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EVALUATION OF HYBRID COMPOSITE MATERIALS FOR CRIBBING APPLICATIONS IN TRAIN DERAILMENT RECOVERY

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Abstract: *Railway systems play a crucial role for transporting goods and passengers. When derailments occur, cranes need a stable base to lift train cars, often relying on wooden sleepers arranged in cribbing structures. However, wood is heavy, susceptible to rot, and raises environmental issues. This study introduces a sustainable alternative through sandwich composite structures featuring hybrid face sheets composed of recycled plastics (rHDPE, rLDPE, rPE) and wood flour from both softwood and hardwood. Ten different material ratios were prepared using twin-screw extrusion and compression molding to assess their mechanical properties. The optimal performing blend consisted of 70% recycled plastic and 30% softwood flour, showing superior strength, surface hardness, and water resistance. The softwood plastic composite sheets exhibit higher flexural and compressive strength compared to materials made from hardwood flour, suggesting that the type of wood flour used influences the overall strength of the composites. Additionally, using rHDPE as the core material further improves the mechanical properties. The sandwich structure with an HDPE plastic core layer showed superior performance in terms of parallel compression, bending resistance, and surface hardness when compared to structures with core layers made of other types of plastics. When compared to conventional wood, the newly developed composite material is lighter in weight, more durable, and exhibits much lower water absorption. This innovative material provides an eco-friendly and effective substitute for traditional wooden sleepers, promoting a more sustainable and robust railway infrastructure.*

Key words: *hardwood, recycled plastics, softwood, sandwich structure, wooden sleepers, wood plastic composites.*

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1. Introduction

Railways have a long history and an important role in the development of society and the economy. They are an important transportation system that helps connect cities, making the transportation of goods and passengers efficient [13, 17]. Although other transportation systems have been developed, such as cars and airplanes, trains are still the main choice of transportation in many countries [6, 18]. When a train derails, it is crucial to address the situation immediately to restore normal transportation operations. To lift the train back onto the tracks, a crane with a large and powerful machine designed for lifting or moving heavy loads is needed. The use of a crane requires a solid base to prevent the crane from falling. Wooden sleepers are placed under the crane legs. The sleepers are arranged in a pigsty-like structure [10], which helps distribute the weight of the crane to the ground. It reduces the risk of the crane legs collapsing into the ground and increases the stability of lifting or moving the train as shown in Figure 1a. In the recent railway development, traditional wooden sleepers were made of natural wood, which is heavy and requires frequent maintenance. Since natural wood is prone to decay when exposed to moisture, it needs to be replaced once it deteriorates, as shown in Figure 1b.


a.


b.

Fig. 1. *The wooden sleepers in a pigsty structure (a.) [23], and the reclaimed railway wooden sleepers (b.)*

In addition, the use of wood also has an impact on the environment due to deforestation and the long-term scarcity of wood resources [1, 9]. As a result, alternative materials such as concrete, steel, and recycled plastic have been introduced to replace wood. These substitutes offer greater durability, can support significant loads, and are more environmentally friendly compared to natural wood [5, 7, 10, 11, 13, 14-22]. The main challenge with these alternative materials is their high cost and weight. To solve this problem, there has been growing interest in developing composite materials made from wood-plastic composites (*WPCs*). To enhance the durability of *WPCs*, a sandwich structure has been designed by incorporating face and bottom sheets layer. This structural design helps improve the strength of materials and overall performance, offering benefits such as lighter weight and a longer service life [7, 8, 20]. A *WPC* sandwich structure can support heavier loads, is more resistant to weathering and erosion, and helps lower maintenance expenses. The use of *WPCs* in railway systems not only minimises environmental impact [15, 19] and incorporates natural wood, but also improves transportation efficiency and the ability to handle heavy loads such as using cranes to lift derailed trains. Using lightweight and durable materials simplifies sleeper transportation, reduces maintenance time and costs, and enhances the safety and efficiency of railway operations [12, 16]. To date, no studies have investigated the use of *WPCs* in train derailment recovery for cribbing purposes. Therefore, this research aims to identify the optimal *WPC* formulation among 10 experimental mixtures that exhibit the best mechanical properties for potential use in sandwich structural applications. Additionally, *WPCs* were evaluated as face and button sheet layers for sandwich composite panels (*SCPs*) to achieve mechanical properties comparable to the properties of wooden sleepers. The newly developed wood-plastic composites are composed of recycled materials such as used plastic bottles, food packaging, and other post-consumer plastics.

