A COMPARATIVE STUDY OF PHYSICAL AND MECHANICAL PROPERTIES OF WOOD PLASTIC COMPOSITE PRODUCED FROM DIFFERENT AGRICULTURE RESIDUES

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Abstract

In recent years, concerns about environmental preservation have fostered research on alternative natural materials, motivated industries to employ more environmentally friendly materials and encouraged the implementation of recycling activities. A comparative study was conducted to investigate the physical and mechanical properties of wood plastic composites (WPC) produced from polypropylene (PP) and recycled polyethylene terephthalate (PET) with different types of fibres (coconut coir, bagasse, and pineapple leaves). The natural fibres were chemically treated then mixed with the PP and PET using a Brabender mixer at the temperature of 200 °C. The WPCs were produced using hot pressing at the temperature of 180 °C with pressure of 0.098 MPa for 15 minutes. Then, the colour, density, water absorption capacity, modulus of rupture, and modulus of elasticity were examined. The results showed that physical and mechanical properties of WPC were strongly dependent on the types and amount of fibres. Moreover, this study also revealed that WPC produced with pineapple leaves fibre possessed excellent physical properties and mechanical properties compared to coconut coir and bagasse fibre. The results of the study indicated that WPC produced from a mixture of PP, recycled PET and pineapple leaves fibre is a viable alternative material to natural wood for wood-based industries.

Keywords
Wood Plastic Composite, Bagasse, Coconut Coir, Pineapple Leaves, Physical Properties, Mechanical Properties

1. Introduction

Environmentally friendly manufacturing practices is fast becoming a strategic marketing tool for the furniture-making business since there is growing environmental concern on the wooden furniture manufacturing industries/ Due to high demand in applications such as construction, automotive, furniture and aerospace industries, biocomposites have received much attention in research, developmental sector as well as industry. Biocomposites are composite materials comprising one or more phase(s) derived from a biological origin. A biocomposite is a material formed by a matrix and a reinforcement of natural fibers like jute, coir, sisal, curaua, ramie, bamboo, banana and bagasse. For instance, cotton, flax, hemp, recycled wood or waste paper and byproducts from food crops are extensively used as fibres for biocomposites (Fowler et al., 2006). Biocomposites are materials that are suitable to be used in furniture industries. Some of the common biocomposites already used in furniture industries are plywood, particleboard, medium density fiber board (MDF), wood plastic composites (WPC), laminated veneer lumber (LVL), oriented strand board (OSB) and hardboard (Suhaily et al., 2012). In terms of processing as well as production and waste management, biocomposites provide advantages of being environmentally friendly materials. Biocomposites became popular when market demand for environmentally friendly products increased with the need to find alternative materials to replace the demand for natural fibers from forest resources (Kamal et al., 2014). Furthermore, biocomposites help to reduce environmental pollution since they consist of biodegradable materials. Other than that, biocomposites tend to have moderate tensile strengths, stiffness, excellent specific strength, lower density, high corrosion resistance, and high creep resistance. However, biocomposites have several disadvantages such as low impact strength, problem of stocking the raw materials for extended periods and low ultra violet resistance (Mitra, 2014).

A wood–plastic composite (WPC) is a commonly used term referring to wood-based materials such as lumber, veneer, fibers, or particles that are combined with polymers to create a composite material. It is a broadly used term and as such, wood elements can be combined with either thermosetting or thermoplastic polymers. The term wood–plastic composite is used interchangeably with wood–polymer composites and the wood composites made from either thermoplastic or thermosetting polymers such as polypropylene (PP), polyethylene terephthalate (PE) and polyvinyl chloride (PVC) are often used due to their low cost as well as low processing temperatures that reduce the degradation of the wood fibers (Gardner, Han, & Wang, 2015). WPC board is also used as an alternative source to wood in the particle board industry to reduce deforestation activities. The increasing demand for WPC production is due partly to the decline of natural resources and offers the opportunity to manufacturers to use more sustainable resources for producing their products. WPC board is ideal due to its colour that highlights the texture and uniformity of rubberwood fibers (Suhaily et al., 2012).

