

CHAPTER 10

BIOMASS-BASED WOOD COMPOSITE FOR BUILDING MATERIAL APPLICATION

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Abstract

Fossil fuel serves as the primary global source of energy. It is anticipated that fossil fuels will be depleted in the next half-century. Using biomass-based wood composite for building applications serves as a substitute for fossil fuels. Biomass-based wood composite has proved to display good properties for application in the building sector. This chapter illustrates the valorization of biomass-based materials, sawdust, and wood flour in various building applications. Sawdust-based polymer resin polystyrene for particle board production displayed excellent compressive and tensile strengths of 0.157 N/mm² and 2.362 N/mm² respectively.

Furthermore, cement substituted with sawdust exhibited satisfactory results for producing bricks or blocks. The results displayed a compressive strength of 10.43 N/mm² following ASTM C67.

Moreover, clay bricks production using sawdust content of 2.5 wt% fired at 1100°C depicted a high compressive strength of 18.2 MPa, following ASTM C62-13a, which required a compressive strength of 17.2 MPa—

according to the American National Standard Institute (ANSI), composites panels produced using sawdust with plastic waste and polystyrene exhibited good mechanical properties which can be applied for flooring application. The results displayed a modulus of elasticity (MOE) from 694.88 MPa to 4604.89 MPa and a modulus of rupture (MOR) from 5.73 to 21.24 MPa. Wood flour (WF) also displayed potential use in furniture applications. The results showed that 30 wt% WF-filled r-PP content wood polymer composite (WPC) displayed 24.8 MPa tensile strength. Moreover, the flexural strength of 46.2 MPa was achieved due to using MAPP as a coupling agent. According to the ASTM D 6662, the lowest flexural modulus of 0.34 GPa and 6.9 MPa flexural strength is required for decking boards. The results displayed excellent flexural modulus ranging from 2.49 to 3.8 GPa and flexural strength from 23.05 to 35.82 MPa. This is further evidence that wood flour-based composite can be utilized in decking application.

Keywords: Biomass-based composite; Flexural strength; Fossil fuels; MAPP; Mechanical properties.

10.1 Introduction

With rapid urbanization development, the sustainability target suffers a significant setback due to environmental pollution and energy depletion (Zhang *et al.* 2022). Sustainability depends on the economy, society, and environment. Recent developments must take account of sustainability factors while maintaining ecosystem balance (Abbas *et al.* 2022). Oil, coal, and methane have recently been the primary energy sources used globally, making up approximately 80% of energy (Biol 2010). In the next 40-50 years, these fossil fuels are anticipated to be depleted (Saidur *et al.* 2011).

Additionally, environmental pollution due to fossil fuel emissions causes acid rain and global warming (Saidur *et al.* 2011). Moreover, fossil fuels produce greenhouse gases, leading to ozone layer depletion and global warming, resulting in a high level of carbon monoxide in the atmosphere, reacting with oxygen to form carbon dioxide. The ozone layer depletion results in ultraviolet radiation reaching the earth's surface and causing health problems such as sunburn and possible skin cancer (Anwar *et al.* 2016). These findings have motivated researchers to expand their research to find environmentally friendly and economically feasible non-fossil fuel resources.

Biomass is renewable matter derived from oxygen, hydrogen, and carbon, which are naturally produced (Adeleke, Ikubanni, *et al.* 2021). One may also define *biomass* as waste materials consequential to living

organisms or rather, waste products of organic materials (Sudeep Yadav, Amitabh K. Srivatava, and R.S. Singh 2015). Biomass includes various products and agricultural wastes generated during processing, such as straw, bagasse, stover, and forestry wood. It could be biological organic waste from industrial activity such as the manufacturing of black liquor paper, and municipal waste, such as sewage and waste from humans and animals. Biomass includes liquids and gases recovered from biodegradable organic materials and non-fossil fuel materials.

