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Editorial

Advanced Eco-Friendly Wood-Based Composites II

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The ongoing twin transition of the wood-based panel industry towards a green, digital, and more resilient bioeconomy is essential for a successful transformation, with the aim of decarbonising the sector and implementing a circular development model, transforming linear industrial value chains to minimize pollution and waste generation, and providing more sustainable growth and jobs. This green transition represents an opportunity to place the wood-based panel industry on a new path of more sustainable and inclusive growth, tackling climate change and reducing our dependence on fossil-derived raw materials, thus improving the industry's resource efficiency and security.

A crucial circular economy principle is exploiting natural resources more effectively to produce various value-added wood-based products, as the demand for wood and wood-based components is anticipated to triple between 2010 and 2050. In efforts to promote effective recycling and reuse, the upcycling of wood and wood-based materials and the search for substitute raw materials, recent legislative regulations and increased awareness of social environments have posed new challenges to both industry and academia. These regulations and laws are related to enhancing the "cascading use" of wood or prioritising the value-added, non-fuel applications of wood and other lignocellulosic resources.

Wood composites are manufactured from different wood and non-wood lignocellulosic raw materials, bonded together with synthetic or bio-based adhesives and used for particular value-added applications and service requirements [1–9]. Conventional wood-based composites are manufactured with synthetic, formaldehyde-based resins, commonly produced from petroleum-based components, such as urea, phenol and melamine [10–13]. The use of these thermoset adhesives has several drawbacks related to the release of harmful volatile organic compounds, such as formaldehyde emissions from the created wood-based composites. Free formaldehyde emissions from the created wood-based composites has been linked to seriously detrimental human health effects, including irritation of the eyes, nose, throat and skin; nausea (short-term exposure); as well as respiratory problems and cancer (long-term exposure) [14–18]. The transition towards a circular, low-carbon wood-based panel industry, increased environmental concerns related to the use of unsustainable petroleum-based resources and the strict legislative requirements of free formaldehyde release from engineered wood composites have tremendously increased the research and development of 'green', eco-friendly wood-based composites [19–25], optimal valorisation of available lignocellulosic resources [26–30], and use of alternative raw materials [31–39]. The adverse free formaldehyde emission from wood-based composites can be mitigated by coating the surfaces of finished composites, by adding various organic or inorganic formaldehyde scavengers to synthetic wood adhesives, or by using bio-based, environmentally friendly wood adhesives [40–49]. The manufacture of binderless wood-based composites is another viable option since wood as a natural raw material is composed of biopolymeric constituents, i.e., cellulose, lignin, and hemicelluloses [50–54].

In this Special Issue, 11 well-written, authentic pieces of research and critical analysis are collated to show instances of recent technological advances in the design, manufacture, characteristics, and future uses of environmentally friendly wood and wood-based composites.

Barbu et al. [55] investigated and evaluated the physical and mechanical characteristics of *Paulownia tomentosa* × *elongata* plantation wood. These characteristics were determined taking into consideration the effects of cross section position and stem height. This study was conducted due to the increased interest in Paulownia as a fast-growing tree species. The authors came to the conclusion that, in terms of wood density and dimensional stability, Paulownia plantation wood becomes stable after the fifth year of growth, and they recommended harvesting trees older than seven years in order to maximise the yield of sawn wood. This recommendation was made in light of the fact that the authors harvested trees younger than five years in order to obtain optimal results.

Bamboo is another sustainable and eco-friendly material that has attracted significant study interest in recent years due to its multiple advantages and abundance, as well as ability to be recycled and reused. Although bamboo is seen as a promising substitute of wood, its poor stiffness and culm diameter are the key reasons restricting its widespread use. To address these issues, bamboo culms can be disassembled into flat thin lamellae and bonded together with an adhesive to create a certifiable structural material known as laminated bamboo [56–58].

The components of bamboo-based composites were investigated by Hao et al. [59] for their bending performance, fracture toughness, and enhancement mechanism. According to the authors' reports, the bamboo composites exhibited greater fracture toughness, compared to bamboo itself. Additionally, the composites exhibited longer deformation and less damage to fibre and parenchymal cell walls. The mechanical strength of cell walls, particularly parenchymal cell walls, was found to be enhanced by phenol–formaldehyde resin, as evidenced by an increase in indented modulus and hardness. According to the authors, the main factor affecting the fracture toughness of bamboo-based composites was the crosslinking effects of phenol–formaldehyde resin with the cell wall and fibres.

The shear performance of laminated boards fabricated from two Malaysian bamboo species was studied by Mohd Yusof et al. [60]. The two species studied were semantan (*Gigantochloa scortechinii*) and beting (*Gigantochloa levis*). Using phenol–resorcinol–formaldehyde (PRF) and polyurethane (PUR) adhesive systems, three-layer laminated bamboo panels with two lay-up patterns, perpendicular and parallel, and three strip arrangements (vertical, horizontal, and mixed) were fabricated. Board delamination, bamboo failure, and shear strength were all measured. It was determined that the lay-up pattern and adhesive type were the primary determinants of shear performance. The authors reported higher values for shear strength and bamboo failure for laminated bamboo boards bonded with PRF compared to those bonded with PUR resin. PUR-bonded bamboo, on the other hand, had a significantly lower rate of delamination, indicating a more durable bond. Overall, PRF was found to be the superior adhesive for bonding laminated bamboo boards due to its superior shear performance.