Plastic is one of the major toxic pollutants of the present. Plastic pollutes the earth and leads to air pollution and water pollution since it is composed of toxic chemicals and it is a non-biodegradable substance. Waste plastic in the environment mixes with the food chain, directly affecting the natural environment, people and animals. There is no safe way to dispose plastic waste and plastic cause serious damage to the environment during its production process, during its usage and during its disposal process. Toxic chemicals released during the manufacturing process is another significant source of the negative environmental impact of plastics (Raman & Sharma, 2014). Today, the demand for plastic such as polyethylene terephthalate (PET) continuously increased. Most of the plastic that people use are normally made from petroleum based materials and not readily biodegradable. This situation is not environmentally friendly and the bulk of plastic waste in the environment can damage the ecological systems. In 2005, the Malaysian National Strategic Master Plan estimated that a total of 31.500 tonnes of solid waste is generated every day by 2020 (Johari et al., 2014). If the plastic waste is not managed properly and effectively, it will lead to negative impacts on the health of communities and the environment.

The agriculture sector has been the backbone of the Malaysian economy since its independence in 1957. In 2017, this sector contributed 8.1 percent to the Gross Domestic Product (GDP) (Department of Statistic Malaysia, 2017). The agriculture sector plays an indispensable role as food provider, creator of job opportunities and generator of national income (Istikoman et al., 2015). A wide range of agriculture products, such as rubber, palm oil, paddy, cocoa, pepper, sago, sugarcane, bamboo, tobacco, tropical fruits, etc. are abundantly produced in Malaysia. Thus, it is not surprising that Malaysia generates large amounts of agriculture residues and these residues are not being fully utilised in economic downstream activities. It was reported that approximately 12 million tonnes of residues per year are available annually (Griffin et al., 2014). However, only 27 % of agriculture residues are utilised as fuel, for brick production, and manufacture of furniture products. The rest are just disposed of. Most of the agriculture residues are abandoned in nature that lead to wastage of natural resources and a cause of environmental pollution (Zafar, 2015). The issues create highly challenging situations in effective management of this type of solid waste.

In order to address these issues, this research aimed to produce WPC from mixtures of agriculture residues (coconut coir, bagasse, and pineapple leaves), polypropylene (PP) and PET. In addition, the study also investigated and compared the physical and mechanical properties of WPC produced with different agriculture residues.

2. Experimental

2.1 Materials

Used plastic bottles made from polyethylene terephthalate were collected from Perwira Residential College, Universiti Tun Hussein Onn Malaysia. Recycled polypropylene granules were obtained from the Ceramic Laboratory, Faculty of Mechanical Engineering and Manufacturing, Universiti Tun Hussein Onn Malaysia.

2.2 Fibre Extraction

Coconut coir was collected from agricultural areas in Senggarang, Malaysia. The coconut coir needed to undergo chemical treatment before it can be used for fabrication of WPC. Firstly, the coconut coir was cut into short pieces and washed with double distilled water in order to remove dust particle impurities (Parkash, 2015). Then, the coconut coir was soaked into the 2% NaOH solution (Merck, German) at ambient temperature for 24 hours to remove lignin from the coconut coir and avoid bacterial infection. After the soaking process, soaked coconut coir was washed and dipped in double distilled water for 6 hours to remove the excess of NaOH. Subsequently, the coconut coir was dried in a laboratory oven at 60 °C for 20 hours to remove the moisture content (Jayabal, et al., 2012). Lastly, the fibres were cut into ≈ 0.9 mm for further use. Bagasse was collected from a fruit stall in Parit Raja, Johor and pineapple leaves were collected from farms in Rengit, Johor. The chemical treatment of bagasse and pineapple leaves is almost similar with coconut coir and bagasse. The only difference is that bagasse was soaked in 2 % NaOH at ambient temperature for 6 hours (Rezende et al., 2011) while pineapple leaves were soaked in 5 % NaOH at ambient temperature for 2 hours (Siregar et al., 2010) before soaking in double distilled water and drying in laboratory oven. The extracted fibres are shown in Figure 1.

Figure 1: Extracted fibre after undergoing chemical treatment.

2.3 WPC Preparation

The polypropylene (PP), polyethylene terephthalate (PET) and fibre were mixed homogenously using Brabender mixer at temperature of 200 °C, at prescribed percentages, as shown in Table 1. The mixture was then pressed using the hot press machine at 180 °C with pressure of 0.098 MPa for 15 minutes.