Moreover, shells, fish heads, skin, husks, pulp, and oil extractions are also biomass products obtained when removing unwanted components from food materials (Jawaid, Paridah and Saba 2017). Biomass materials are categorized into woody and non-woody groups, as depicted in Figure 10.1 below. Both woody and non-woody materials are produced from agricultural sources for bioenergy production. However, woody biomass materials are obtained only from forestry. Agriculture sources are non-woody biomass materials such as starch, plant leaves, stems, stalks, and soybeans. The biomass components include hemicelluloses, cellulose, lignin, proteins, starches, extractives, sugars, lipids, hydrocarbons, and alkaline and heavy metals (Jawaid, Paridah and Saba 2017). The principal components of biomass are hemicellulose, cellulose, and lignin. To reduce the utilization of fossil fuels required by the increasing population, biomass is considered as an alternative renewable source (Adeleke, Odusote *et al.* 2021). The use of biomass in different industries such as the automobile, aerospace, building, and construction industries has attracted attention due to its excellent mechanical and physical properties. This chapter will present the various uses of sawdust-based composite/s for producing particle boards, bricks, and floor panels. The production of furniture and decking materials using wood flour will also be investigated. These studies will also illustrate their mechanical and physical properties according to their required testing standards.

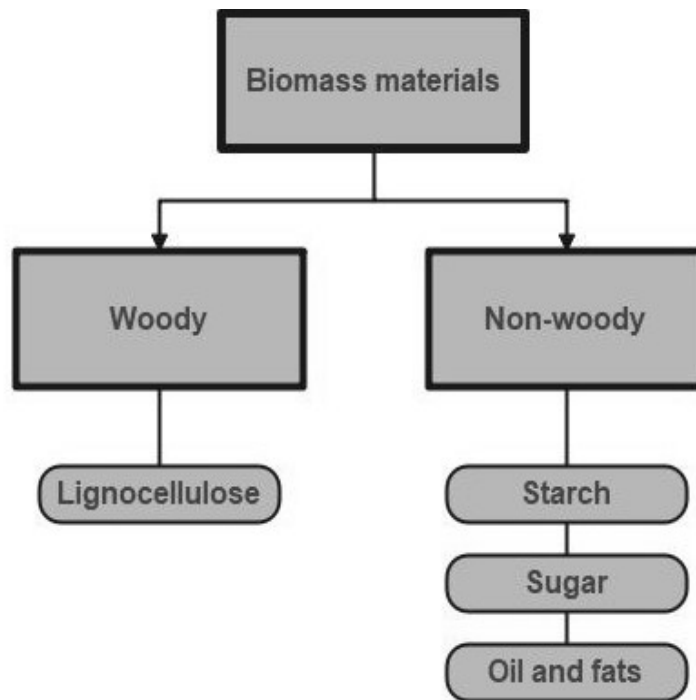


Figure 10.1 Biomass materials categories (Jawaid, Paridah and Saba 2017).

10.2 Wood-Based Composites

Wood-based composites refer to materials made from wood and resin. Resin or polymer can be thermoset or thermoplastic, enabling integration and consequently improving the properties of the composite (Renner *et al.* 2021). Wood materials can be wood fibers or wood waste generated from processing wood. The use of wood waste is beneficial for environmental sustainability as it limits waste being incinerated or landfilled in the environment (Renner *et al.* 2021).

10.2.1 Sawdust-Based Composites

Sawdust, or wood dust, is the by-product of sawing lignocellulosic materials, cutting, drilling, furniture manufacturing, polishing, and riveting (Olaiya, Lawan, and Olonade 2023). The most substantial source of sawdust

is sawmilling. The quantity of sawdust generated by sawmilling depends on the sawmill productivity and varies with the employed technology. Moreover, the machinery utilized can also influence the volume of sawdust produced. It was found that the lack of a proper operational machine process in timber sawing results in the high production of sawdust (Charis, Danha, and Muzenda 2019). The production quantity of sawdust generated annually varies by country. Table 10.1 below depicts the wood waste sawdust generated from timber-producing countries. It is denoted that sawmilling produces over 2 million m³ of sawdust per year.

Table 10.1 Wood waste and sawdust production for various countries.

| Total Wood Waste Generated Total Sawmilling Input Volume (%) | Proportion of Sawdust Produced (%) | Amount of Sawdust Produced Annually (million m³) | Country | References |
|---|---|--|----------------|---|
| 48 | 20 | 4.7 | South Africa | <i>(Department of Environmental Affairs (DEA), South Africa State of Waste Report (2018) A Report on the State of the Environment 2018)</i> |
| 27.5 | 14.7 | - | Ghana | <i>(Adu et al. 2014)</i> |
| 31-56 | 16-35 | 8.6 | Nigeria | <i>(Peter, Albert, and Anthony 2017)</i> |
| - | 35 | 9.5 | Mexico | <i>(Daniel et al. 2015)</i> |
| - | - | 2.72 | Chile | <i>(Garay 2012)</i> |