2. Materials and Methods

2.1. Wood Species Used in the Sandwich Composites

To achieve optimal properties of sandwich composites for train derailment recovery, the initial stage of this study focused on fabricating *WPCs* for the face layers. Recycled high-density polyethylene (*rHDPE*) was chosen as the matrix material and combined with either softwood or hardwood fibres. Softwoods, including rubberwood (*Hevea brasiliensis* A. Juss), generally exhibit a flexural strength of less than 600 kg/cm², whereas hardwood, such as Lumpor wood (*Intsia bakeri* Prain.) and Red Seraya wood (*Shorea curtisii* Dyer ex King.), typically has values greater than 1,000 kg/cm². Once the optimal *WPC* formulation was identified, it was employed to fabricate sandwich composites by varying the core layer materials, which included recycled low-density polyethylene, recycled high-density polyethylene (*rHDPE*), and recycled polyethylene (*rPE*) in order to identify the most efficient combination.

2.2. Materials

The *WPC* compositions consisted of recycled high-density polyethylene as the matrix material and reclaimed natural flour as the reinforcing component. As illustrated in Figure 2, this study utilised two types of natural flour: rubberwood flour, obtained from a local timber factory and used as the softwood component, and reclaimed hardwood flour sourced from decommissioned railway sleepers supplied by the railway station maintenance department. Railway sleepers are generally made from various hardwood species. In this research, the reclaimed hardwood, whose exact species could not be identified, served as the control sample. The matrix material includes three varieties of recycled polyethylene, namely *rLDPE*, *rHDPE*, and *rPE*, as shown in Figure 3. All of these matrix materials were sourced from local scrapyards and junk shops.

a. b.

Fig. 2. *Wood sawdust: a. softwood; b. hardwood*

a. b.

Fig. 3. *Waste plastic: a. HDPE and LDPE bottles; b. PE plastic bag*

2.3. Sandwich Composites Fabrication

The softwood and hardwood materials were initially crushed and ground using a grinding machine. The resulting wood flour was then sieved to classify the particle size, using a sieve with a mesh range of 40-60. The selected wood flour was oven-dried at 100°C for eight hours to remove any moisture content. For the recycled plastic component, plastic bottles were first thoroughly cleaned to remove dirt and stains, followed by sun-drying for one day. The dried plastic bottles were then cut into small pieces and further crushed and ground using a grinding machine to achieve particles of approximately 1 × 1 cm in size. To prepare the test sample, the volume ratio of plastic to wood flour was varied from 80:20 to 40:60 wt%, as detailed in Table 1. The components were manually mixed by hand-shaking for five minutes. The blended mixture was then processed using a twin-screw extruder operating at a temperature range of 150-170°C with a screw rotation speed of 50 rpm to produce the WPC pellets. These pellets were later molded into *WPC* panels using a compression molding machine set at a temperature of 165°C, under a compression pressure of 1,000 psi for a duration of 15 minutes.

Formulation of WPCs Table 1

Formulation	Wood type	HDPE plastic [wt%]	Wood sawdust [wt%]
P80H20	Hardwood	80	20
P70H30	Hardwood	70	30
P60H40	Hardwood	60	40
P50H50	Hardwood	50	50
P40H60	Hardwood	40	60
P80S20	Softwood	80	20
P70S30	Softwood	70	30
P60S40	Softwood	60	40
P50S50	Softwood	50	50
P40S60	Softwood	40	60

The fabrication of sandwich composite panels (*SCPs*) involved the assembly of three layers: a face sheet, a core layer, and a bottom sheet, with a thickness ratio of 3:4:3 cm (as shown in Table 2). The face and bottom sheets were made from WPC panels that demonstrated optimal mechanical properties, developed during the earlier stages of the study. The core layer, designed to enhance the overall mechanical performance of the *SCPs*, was composed of different types of recycled plastics, specifically *rHDPE*, *rLDPE*, and *rPE*. These materials were processed into panels using the same compression molding parameters applied to the *WPCs*. These components were stacked in the order of *WPC* panel, plastic core panel, and another *WPC* panel, resulting in a total panel thickness of 10 cm. The assembled layers were then bonded together into a single integrated composite panel through compression molding at a temperature of 165°C, under a pressure of 1,500 psi for 20 minutes. A schematic diagram of the *WPCs* preparation process is displayed in Figure 4.

