

Experimental Investigation of the Structural Performance of Waste-Derived Particleboards

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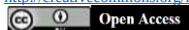
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ABSTRACT

This study experimentally investigated the structural properties of particleboards manufactured from locally available waste materials, namely rice husk, sawdust, oil-palm fruit fibre, breadfruit seed coating, and shredded plastic waste. Five waste-derived particleboards were produced and compared with a commercially available medium-density fibreboard (MDF) used as the control. The evaluated properties included modulus of rupture (MOR), modulus of elasticity (MOE), compressive strength, and Charpy impact energy. The experimental results showed that MOR values ranged from 0.69 to 11.67 N/mm², MOE values ranged from 0.35 to 5.90 N/mm², compressive strength ranged from 0.176 to 0.878 N/mm², and impact energy ranged from 14 to 48 J. The control (MDF) recorded the highest density (643 kg/m³), compressive strength (0.878 N/mm²), MOR (11.67 N/mm²), and MOE (5.90 N/mm²). Among the waste-derived boards, the rice-husk particleboard exhibited the best overall mechanical performance, with MOR, MOE, compressive strength, and impact energy of 10.69 N/mm², 5.35 N/mm², 0.405 N/mm², and 38 J, respectively. The shredded-plastic particleboard recorded the lowest values for most of the evaluated structural properties. The results demonstrate that agricultural waste, particularly rice husk and sawdust, can be converted into useful low-density composite boards. However, the relatively low strength and stiffness of most of the experimental boards indicate that they should not presently be regarded as substitutes for structural-grade particleboard without further optimization. The observed performance limitations were primarily associated with particle morphology, particle size, board density, compaction, moisture conditioning, and manufacturing conditions. The study demonstrates the potential of waste-derived particleboards for selected non-load-bearing and light-duty applications while contributing to waste valorization and reduction of dependence on conventional wood products.

Introduction

The rapid generation of agricultural residues, sawdust and post-consumer plastic waste has become an important environmental concern in many developing countries (Kariuki et al., 2020). In Nigeria, large quantities of residues are generated from timber processing, rice milling, palm-oil processing and agricultural activities (Onu et al., 2022). Much of this material is either openly burned, dumped indiscriminately or left to decompose without productive utilization. Converting such residues into Particleboard provides an opportunity to reduce waste while developing alternative materials for construction and furniture applications (Nicolao et al., 2020; Onu et al., 2022).

Particleboard is an engineered panel manufactured by bonding particulate lignocellulosic materials with an adhesive and consolidating the resulting mat under pressure (Kariuki et al., 2020). Conventional particleboards are predominantly manufactured from wood residues; however, increasing research attention has been directed toward agricultural and industrial residues as alternative raw materials (Nicolao et al., 2020; Onu et al., 2022; Ndububa, (2013). The attractiveness of these materials lies in

their availability, low cost and potential contribution to resource conservation (Osarenmwinda and Nwachukwu 2007).

The mechanical performance of particleboard depends on several interacting variables, including particle size and geometry, raw-material type, adhesive content, board density, moisture content, pressing conditions and degree of compaction (Nicolao et al., 2020; Onu et al., 2022; Čuk et al. (2011)). Astari et al. (2018), for example, investigated particleboards manufactured from wood waste with different particle sizes and adhesive contents and reported that increasing adhesive content improved mechanical performance, while finer particles generally produced better properties.

The present study therefore investigates the structural performance of particleboards produced from five different waste materials: rice husk, sawdust, oil-palm fruit fibre, breadfruit seed coating and shredded plastic waste. A commercially available Medium dense Fiberboard panel was used as the control material. The study specifically sought to:

1. Produce particleboards from selected agricultural and plastic wastes using locally available materials and equipment;
2. Determine the mor and moe of the manufactured boards;
3. Determine their compressive strength and impact energy;
4. Compare the performance of the waste-derived boards with commercially available mdf; and
5. Identify the most promising waste-derived material for further development.

2.0 Materials and Methods

2.1 Materials.



Sawdust



Oil-Palm Fruit Fibre



Breadfruit Seed Coating



Plastic Waste



Topbond Rice husk

2.2 Collection and Preparation of Raw Materials

Table 1. Collection and Preparation of Raw Materials

Raw Material	Source/Location	Preparation Procedure	Final Processing
Sawdust	Ogbo Osisi, timber-processing area, Nkwo Nnewi, Anambra State	Air-dried for 7 days, then oven-dried at 60 °C for 24 h; moisture content reduced from 15.56% to 9.42%	Sieved through 2.56 mm and 1.18 mm sieves to obtain uniform particles
Breadfruit Seed Coating	Eke Awka Market, Anambra State	Washed, air-dried for 7 days, and oven-dried at 60 °C for 24 h	Mechanically ground and sieved to obtain relatively uniform particles
Rice Husk	Rice-processing mill, Oba Ofemmili, Anambra State	Oven-dried at 60 °C for 24 h	Sieved through the selected sieve sizes