Sawdust contains small or tiny discontinuous particles and wood chips (Tilak, B. and Singh 2018). The disposal of sawdust does not follow acceptable environmental disposal regulations as it is exposed to the atmosphere, dumped, and burned (Adu *et al.* 2014). The presence of sawdust in landfills results in air pollution, and incinerated sawdust produces greenhouse gas emissions (Mwango and Kambole 2019). Apart from greenhouse gas emissions and air pollution, sawdust can find its way into the aquatic environment through runoff or blown by wind, adversely affecting aquatic life. Additionally, sawdust in the environment threatens plant life. Valorization of sawdust can address environmental, societal, and economic concerns. Composite material-based sawdust has been utilized in building applications for decades. Sawdust concrete as a composite has been utilized for over 40 years (Kumar *et al.* 2014). Sawdust application is not limited to concrete. Literature also explores other applications such as sawdust composite in particleboards, ceiling boards, partitioning, floor panels, and concrete bricks and blocks (Olaiya, Lawan and Olonade 2023).

10.2.1.1 Particle Boards

Particle boards are panel products fabricated under pressure and temperature by compounding various proportions of sawdust or lignocellulosic material with a resin (Abdulkareem, Raji and Adeniyi 2017). They have been utilized in different applications, such as house construction and furniture manufacturing (Atuanya and Obele 2016). The study conducted by Atoyebi Dotun *et al.* (2018) researched the production of particleboards made from sawdust and recycled polyethylene terephthalate (PET) using the flat-pressed method for indoor application (Dotun, Adesoji and Oluwatimilehin 2018). The study showed that particle boards with 50% sawdust content and 50% PET exhibited 9.03 N/mm² and 964.199 N/mm² modulus of rupture and elasticity, respectively. Moreover, thickness swelling and water absorption decreased when PET concentration increased. The fabricated particle boards are utilized for indoor buildings and not load-bearing or structural applications due to excellent physical properties over mechanical properties.

Similarly, research by Akinyemi *et al.* using sawdust and corncob with formaldehyde binder to produce panel boards showed more suitable indoor applications in buildings than load-bearing applications (Akinyemi, Afolayan and Oluwatobi 2016). Sawdust-based polystyrene composite was fabricated using organic glue as an adhesive produced from dissolving polystyrene in petrol. The composite exhibited better properties in suspended ceilings and partitioning boards (Agoua *et al.* 2013). Another study investigated the use of sawdust, polystyrene foam, and eggshells to

develop ceiling boards. The ceiling boards' properties were investigated following appropriate ASTM standards and exhibited 0.52% water absorption, 2.362 N/mm² tensile strength, 0.157 N/mm² compressive strength, 0.0221 W/M.K thermal energy, and 0.677 mm elongation at break as shown in Figure 10.2 below (Shuaib-Babata *et al.* 2022).

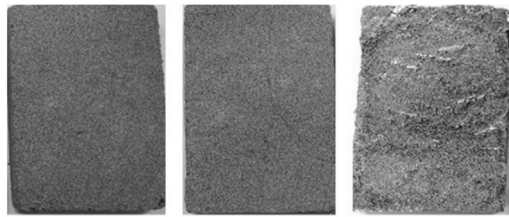


Figure 10.2 Ceiling boards made from sawdust(Shuaib-Babata *et al.* 2022).

10.2.1.2 Mortar and Bricks or Blocks

The use of mortar for building applications has post-cracking effects. Sawdust-based mortar was observed to improve the post-cracking and thus improve the ductility of the mortar (Gil, Ortega and Pérez 2017). Alyouef *et al.* (2020) investigated using 100% sawdust to produce high-performance cement-free mortar in building applications. The results show that sawdust is a substitute for cement and exhibits a satisfactory compressive strength of 48.6 MPa (Alyouef, Algaifi and Alaskar 2020). Similarly, Boob (2014) produced blocks by partial use of sawdust in the mixture of cement and sand using a mix ratio of 1:6 (cement: sawdust + sand). The manufactured blocks with dimensions 100 mm × 100 mm × 100 mm exhibited a compressive strength of 4.5 MPa. The results followed the BS 6073 standard, which requires a minimum of 2.8 MPa (Boob 2014). Similarly, Algin and Turgut investigated the fabrication of blocks using limestone powder and sawdust. The results obtained were 7.2 MPa compressive strength and 3.1 MPa flexural strength, which complied with BS 6073 and ASTM C67-03a international standards requirements (Parki and Algin 2007).