Formulation of sandwich composite panels Table 2

Plastic type	Thickness ratio [%]		
	WPCs	Plastic	*WPCs*
rHDPE	30	40	30
rPE	30	40	30
rLDPE	30	40	30

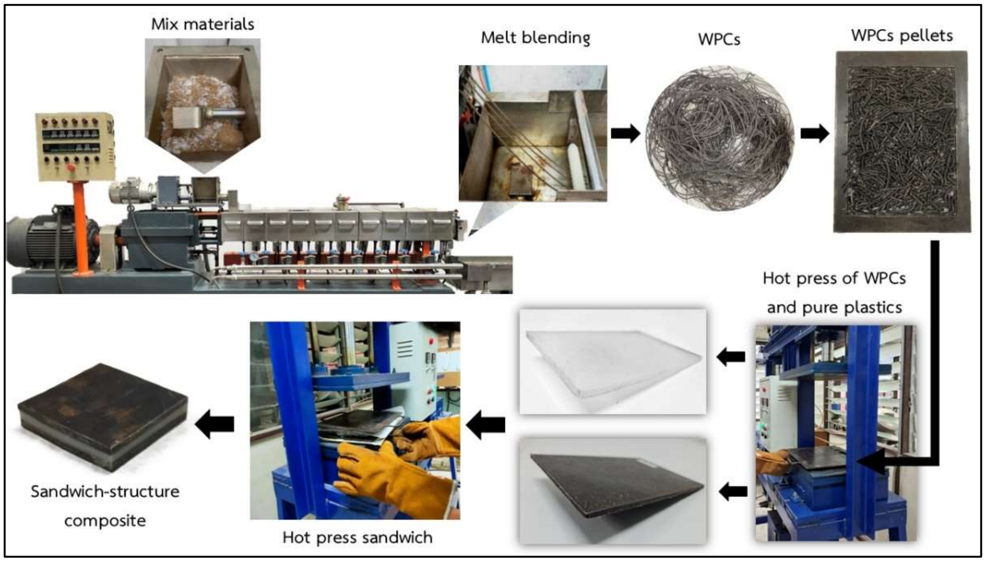


Fig. 4. *Schematic diagram of the sandwich composites fabrication*

2.4. Material Testing
2.4.1. Flexural Strength Test

The flexural strength of the *WPC* samples was assessed using a three-point bending test in compliance with ASTM D790-92 [5]. The test specimens were prepared with dimensions of 13 mm × 100 mm × 10 mm and evaluated using a Universal Testing Machine (UTM; Instron Model 5582) at a crosshead speed of 2 mm/min. Each formulation was tested in triplicate to ensure reliable results. For the sandwich composite panels, the flexural strength was evaluated according to the ASTM D143-22 standard [1], which is commonly used for testing the mechanical properties of wood. This standard specifies a sample dimension of 25 mm × 25 mm × 410 mm. Hardwood obtained from a decommissioned railway (as shown in Figure 5) was used as the control sample for comparison with the *SPCs*. The flexural tests were conducted on the same UTM under a constant loading rate of 1.3 mm/min. Each *SCP* formulation was tested in three replicates to ensure consistency.

2.4.2. Perpendicular and Parallel Compressive Strength Test

The compressive strength of the *WPC* samples was evaluated using the ASTM D695 standard [3]. The test specimens were prepared with dimensions of 4 mm × 4 mm × 8 mm and tested using a Universal Testing Machine. A constant crosshead speed of 2.5 mm/min was applied until deformation occurred in the sample. For the sandwich composite panels, the compressive strength was assessed to compare their performance with traditional wooden sleepers, which served as the control samples. The evaluation followed ASTM D143-22 [1], a standard that includes testing under both perpendicular and parallel loading conditions. Each specimen was positioned on the base of the *UTM* such that the pressing head was aligned either perpendicularly or parallel to the sample's surface, depending on the required loading direction. Force was then applied at a constant crosshead speed of 2.5 mm/min until deformation was observed. To ensure reliability and repeatability of the results, three replicates were tested for each formulation.

a. b. c. d.

Fig. 5. *Hardwood from railway sleepers as control samples: a. hardness sample; b. compressive sample; c. bending sample; d. water absorption sample*

2.4.3. Shore D Hardness Test

The Shore D hardness of the *WPC* samples was determined following the ASTM D143-22 standard [1]. The test specimens were prepared with dimensions of 50 mm × 50 mm × 150 mm and placed on a flat and stable base. A steel ball with a diameter of 11.3 mm was used to apply pressure to the surface of each specimen. To ensure uniformity and accuracy, five different measurement points were selected on each sample. Each formulation was tested in triplicate to enhance the reliability of the results.