Raw Material	Source/Location	Preparation Procedure	Final Processing
Oil-Palm Fruit Fibre	Oil-processing mill, Amansea, Awka, Anambra State	Air-dried for 7 days and oven-dried at 60 °C for 24 h	Mechanically ground and sieved
Plastic Waste	Nnamdi Azikiwe University, Awka	Washed to remove contaminants, air-dried for 7 days, and oven-dried at 60 °C for 24 h	Mechanically shredded

2.3 Particleboard Mould and Adhesive

A plywood mould with internal dimensions of approximately 200 mm × 200 mm and a depth of 50 mm was fabricated for board production. The mould cover had a thickness of approximately 15 mm. Prior to filling, the mould surfaces were lightly coated with oil. Urea-formaldehyde adhesive (Top Bond) was procured from a dealer at Eke Awka Market, Anambra State.

2.4 Particleboard Production

Table 2. Procedure for Particleboard Production

Stage	Procedure
1. Particle Measurement	Loose particles were measured by filling and weighing the mould.
2. Adhesive Measurement	Adhesive was weighed according to the required percentage.
3. Mixing	Half of the particles were mixed with the adhesive, followed by the remaining particles.
4. Homogenization	The mixture was thoroughly mixed until a uniform composite was obtained.
5. Mould Preparation	The mould was lightly oiled to facilitate board removal.
6. Casting and Compaction	The mixture was placed in the mould, tamped to remove air voids and levelled.
7. Pressing	The mould was covered and compressed using a manual compression machine.
8. Oven Drying	The compressed panels were oven-dried.
9. Cooling and Sun Drying	The panels were cooled and subsequently sun-dried.
10. Storage	The dried panels were removed from the mould and stored on a flat surface.

Table 3. Experimental particleboard production matrix

Composite Code	Particles Used	Mass of Particles used (g)	Mass of Adhesive used (g)	Total mass used(g)
A	Rice Husk	214	492.2	706.2
B	Sawdust	214	492.2	706.2
C	Oil Palm fruit Fiber	214	492.2	706.2
D	Grinded Breadfruit seed Coating	214	492.2	706.2
E	Shredded Plastics	114	342	456
F (Control)	Medium Dense Fiberboard	-	-	-

2.4.1 Produced Particleboard



Sample A



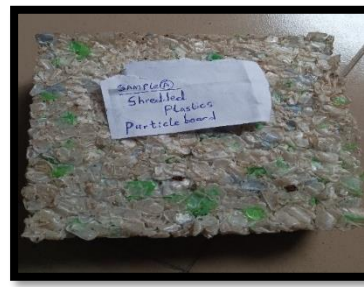
Sample B



Sample C



Sample D



Sample E



Sample F

2.5 Structural Properties Test

2.5.1 Static Bending Test

The bending properties of the boards were evaluated using the procedures described in ASTM D1037.

The modulus of rupture was calculated as:

$$MOR = \frac{3P_b L}{2bh^2} \quad (1)$$

Where, P is the maximum load (N),
b is the width of the specimen (mm),
h is the thickness of the specimen (mm),
L is the span (mm).

Modulus of elasticity (MOE) was calculated from the following formula:

$$MOE = \frac{PL^3}{4dbh^3} \quad (2)$$

Where, P = the maximum load (N),
L = the span (mm),

b = the width of the specimen (mm),
d = Deflection at beam center at proportional limit,
h = the thickness of the specimen (mm),

2.5.2 Impact Energy Test

The impact test of the board composites sample was conducted in accordance with ASTM D D1037 using a fully instrumented Avery Denison test machine.

2.5.3 Compression Test

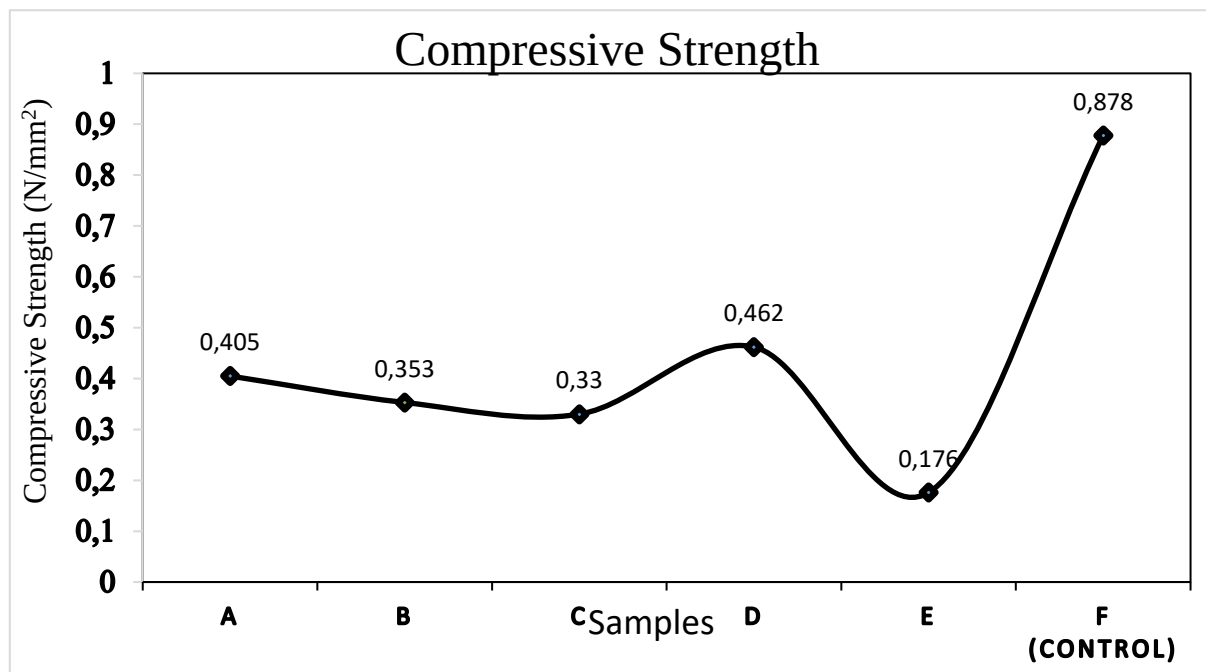
The test was carried out based on ASTM standard method (D1037-99, ASTM, 1999):