Phonphuak *et al.* (2020) illustrated the potential partial substitution of sawdust to produce clay bricks. Sawdust content of 0 wt%, 2.5 wt%, 5 wt%, 7.5 wt%, and 10 wt% was used to produce clay bricks. The specimen of the bricks was heated at 900 °C, 1000 °C, and 1100 °C for water absorption evaluation. This study confirmed that the incorporation of sawdust content increases water absorption. Properties such as compressive strength, thermal conductivity, apparent porosity, and bulk density of the fired bricks were also investigated. The results showed that utilizing sawdust for clay brick production reduces bulk density from 1.83 to 1.41 g/cm³.

Similarly, compressive strength decreases as sawdust content increases. However, increasing the firing temperature increases compressive strength. Sawdust content of 2.5 wt% fired at 1100°C depicted a high compressive strength of 18.2 MPa, following ASTM C62-13a, which required a compressive strength of 17.2 MPa. Thermal conductivity was evaluated for bricks fired at 1000 °C with sawdust content of 2.5-10 wt%. The results displayed a decrease from 0.47 to 0.22 W/mK of thermal conductivity (Phonphuak *et al.* 2020). The properties and structural behavior of sawdust and its use in interlocking bricks was investigated. The study focused on the possibility of using sawdust and supplementary cementitious (silica and fly ash) to produce interlocking bricks, which would potentially be an alternative to conventional bricks. The results illustrated good mechanical properties, such as a compressive strength of 10.43 N/mm² (Mohammed and Aswin 2016). The attained compressive strength was above the required compressive strength of 10.3 N/mm² for conventional bricks, according to ASTM C67. The modulus of rupture was attained at 0.02128 MPa, as per ASTM C67 standards.

10.2.1.3 Floor Panels

The study of sawdust, plastic waste, and polystyrene for the development of floor panels was conducted by Chanhoun *et al.* (2018). The fabrication of sawdust-based waste plastic and polystyrene waste exhibited a 694.88 MPa to 4604.89 MPa modulus of elasticity (MOE) and a modulus of rupture (MOR) from 5.73 to 21.24 MPa (Chanhoun *et al.* 2018). All the composite panels produced met the standards of the American National Standard Institute (ANSI) and will be utilized as internal floor panels and in external flooring. Juvenil *et al.* (2023) investigated using natural fibers as an alternative to synthetic materials to develop panels. Sawdust from eucalyptus wood, chamotte, and vegetal polyurethane resin (castor oil) was fabricated using a metallic mould in a hydraulic press machine under 4 MPa of continuous pressure. The results indicated good mechanical properties, such as tensile strength from 1.91 MPa to 3.449 MPa. Moreover, impact izod testing exhibited 47.61 J/m and 115.44J/m. These results were due to a decrease in bubble formation with the composite formation when sawdust and chamotte were fabricated with castor oil, producing a feasible composite panel (de Oliveira Júnior *et al.* 2023).

10.2.1.4 Wood Flour (WF)

Wood flour (WF) production has high absorption capacity, low cost, biodegradable, inert characterization, and is environmentally friendly. The

structure of WF is composed of cellulose fibers, hydroxyl groups, amorphous cellulose, hemicellulose, and lignin. Wood flour is disposed of in landfills, which causes environmental concern. To limit the unacceptable disposal of WF, it can be used as a filler in natural fiber-reinforced composite or wood polymer composite mainly used in furniture, packaging, automobiles, buildings, and construction. The wood flour-based composite's mechanical properties generally decrease due to its hydrophilic nature, impairing polymer bonding (Kumar, Tyagi, and Sinha 2011). Table 10.2 below shows some of the properties of wood flour.

Table 10.2. Some of wood flour properties (Kumar, Tyagi, and Sinha 2011).

| Properties | Value |
|--------------------------------|----------|
| Density (g/cm ³) | 0.4-1.35 |
| Modulus (MPa) | 10000 |
| Decomposition temperature (°C) | 200 |
| Hardness (Mohs) | 2 |