2.4.4. Brinell Hardness Test

The Brinell hardness of the *SCPs* was tested in accordance with ASTM D785-23 [4]. The test specimens were prepared with dimensions of 25 mm × 25 mm × 6 mm and placed on the compression platform of the *UTM*. A steel ball indenter with a diameter of 12.7 mm was used to apply a controlled load onto the surface of each specimen. After the indentation process, the diameter of the resulting impression was measured using a microscope. Brinell Hardness Numbers (*BHN*) were then calculated. The hardness values obtained from the *SCPs* were compared with those of the hardwood control samples to assess their mechanical performance relative to traditional materials.

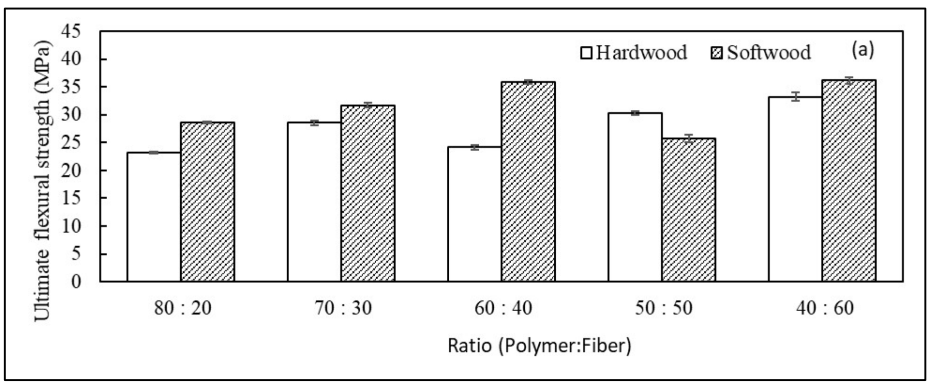
2.4.5. Water Absorption Test

The water absorption test was carried out following the ASTM D570-98 standard [2] for a duration of 24 hours. The specimens were fabricated with dimensions of 30 mm × 30 mm × 4 mm. Each formulation was tested using four replicates. Prior to testing, all specimens were oven-dried at 60°C for 24 hours to remove moisture and then immediately weighed to determine the initial dry weight. The specimens were subsequently immersed in water at room temperature (25°C) for 24 hours. After removal from the water, any surface moisture was wiped away, and the specimens were reweighed. The percentage of water absorption was calculated based on the difference in weight.

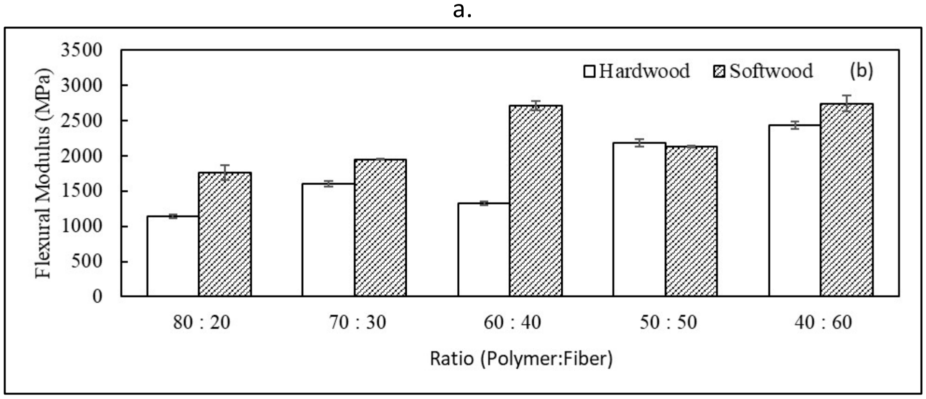
3. Results and Discussion

3.1. Flexural Test of *WPCs* and *SCPs*

The findings presented in Figure 6 reveal notable differences in the flexural strength of wood-plastic composite samples made of hardwood and softwood flour. At a plastic-to-wood flour ratio of 40:60, hardwood-based composites achieved the highest flexural stress of 33.23 MPa, while the 80:20 ratio yielded the lowest value of 23.20 MPa. A similar trend was observed in softwood-based composites, with the 40:60 ratio producing the highest flexural stress of 36.18 MPa. However, in contrast to the hardwood samples, the lowest flexural strength for softwood-based composites was found at the 50:50 ratio. These results indicate that softwood flour generally offers better flexural strength than hardwood flour, particularly at higher wood content levels. This may be attributed to the larger surface area and improved interfacial adhesion between softwood flour and the polymer matrix, which enhances stress transfer under loading. As a result, *WPCs* containing softwood flour exhibited consistently higher flexural strength across different formulations compared to those made with hardwood flour.