Table 1: Experiment design of environmental friendly WPC

Sample	Fibre	PET (wt%)	PP (wt%)	Fibre (wt %)
A	Coconut Coir	15	70	15
B			65	20
C			50	30
D	Bagasse		70	15
E			65	20
F			50	30
G	Pineapple Leaves		70	15
H			65	20
I			50	30

2.4 Characterisation Testing

2.4.1 Physical Testing

Colour analysis was conducted to analyse the colour changes between all three different fibre compositions (5%, 10% and 20% fibre) in this research. The colour of WPC was captured using a digital single-lens reflex camera (DSLR D1100, Nikon). The density of WPC was measured using density kit (Mettle Toledo). The distilled water was used as the reference density in this test. Weight in air and weight in liquid were recorded to calculate the density of samples. Equation 1 shows the formula to calculate the density of samples. Meanwhile, the water absorption was determined by weighing the samples at regular intervals as described in ASTM D570 (Maslinda et al., 2017). The samples were immersed in the distilled water for 24 hours. Upon removal from distilled water, the surface of the sample was wiped using dry tissue. The difference between the substantially saturated weight and the dry weight gives the value of water absorption of sample, as shown in Equation 2.

$$\text{Density (g/cm}^3\text{)} = \text{(Weight in air) / (Weight in air – Weight in water)} \quad \text{Eq. 1}$$

$$\text{Water absorption (\%)} = [\text{(Wet weight - Dry weight)/ Dry weight}] \times 100 \quad \text{Eq. 2}$$

2.4.2 Mechanical Testing

Bending strength was done according to ISO 178:93 to determine the modulus of rupture (MOR) and modulus of elasticity (MOE). MOR is a measure of specimen’s strength before rupture while the MOE is a number that measures an object or substance’s resistance to being deformed elastically when a force is applied to it. Most commonly, the specimen lies on a support span and the load is applied to the center of the loading nose with a depth ratio of 16 mm and 5 mm respectively. The parameters of this test are support span, the speed of the loading and the maximum deflection of the test. These parameters are based on the test specimen thickness with 70 mm x 10 mm x 7 mm and defined by ISO 178:1993 (Mahzan, 2011). The test is stopped when the specimen breaks. Equation 3 and 4 show the formula to calculate MOR and MOE.

$$MOR = (3PL) / (2bh^2) \quad \text{Eq. 3}$$

Where, P = Maximum load (N)
L = Distance between two supports (m)
b = Sample’s width (m)
h = Sample’s thickness (m)

$$MOE = PL^3 / 4\Delta bh^3 \quad \text{Eq. 4}$$

Where, P = Maximum load (N)
L = Distance between two supports (m)

Δ	=	Distance of maximum load (m)
b	=	Sample's width (m)
h	=	Sample's thickness (m)

3. Results and Discussion

3.1 Physical Properties

3.1.1 Colour Analysis

The colour gives an aesthetic value to the product. Since the study was conducted to develop an alternative to natural woods, therefore, the colour of WPCs must be similar to the natural woods to give the same outward appearance as the original woods. Figure 2 shows the visual appearance of the WPCs obtained from different types and amount of fibres. It can be clearly seen that the colours of WPCs produced with coconut coir fibre are dark brown since coconut coir is naturally brown in colour. Other than that, it can be observed that there was not much difference in colour for WPCs made of 15 %, 20 % and 30 % of coconut coir fibre. For WPCs produced with bagasse fibre, light brown colour was observed. Similarly, there were no significant changes in colour even though the amount of fibre was increased to 30 %. On the contrary, increasing the pineapple leaves fibre amount resulted in different colours of WPCs. The sample with 15 % of pineapple leaves fibre appeared to be light brown while the samples with 20 % and 30 % of fibres tended to be dark brown in colour. Hence, it could be inferred that the colour of WPCs is strongly dependent on the types and amount of fibres.