10.2.1.5 Furniture

The study by Gill *et al.* (2022) demonstrated the potential fabrication and characterization of wood flour/polypropylene composite using the extrusion technique for application in furniture. To enhance the compatibility of the composite, a PP-g-MA compatibilizer was utilized. The operating extrusion temperature was maintained at 180-210°C to prevent the wood cellulose chain from disintegrating at >220°C—the morphological analysis characterized by SEM depicted well-dispersed irregular-shaped particles. The wood flour/PP composited thermal stability process was performed using TGA and revealed thermal stability at 220°C due to its excellent high temperature performance and was thus considered for potential use in furniture applications (Gill *et al.* 2022). Another study by Basalp *et al.* (2020) demonstrated using recycled bulky post-consumer plastic waste and wood flour to develop crates, tables, and chair legs. The study was motivated by the excess waste generated, which caused adverse environmental and economic effects. The waste valorization was achieved by fabricating wood flour/r-PP composite using injection moulding at 185°C. MAPP was utilized as the compatibilizer to enhance adherence between the wood flour and recycled polypropylene (r-PP). The results showed that 30 wt% WF-filled r-PP content wood polymer composite (WPC) depicted the highest tensile strength of 24.8 MPa. Moreover, 46.2 MPa of flexural strength was achieved. This was due to the enhanced

compatibility between wood flour and polymer resin, influenced by MAPP. Furthermore, a void fraction 0.0019 was observed because of good adhesion within the WPC. The impact strength was lower at 4 kJ/m², which was attributed to the use of recycled polymer.

10.2.1.6 Decking

Wood polymer composites have found their way not only into furniture applications but also into decking applications. Decking boards showed promising properties and gained a more than 20 percent decking market. Mengeloglu (2001) study illustrated the selected mechanical properties of fabricated decking boards. The two composite decking boards, which are wood flour-based PP (WF/PP) and WF/high-density polyethylene (HDPE) (WF/HDPE), are produced using Davis-Standard WT-94 Woodtruder. The decking board's mechanical properties, such as flexural strength, tensile strength, and impact properties were evaluated. A 2% maleated propylene (MAPP) coupling agent was utilized to enhance the compatibility of both boards. The results exhibited 35.82 MPa flexural strength and 3.84 GPa modulus of fabricated WF/PP. WF/HDPE depicted a flexural strength of 23.05 MPa and a flexural modulus of 2.92 GPa. The flexural modulus and strength were increased, attributed to MAPP coupling agents. According to the ASTM D 6662 standard, flexural modulus and strength of 0.34 GPa and 6.9 MPa are required for decking boards. The study obtained excellent flexural modulus ranging from 2.49 to 3.8 GPa and flexural strength from 23.05 to 35.82 MPa. The impact strength of 34.74 J/m and 43.13 J/m was obtained for WF/PP and WF/HDPE, respectively (Mengeloglu *et al.* 2007). The tensile properties at the break of decking boards displayed satisfactory results, as shown in Table 10.3 below.

Table 10.3 Tensile testing properties.

| Specimen | Tensile Strength (MPa) | Tensile Modulus (GPa) | Elongation at Break (%) |
|-------------------|------------------------|-----------------------|-------------------------|
| WF/PP +2% MAPP | 18.80 | 2.68 | 2.11 |
| WF/HDPE + 2% MAPP | 13.50 | 3.45 | 1.76 |

A recently similar study by Fatima *et al.* (2023) also illustrated the improved properties of wood flour-reinforced HDPE at different wood contents. The three (40%, 50%, and 60%) WF/HDPE biocomposites were

evaluated for thermal analysis, flexural strength, density and hardness. The obtained WPC results showed that 40% to 60% of wood content increased in density from 1.047 g/cm³ to 1.097 g/cm³. A similar trend was observed with the hardness test from 64.5 to 67.7. On the contrary, 60% WF content WPC flexural strength depicted a decrease from 37.524 MPa to 27.512 MPa, while an increase from 2176.125 MPa to 3568.284 MPa of flexural modulus was observed (Fatima *et al.* 2023). Generally, the study depicted good mechanical properties for decking application.

10.3 Conclusion

In this chapter, the utilization of wood biomass-based composite was investigated. This was motivated by the use of fossil fuels which have a negative impact on the environment and the economy. Wood-based biomass such as sawdust and wood flour used in the development of biocomposite to be utilized in building application serves as an alternative use to fossil fuels. Sawdust-based thermoplastic biocomposite exhibited excellent mechanical properties that can be utilized in producing particleboards, mortar and bricks and floor panels. These mechanical characteristics such as tensile strength and compressive strength are in accordance with ASTM standards. Moreover, furniture and decking materials produced from wood flour-based composite exhibited good mechanical and physical properties. These excellent mechanical properties are influenced by using compatibilizer which enhances the compatibility of wood sawdust and flour and polymer.

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