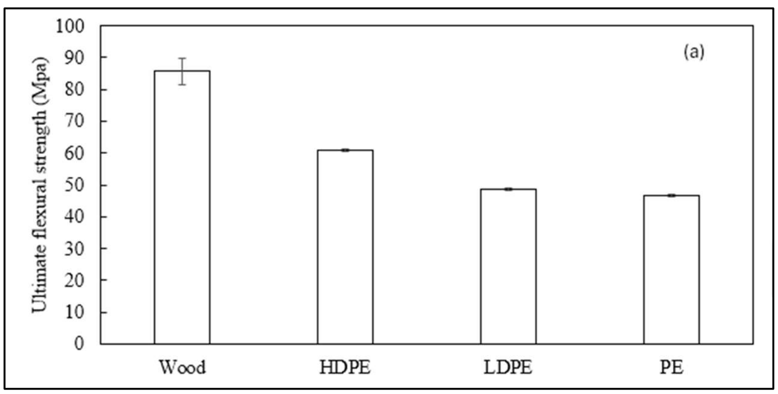
a.



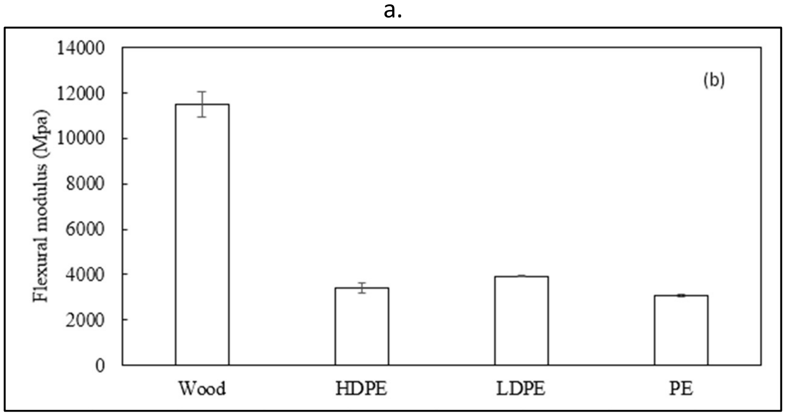
b.

Fig. 6. *Flexural test of WPCs: a. ultimate flexural strength; b. flexural modulus*

Regarding flexural modulus, which reflects the stiffness of the material, the composites exhibited a similar trend to flexural strength. At the optimal plastic-to-wood flour ratio of 40:60, the flexural modulus reached 2,437.48 MPa for hardwood-based *WPCs* and 2,741.61 MPa for softwood-based *WPCs*. The lowest values were observed at the 80:20 ratio, with hardwood and softwood composites showing 1,139.60 MPa and 1,763.05 MPa, respectively. These results confirm that increasing wood content, particularly with softwood, improves the stiffness of *WPCs*. This further confirms that softwood flour plays a more important role in enhancing the stiffness of the composite material. The results demonstrate that both the type and proportion of wood flour significantly affect the mechanical properties of *WPCs*. Increasing the wood flour content up to a 40:60 plastic-to-flour ratio improves both flexural strength and modulus. Softwood flour consistently outperformed hardwood flour, indicating its greater effectiveness in reinforcing wood-plastic composites.



a.



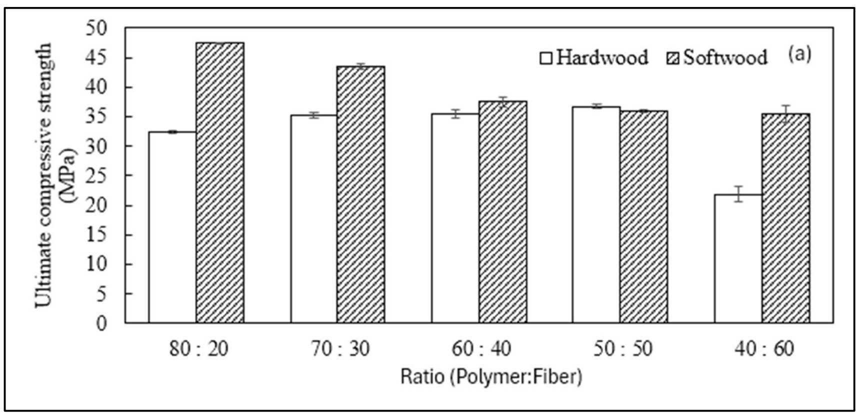
b.