Particleboard made of sengon (*Paraserianthes falcataria*) wood was fabricated by Iswanto et al. [61]. In their study, single-layer particleboard with a density of 750 kg.m^3 was produced. Urea–formaldehyde (UF) resin added with methylene diphenyl diisocyanate (MDI) was used as a binder for the particleboard. The physico-mechanical properties of the resultant particleboards were explored. Four different hot-pressing temperatures (130, 140, 150, and 160 °C) were used to produce the particleboard. Based on a total adhesive content of 12%, the used UF/MDI mixtures were composed of 100% UF and 0% MDI, 85% UF and 15% MDI, 70% UF and 30% MDI, and 55 UF and 45% MDI, respectively. Hot pressing at 140 °C with an adhesive system consisting of 85UF/15MDI produced particleboard with physical and mechanical properties meeting the requirements for type 8 boards, as specified in JIS A5908-2003. Additionally, the particleboard fulfilled the requirements for type 2 boards according to EN 312 standards.

Another interesting study was carried out by Yusof et al. [62] on the influence of boric acid pretreatment on bamboo strips. The physical and mechanical performance of the pre-treated bamboo strips was assessed after boric acid treatment. Adhesion properties were also studied, as well as the morphological characteristics of the bamboo strips. These bamboo strips were derived from four widely distributed bamboo species in Malaysia: *Gigantochloa scortechinii*, *Gigantochloa levis*, *Bambusa vulgaris* and *Dendrocalamus asper*. According to the authors' findings, treating bamboo strips with boric acid improved their wettability, dimensional stability, and mechanical properties, resulting in a greater potential for use in composite applications. Most importantly, treatment with boric acid may improve the biological durability of the bamboo strips and broaden the range of potential applications for these laminated panels in the exterior environment.

The ongoing digitalization of the wood-based panel industry via the adoption of Industry 4.0 principles and technological advances, referring to enhanced automation and use of smart, data-driven manufacturing systems, is a prerequisite for the green and digital transformation of sector, enhancing its competitiveness and sustainability.

Kminiak et al. [63] used a computer numerical control machine for the adaptive control of cutting processes to examine the impact of various input parameters on processing wood-based composites (particleboards). The authors conducted experiments to determine the relationship between feed speed, revolutions, and radial depth of cut, as well as the equivalence of sound pressure level and milling tool temperature. The obtained results show that the noise level and temperature of the milling tool were affected by all of the investigated parameters, with the rate of radial depth of cut having the greatest influence on the rise in temperature, and the number of revolutions having the greatest influence on the sound pressure level.

Buildings are designed and constructed with careful consideration given to the selection and application of structural materials that are renewable and friendly to the environment. When compared to a reinforced concrete road bridge of the same span and load, the performance of a cross-prestressed timber-reinforced concrete bridge is superior. Mitterpach et al. [64] used the LCA principle to investigate and evaluate the environmental performance of each structure. The results show that the timber-reinforced concrete bridge was more eco-friendly than the steel-concrete road bridges. The findings have important implications for evaluating the ecological effectiveness of building components and structures.

Adhering to circular economy practices, which include the upcycling of raw materials and the increased utilization of by-products to manufacture new products with added value, Pędzik et al. [65] studied the possibilities of using forest residues generated from Scots pine harvesting as a substitutional material for manufacturing particleboards. Markedly, the composites, fabricated from forest biomass residues, exhibited satisfactory mechanical properties, fulfilling the requirements for type P5 particleboards, suitable for load-bearing applications for use in humid conditions in accordance with EN 312 standard. However, the lower dimensional stability of the produced composites allowed their classification as type P2 particleboards, suitable for internal use (including furniture) in dry conditions.

Particleboard and oriented strand boards (OSB) are two types of wood-based composite that, if burned, could create a dangerous environment in homes and public buildings. Marková et al. subjected unfinished particleboards and OSB panels were to radiant heat testing and evaluation [66]. Mass loss and time-to-ignition of the composites were reported to be significantly affected by heat flux. The experiment findings reveal that the ignition time and the temperature at which thermal decomposition occurred were both significantly higher for OSB panels than for particleboards.

Paulownia (*Paulownia tomentosa* (Tunb.) × *elongata* (S.Y. Hu)) sawn wood from three European plantation sites was studied for its physical and mechanical properties by Barbu et al. [67]. The results conclusively show that Paulownia wood's physical and mechanical qualities were significantly affected by the growing conditions. Paulownia wood was found to have a significant promise as an alternative natural feedstock to be used in specialised applications, such as non-load-bearing structural components and thermal insulation, despite having inferior physical and mechanical properties compared to traditional tree species.

Finally, Maulana et al. [68] conducted a comprehensive overview on the latest advancements in the field of "green," eco-friendly, starch-based wood adhesives. These can be used to produce wood-based composites that are non-toxic, have low emissions, superior properties and a reduced negative impact on the environment. The authors described and analyzed the vast potential of starch as a cheap and abundant natural feedstock for use in wood adhesives. New methods of starch modification were also discussed, with the goal of enhancing the effectiveness of starch-based wood adhesives.

A significant precondition for the ongoing movement toward the production of environmentally friendly, high-performance wood-based composites is the industry's ongoing transformation from a linear to a circular bioeconomy. This transition is a strong prerequisite for this production trend. This Special Issue provides a detailed summary of potential developments in the design, production and applications of sustainable, environmentally friendly wood-based composites with enhanced properties and a reduced carbon footprint, which form the focus of this discussion.

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