban communities with sustainable, value-added commodity and non-traditional products. Wood and biocomposite technologies can also promote value-added uses for post-consumer and/or post-industrial waste materials.

If one of our societal objectives is to evolve to a sustainable global economy, then we must commit ourselves to promoting renewable, recyclable, and reusable materials. To do this, we must develop the fundamental and applied science and technology necessary to provide improved value, service-life, and utility while at the same time meeting the needs of consumers for a wide array of sustainable materials. This will require networking with international collaborators to provide a broad range of tools to resource managers that, regardless for resource type or quality, promote sustainability and recyclability, increase economic value-added, and reduce adverse environmental impacts.

Transitioning to a Bio-based, Sustainable Future

We must develop tools to address resource sustainability, enhance recyclability, and minimize the environmental impacts of composite processing. Then whenever forest resource options change, or as excess (e.g., discarded wood and fibre) waste-stream wood resources become available, or as alternative non-wood and non-lignocellulosic materials become more economical and available, and/or as air- and water-quality regulations become more stringent, we can adapt and sustainably address each of these issues by adapting materials processing. Engineered biocomposites assembled from small pieces of wood or lignocellulosic materials provide technology that is very adaptable to a changing resource base. These products can incorporate a variety of wood and natural lignocellulosic-based raw materials in the form of fibres, particles, flakes, strands, and veneers. But engineered biocomposites must also be durable, have specific performance properties and generally serve for many years as users expect regardless of climate or whether they are manufactured from a variety of natural fibrous sources alone or combined as hybrid products with non-wood materials like cement, ceramics, plastics, or synthetic fibres.

We must focus on fundamentally understanding the relationship between performance and the contributions of constituent lignocellulosic materials, ranging from veneer, flakes, particles, fibres, and flour-like materials and from the marriage of lignocellulosics and advanced high-performance materials, like Kevlar, polyamides, polyolefin, or fibreglass. This will also include learning to use natural nano-scale reinforcement materials, like cellulose nanocrystals and microfibrils.

Another major advance in engineered wood and biocomposites is in product and performance enhancement. Advanced engineered biocomposites are currently being developed that will simultaneously meet the diverse needs of users for high-performance and economical commodity products. These engineered biocomposites will provide advanced performance, durability, value, service-life, and utility while at the same time being a fully sustainable technology. The next generation of engineered biocomposites will provide construction materials and building products that far exceed current expectations (such as higher performance, lower cost, more adaptable, more reliable, lower maintenance, smarter) while opening new markets (such as commercial construction, automotive, aerospace) and reducing effects on the environment (such as energy, air, water, and waste). These advanced engineered biocomposites will:

- combine wood and natural biofibre for synergistic hybrid materials,
- provide hyper-performance and superior serviceability,
- be more durable, dimensionally stable, moisture proof, and fire resistant,
- possess advanced sensory capabilities for warning users when problems are imminent,
- be renewable, recyclable, and sustainable,
- decrease environmental impacts from processing and use, and
- have both materials and processes engineered to customize and optimize performance.

Research Needs

To accomplish these goals will require a focused, coordinated research program. To successfully meet these broad international scale goals it will be critical to collaborate and coordinate multi-national, multi-partner research programs. Development of advanced engineered biocomposites will require significant scientific advances. Governments, academia, industry, and users must work together to develop a shared vision and then coordinate limited research funds to systematically address a complex series of problems.

The research goals will need to include coordinated efforts to fundamentally relate materials, processes, and performance. We must learn to utilize an array of environmentally-friendly raw materials with performance-enhancing additives and advanced binders to produce sustainable biocomposite materials with unique capabilities (e.g., biomemetic systems, enhance recyclability, or smart systems). We need to both improve existing processes and develop new processes that result in environmentally responsible processes that optimize energy–performance relationships. We must also learn to make high-performance products with enhanced mechanical and physical properties, reliable durability and serviceability, and products designed to use recycled materials and have end-of-life recyclability.

We will then need to develop basic understandings of material applications, their use-environments, and controlling economics. We must identify perceived problems with the performance of current-generation wood-based composites and identify unfulfilled future markets for enhanced products. We need to minimize environmental and life-cycle impacts of new and reused bio-based products. We will also need to evaluate economic feasibility for commercial production of bio-based products. Finally, we must understand market trends and economic factors to promote advanced bio-based systems that improve materials performance, meet user needs, and promote resource sustainability.

A critical tool to achieve these goals may require using the new science of nanotechnology to manipulate and control materials and processes at the nanoscale. Nanotechnology, if many of its apparent promises can be achieved, may present a tool to improve structural performance and extend serviceability by orders of magnitude. Nanotechnology offers three potential opportunities for development of advanced wood- or lignocellulosic-based biocomposites. First, it is currently leading to new analytical technologies that will provide us a fundamental understanding of material behavior at the nanoscale. Next, it may include the incorporation of nanoparticles into advanced biocomposites to achieve enhanced performance. Finally, it may also lead to modifications of the wood and lignocellulosic raw material surfaces at the nanoscale. This knowledge will then provide tools with which we can begin to understand relationships between "Materials-Process-Performance". Then we may be able to exploit these three potential opportunities to identify, control, and optimize material and process factors in real-time so as to engineer products having highly specified performance characteristics with both economic and environmental advantages.

We must also address our objectives for a sustainable future and advanced product using integrated approaches that simultaneously provide environmental, utilitarian, and economic advantages. For example, an integrated vision for sustainable biomass utilization is now evolving that includes a series of sequential processing approaches including an initial biorefinery stage to obtain ethanol/biodiesel fuels either thermochemically or biochemically, followed by production of biocomposite or paper-based products from the biorefinery residues, and then production of bio-based electrical energy from biocomposite- or paper-mill residues. Such an integrated resource solution is thought by many to offer the optimum long-term solution to meeting both user needs and sustainable development.

Summary

One of our global challenges will be to meet the needs of growing populations with biocomposites from under-utilized low- or no-value virgin or waste biomass materials. To accomplish this, we need to work together to advance the fundamental and applied science and technology of manufacturing engineering bio-based composite materials to:

- Encourage the use of our ever-changing wood and lignocellulosic resources by providing baseline data required to allow for the optimal use.
- Develop highly adaptable manufacturing processes to produce advanced biocomposite products that meet consumer needs while simultaneously empowering resource managers to sustainably manage and improve the forest resource.
- Accelerate the on-going development of engineered structural lumber, panel composites and three-dimensional molded and/or extruded composites from small diameter, low quality timber derived from mixed species and previously unused lignocellulosic fibre sources

In summary, the utilization of engineered biocomposite materials that meet user needs and maximize the environmental sustainability is fast becoming a reality. We must commit ourselves to developing the fundamental and applied science and technology necessary to provide improved value, service-life, and utility so the world can use sustainable bio-based materials. Then as forest resource options change, as excess bio-based waste-streams become available, as alternative non-wood and non-lignocellulosic materials become more economical and available, and/or as air and water quality regulations become more stringent, we will have the tools to address the problem of achieving resource sustainability and enhancing economic development through biomass utilization.

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