Fig. 7. *Flexural test of SCPs: a. ultimate flexural strength; b. flexural modulus*

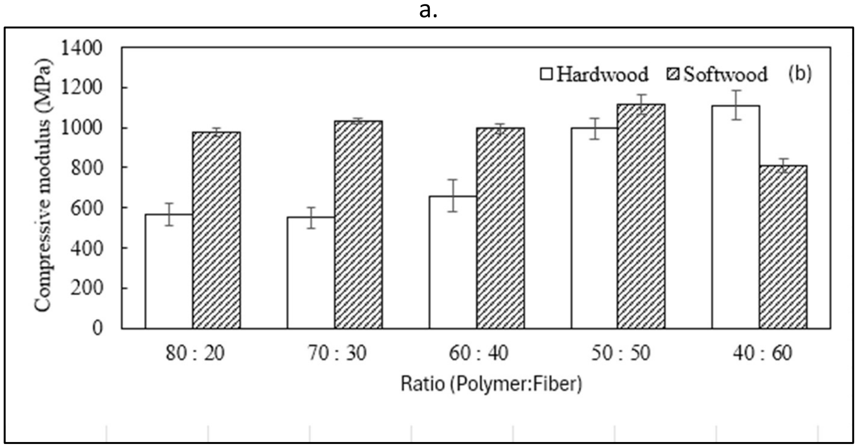
A flexural strength test was conducted with three repetitions. Among the sandwich structural materials, the specimen with an *HDPE* core exhibited the highest flexural strength, reaching 60.86 MPa, while the *PE* core produced the lowest value of 46.71 MPa, as shown in Figure 7. In terms of flexural modulus, the *LDPE* core achieved the highest value of 3934.24 MPa, whereas the *PE* core had the lowest value at 3,087.70 MPa. These findings further demonstrate how the type of core material significantly influences the mechanical behaviour of sandwich structures. Materials with *LDPE* cores tend to perform better in perpendicular compressive strength, while *HDPE* cores provide superior flexural and compressive strength in the parallel direction. This variation highlights the importance of the type of core plastic in determining the overall structural performance of sandwich composites.

3.2. Compression Test of *WPCs* and *SCPs*

Figure 8 shows the results of the compressive strength test for WPCs made from hardwood and softwood flour.



a.



b.

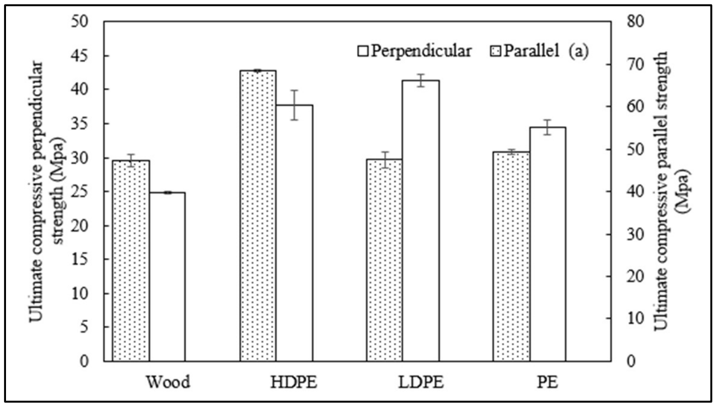
Fig. 8. *Compression test of WPCs:*
a. ultimate compressive strength; b. compressive modulus

Hardwood-based composites achieved a maximum compressive stress of 36.73 MPa at a plastic-to-wood flour ratio of 50:50, whereas softwood-based composites reached a higher value of 47.48 MPa at the same ratio. *WPCs* made with softwood flour show higher compressive strength because softwood fibres are generally longer and thinner (having a higher aspect ratio) than those from hardwood. This leads to improved interfacial bonding and more efficient stress transfer within the polymer matrix. However, increasing the hardwood fibre content in the composites enhances their overall compressive strength, whereas adding more softwood fibre results in the opposite effect.

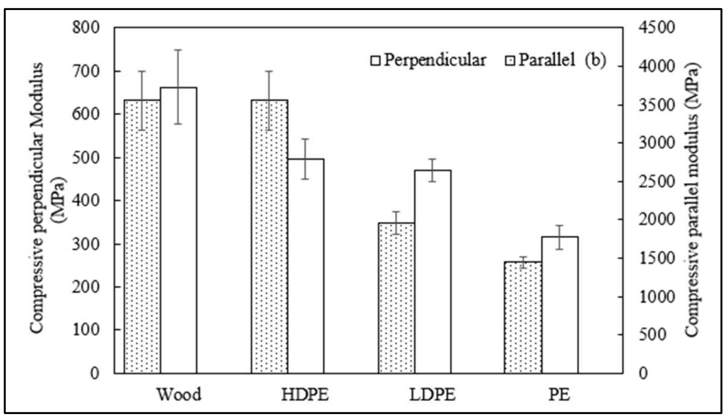
In terms of compressive modulus, which reflects the material's stiffness, hardwood-based composites had the highest value of 1,112.73 MPa, while softwood-based composites achieved a slightly higher value of 1,115.88 MPa. These results follow a similar trend to the compressive strength, further supporting the conclusion that softwood flour improves both the strength and stiffness of *WPCs*. These findings indicate that both the type of wood flour and the mixing ratio of plastic to flour significantly influence the compression behaviour of *WPCs*. Hardwood-based composites showed a noticeable decrease in compressive strength at higher wood content levels, while increasing the wood flour content, especially up to the 40:60 ratio, tended to improve the compressive modulus. This suggests that the amount and type of wood flour are critically important when evaluating the overall mechanical performance of the composites.