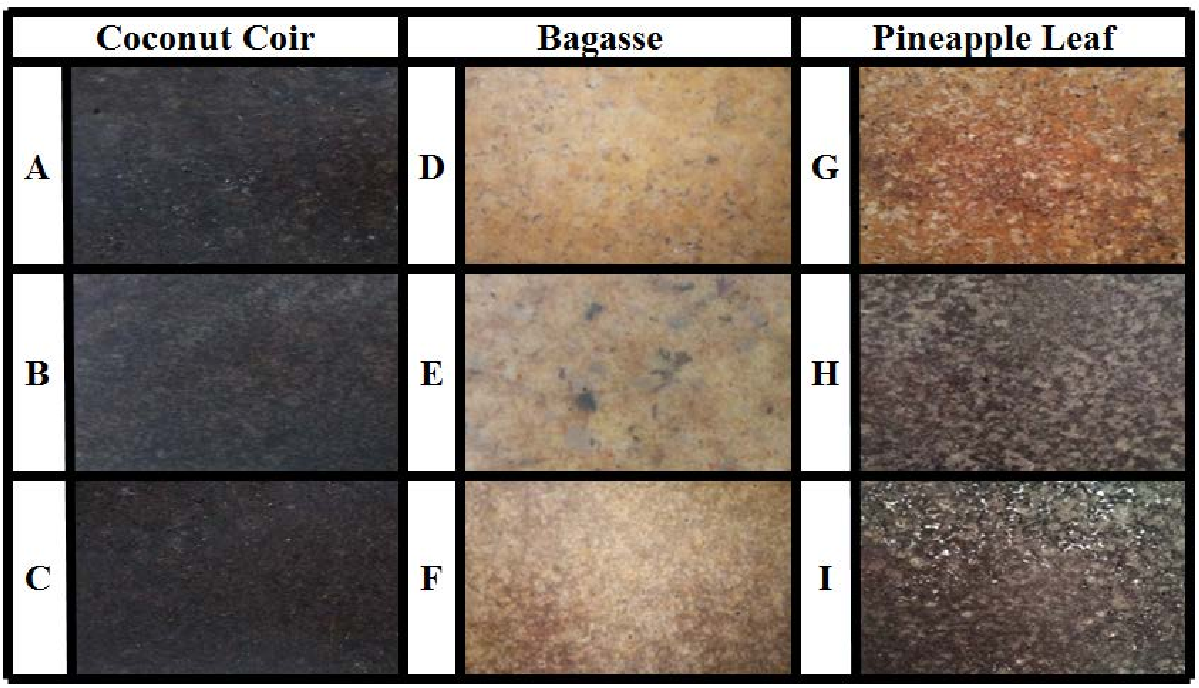

Figure 2: Colours of WPCs produced with different types and amount of fibres

3.1.2 Density Test

The density of WPCs with varying types and amount of fibre is shown in Figure 3. The range of density of WPCs produced with coconut coir fibre, bagasse fibre, and pineapple leaves fibre were from 0.32-0.57 g/cm^3, 0.34-0.82 g/cm^3 and 0.57-0.73 g/cm^3, respectively. It can be noted that the density of WPCs decreased with the increasing amount of fibre in composites. This is mainly due to the fibre agglomeration as the amount of fibre was increased which leads to the formation of voids inside the composite. It is noteworthy to mention that the voids may be present in either matrix, fibre-matrix interface, or within the fibre lumens (Abdul Khalil et al., 2007). Consequently, this will decrease the density of WPCs and affect their mechanical performance.

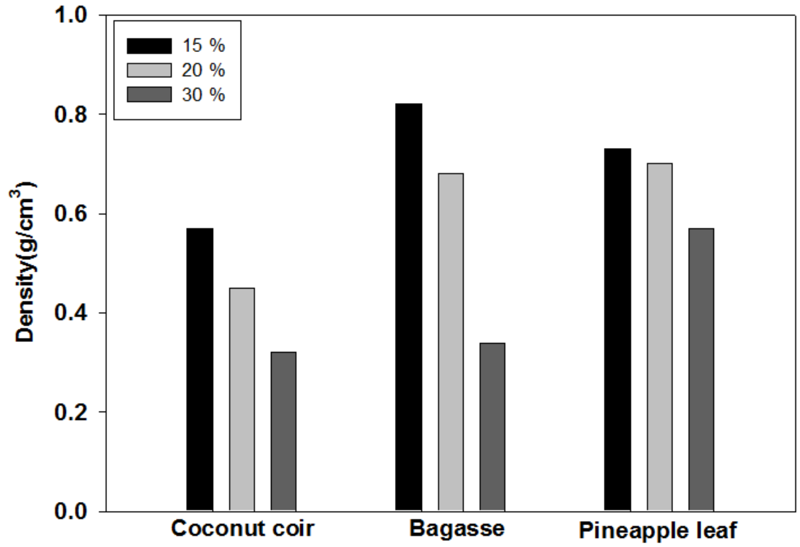

Figure 3: Density of WPCs produced with different types and amount of fibres.