A flexural strength test was conducted with three repetitions. Among the tested samples, those with an *LDPE* core exhibited the highest perpendicular compressive strength at 41.27 MPa, while those with a PE core showed the lowest at 34.44 MPa, as shown in Figure 9. In terms of compressive modulus, the *HDPE* core layer achieved the highest value of 494.92 MPa, whereas the *PE* core layer had the lowest at 314.96 MPa. These results indicate that the type of plastic used in the core layer significantly affects the perpendicular compression properties of the sandwich structures. Specifically, materials with *LDPE* cores generally exhibit higher perpendicular compressive strength compared to those with *PE* and *HDPE* cores. Additionally, *HDPE* cores tend to provide higher compressive modulus values than both *LDPE* and *PE*. When compared to traditional wooden sleepers used as control samples, which have perpendicular compressive strength and modulus values of 24.91 MPa and 662.83 MPa, respectively, the sandwich materials show competitive mechanical performance. The *SCPs* with an *LDPE* core demonstrated strength and modulus that were 65% greater than those of wooden sleepers. However, the perpendicular compressive modulus of *SCPs* was lower by 41% compared to wooden sleepers.

The parallel compressive strength test was also conducted with three replications. The sandwich material with an *HDPE* core showed the highest parallel compressive strength at 68.48 MPa, while the one with an *LDPE* core recorded the lowest value at 47.45 MPa. Regarding the parallel compressive modulus, the *HDPE* core again achieved the highest value at 3,551.75 MPa, while the *PE* core had the lowest at 1,444.79 MPa. These findings highlight the significant influence of the core material type on the mechanical performance of sandwich structures. While *HDPE* cores generally offer the best performance in the parallel direction, *LDPE* cores perform better in terms of perpendicular compressive strength compared to *PE* and *HDPE* cores.



a.



b.

Fig. 9. *Compressive strength of SPCs: a. ultimate compressive strength: b. compressive modulus*

When compared to traditional wooden sleepers, which have parallel compressive strength and modulus values of 47.27 MPa and 3,551.75 MPa, respectively, the sandwich materials, particularly those with *HDPE* cores, show comparable or even superior performance. The parallel compressive strength of *SCPs* was 44% of that of wooden sleepers, while the parallel compressive modulus was 81% of the control sample. However, *SCPs* still demonstrate promising performance for railway applications. Previous studies have shown that composite material can achieve a compressive strength of 26.42 MPa [22], which exceeds the minimum requirement of 6.2 MPa set by the American Railway Engineering and Maintenance of way Association (AREMA).

3.3. Hardness Test of *SCPs*

A surface hardness test was conducted on three-layer sandwich structural materials, which consisted of face sheets made from a composite of 70% *HDPE* plastic and 30% rubberwood flour, as shown in Figure 10. The test was carried out using a Shore-D hardness tester. Among the samples, the sandwich panel with an *HDPE* core showed the highest surface hardness, measuring 69.4 *HD*, while the *LDPE* core had the lowest value at 66.4 *HD*. These findings suggest that the type of plastic used in the core layer has a significant impact on surface hardness. In particular, sandwich structures with *HDPE* core exhibited greater hardness compared to those with *PE* or *LDPE* cores, indicating that *HDPE*-based configurations offer better resistance to surface deformation.

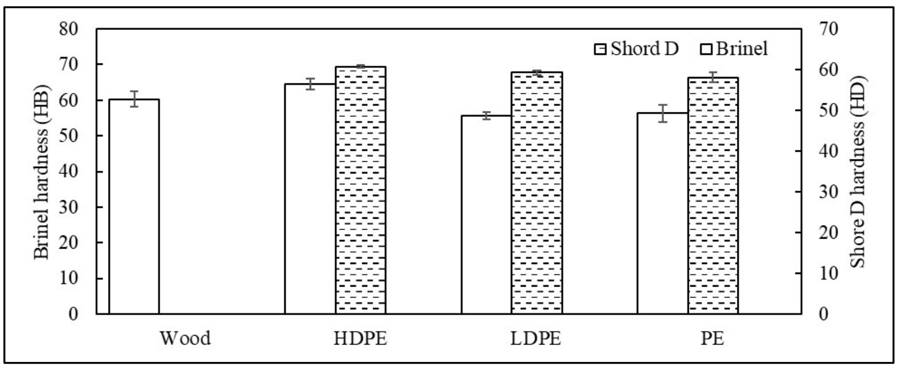


Fig. 10. *Hardness of SCPs*

3.4. Water Absorption of *SCPs*

As shown in Figure 11, the sandwich structural material with an *HDPE* core exhibited an average water absorption rate of 0.36%, with no observable swelling in any dimension (0% in width, length, and height). Similarly, the sample with a *PE* core layer had a lower average water absorption of 0.26%, also showing no dimensional change. In contrast, the *LDPE* core layer exhibited a slightly higher water absorption rate of 0.55%, but still showed no swelling in any direction. For comparison, wood sleepers, which are used as reference materials, demonstrated significantly higher water absorption, averaging 14.16%, along with noticeable dimensional expansion: 1.84-4.00% in width, 1.85-2.65% in length, and 1.89-7.87% in height after 24 hours of exposure to water.

Such behaviour demonstrates the hydrophilic nature of wood. In contrast, the sandwich composites showed minimal water absorption and almost no dimensional change, even though they contained wood flour as a reinforcing component. This behaviour is due to the plastic matrix surrounding the wood flour, which effectively shields it from water exposure. As a result, the wood-plastic composites do not exhibit the typical hydrophilic properties seen in natural wood. This finding aligns with the established theory on the water absorption and swelling behaviour of wood-plastic composites [21].

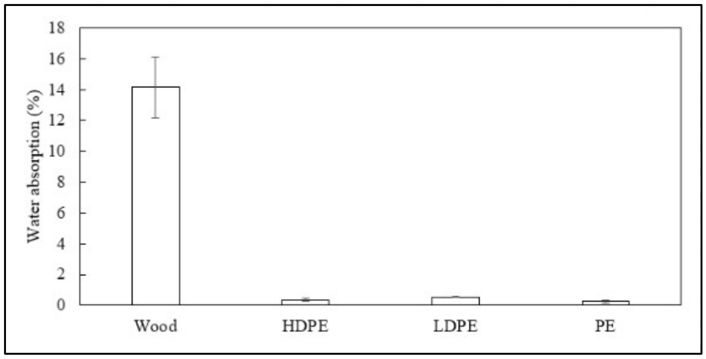


Fig. 11. *Water absorption of SCPs*

4. Conclusions

This study investigated the mechanical and physical performance of wood-plastic composites and their application in sandwich structural materials. *WPC* sheets reinforced with softwood flour consistently showed better mechanical properties than those made with hardwood. Increasing the softwood content slightly improved both flexural and compressive strength, while higher hardwood content reduced compressive performance. A wood-to-plastic ratio of 40:60 enhanced the flexural and compressive modulus, indicating increased stiffness. Among the tested formulations, a 70:30 plastic-to-wood ratio provided the best combination of mechanical strength and processability, making it a suitable alternative for replacing traditional wooden sleepers. The type of plastic in the core layer significantly influenced the performance of sandwich structural materials. *HDPE* cores yielded the highest values in parallel compressive strength, flexural strength, and surface hardness, while *PE* and *LDPE* cores showed comparable performance in perpendicular compression and water absorption. Compared to wooden sleepers, *WPC*-based sandwich structures exhibited superior compressive strength and hardness, which are key characteristics for supporting heavy loads, such as crane legs during derailment recovery. Additionally, the *WPC* sandwich structures showed low water absorption (≤0.55%) with no dimensional swelling, whereas wooden sleepers absorbed up to 14.16% of water and experienced noticeable expansion. This moisture resistance is attributed to the plastic matrix that encapsulates the wood flour, preventing water from penetrating and maintaining structural integrity in humid conditions. These findings emphasise the attractiveness of *WPC* sandwich composites, particularly those with *HDPE* cores, as durable and reliable alternatives to wood in structural applications. A challenge for future work is to scale up the *WPC* sandwich composites to an appropriate size for use in cribbing applications during train derailment recovery. The dimensions of the *WPC* sandwich composites may need to be redesigned to ensure suitability for this application and for practical fabrication.

Acknowledgements

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