3.1.3 Water Absorption

The water absorption results of WPCs after 24 hour immersion are shown in Figure 4. The range of water absorption of WPCs produced with coconut coir fibre, bagasse fibre, and pineapple leaves fibre were from 12.09-34.56 %, 22.23-37.45 % and 12.40-32.80 %, respectively. It is also interesting to note that the higher amount of fibre resulted in higher water absorption. This is mainly attributed to the hygroscopic property of natural fibre. The cell walls of natural fibres contain hydroxyl and other oxygen-containing groups which attract the water through hydrogen bonding (Wirawan et al., 2012). Additionally, it was found that WPCs produced by bagasse fibre exhibited the highest water absorption compared with other fibres owing to its high hygroscopic property.

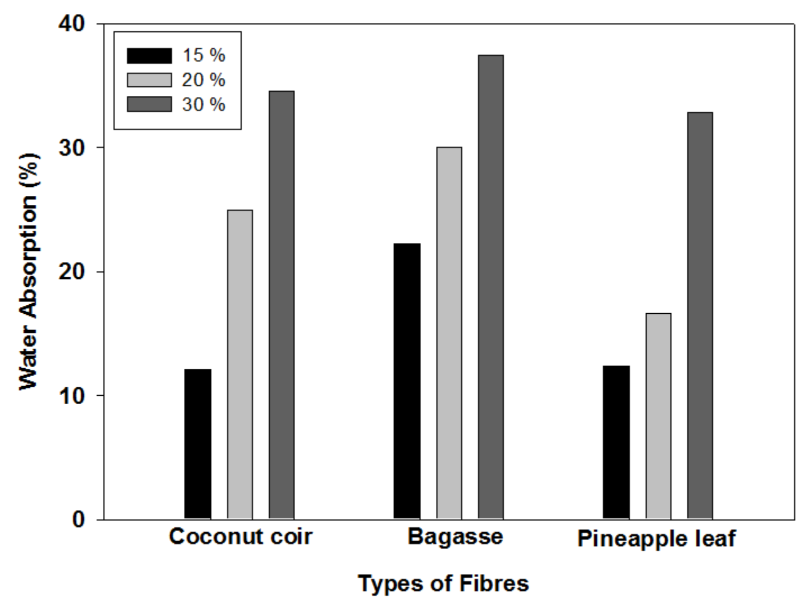

Figure 4: Water absorption of WPCs produced with different types and amount of fibres.

3.2 Mechanical Properties

3.2.1 Modulus of Rupture (MOR)

Figure 5 shows the MOR of the WPCs obtained from different types and amount of fibres. It can be clearly seen that MOR decreased with the increased amount of fibre. The recorded MOR for WPCs produced with coconut coir, bagasse, and pineapple leaves were 4.15-8.13 MPa, 4.01-11.02 MPa and 5.74-8.3 MPa, respectively. Hence, it can be concluded that WPCs produced with bagasse exhibited the highest MOR value compared to the others. These results are consistent with the results of density variation which suggests that MOR increased with the increase in density. These findings concur with the work done by other researchers which concluded that higher density resulted in improvement of mechanical properties of wood-based composites (Lias et al., 2014; Sarmin et al., 2013). This is mainly attributed to the higher density leading to higher compaction ratio of the board and consequently improves the mechanical properties of the board (Lias et al., 2014).

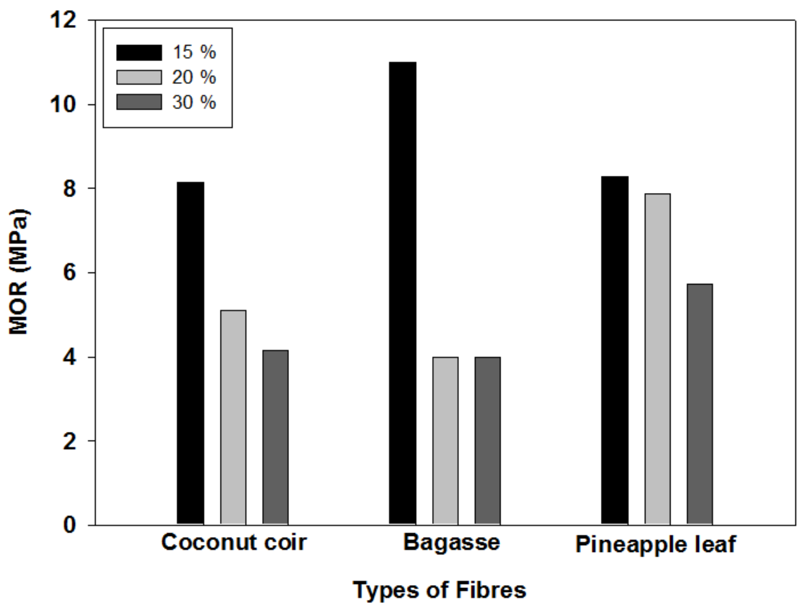

Figure 5: MOR of WPCs produced with different types and amount of fibres.

3.2.2 Modulus of Elasticity (MOE)

The MOE of the WPCs obtained from different types and amount of fibres is shown in Figure 6. Similar to the MOR results, MOE decreased with the increased amount of fibre. The recorded MOE for WPCs produced with coconut coir, bagasse, and pineapple leaves were 192-353 MPa, 402-423 MPa and 821-1353 MPa, respectively. Among these, WPCs produced with pineapple leaves demonstrated the highest MOE value compared to others. This is mainly due to the fact that pineapple leaves fibre has higher tensile strength compared to coconut coir and bagasse fibre. As reported by previous researchers, the range of tensile strength for coconut coir, bagasse, and pineapple leaves fibre are 175-220 MPa, 170-290 MPa and 293-1627 MPa, respectively (Asim et al., 2015; Saw & Datta, 2009). There is no doubt that WPCs produced with pineapple leaves fibre exhibited excellent MOE due to its high tensile strength. These findings concur with the work done by previous researchers on the same subject (Juki et al., 2013; Lias et al., 2014).

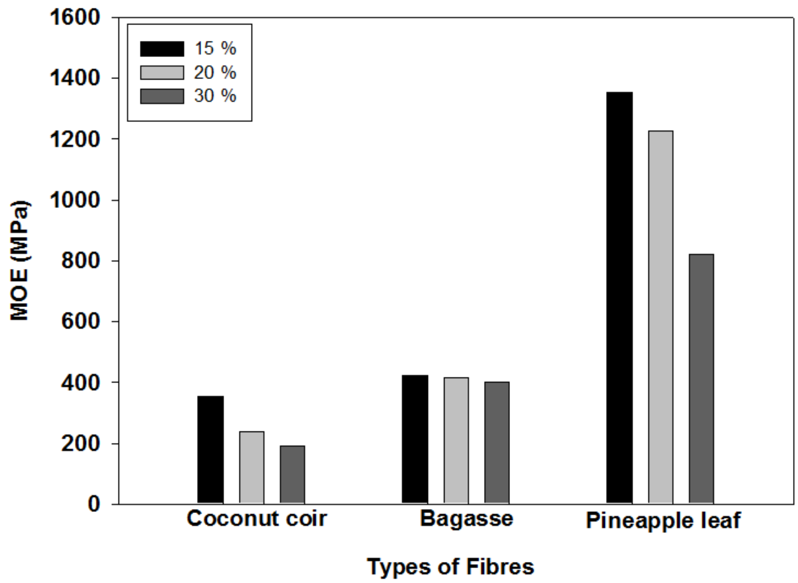

Figure 6: MOE of WPCs produced with different types and amount of fibres.

4.0 Conclusions

In conclusion, the mixture of polypropylene, recycled PET and natural fibres makes possible the manufacture of environmentally friendly WPCs. The colour, density, water absorption, MOR, and MOE are strongly dependent on the types and amount of fibres. The density, MOR and MOE decreased with increase in amount of fibre due to fibre agglomeration inside the composite which lead to the formation of voids and eventually affected the physical and mechanical properties of WPCs. On the contrary, water absorption increased with the increase in the amount of fibre. This is mainly attributed to the hygroscopic property of natural fibre. In term of physical properties, WPCs produced with coconut coir, bagasse and pineapple leaves exhibited light brown and dark brown colours which are similar to the natural colour of wood. Additionally, it appears that WPCs produced with pineapple leaves exhibited excellent mechanical properties (MOE = 8.3 MPa and MOR 1353 MPa) compared to coconut coir (MOE = 8.13 MPa and MOR 353 MPa) and bagasse (MOE = 11.02 MPa and MOR 423 MPa). Further research is needed to optimise the processing parameters for improving the physical and mechanical properties of WPC produced with the mixture of polypropylene, recycled PET, and natural fibres.

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