$$\text{Compressive strength} = \frac{\text{Ultimate Load (N)}}{\text{Cross sectional area (mm}^2\text{)}} \quad (3)$$

3.0 Results and Discussion

3.1 Compression Test

Figure 1. Compressive Strength (N/mm²) against Samples



The control MDF recorded the highest compressive strength of 0.878 N/mm². Among the waste-derived boards, Sample D, manufactured from breadfruit seed coating, recorded the highest compressive strength at 0.462 N/mm², followed by Sample A (rice husk) at 0.405 N/mm² and Sample B (sawdust) at 0.353 N/mm². Sample E, produced from shredded plastic, recorded the lowest value at 0.176 N/mm².

The relatively high compressive strength of the control can be associated with its comparatively dense and uniform internal structure. In engineered wood panels, density and internal bonding are important contributors to mechanical performance. Previous investigations have demonstrated the influence of particle size, density and adhesive content on particleboard strength.

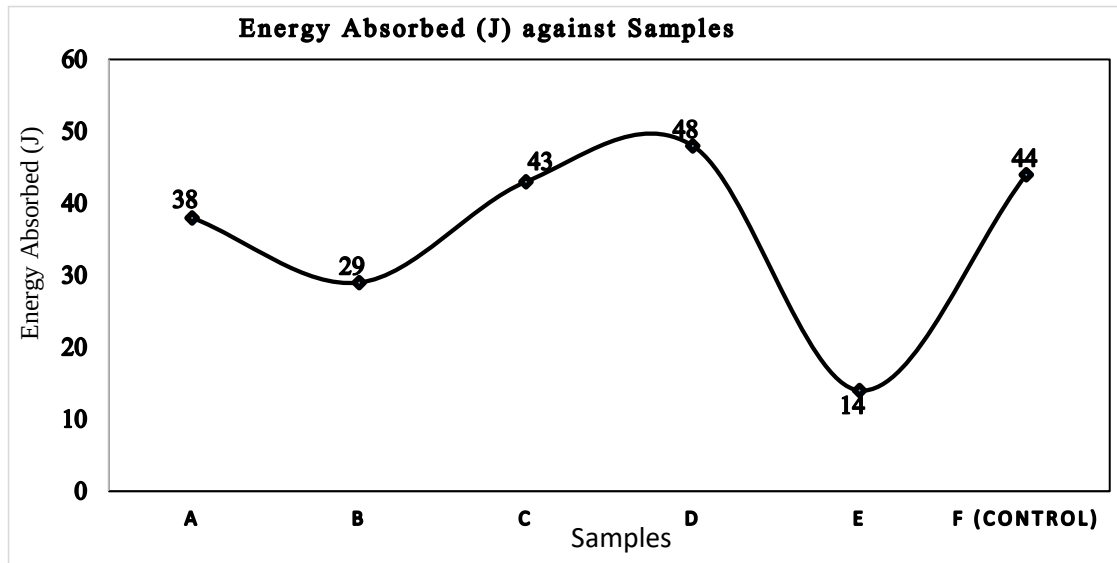
The comparatively low strength of the experimental boards may have resulted from incomplete consolidation, non-uniform particle distribution, relatively coarse particles and variations in particle–adhesive compatibility. In particular, the shredded-plastic board may have experienced inadequate adhesion between the polymeric particles and the water-based adhesive.

The results indicate that the experimental boards should not be considered direct substitutes for structural concrete or sandcrete masonry units. More importantly, comparisons with sandcrete-block strength requirements should be avoided when evaluating particleboards because the two materials have different material classifications, loading mechanisms and intended applications. Instead, particleboard

performance should be evaluated against the relevant requirements for wood-based panels and the intended end use.

3.2 Charpy Impact Test

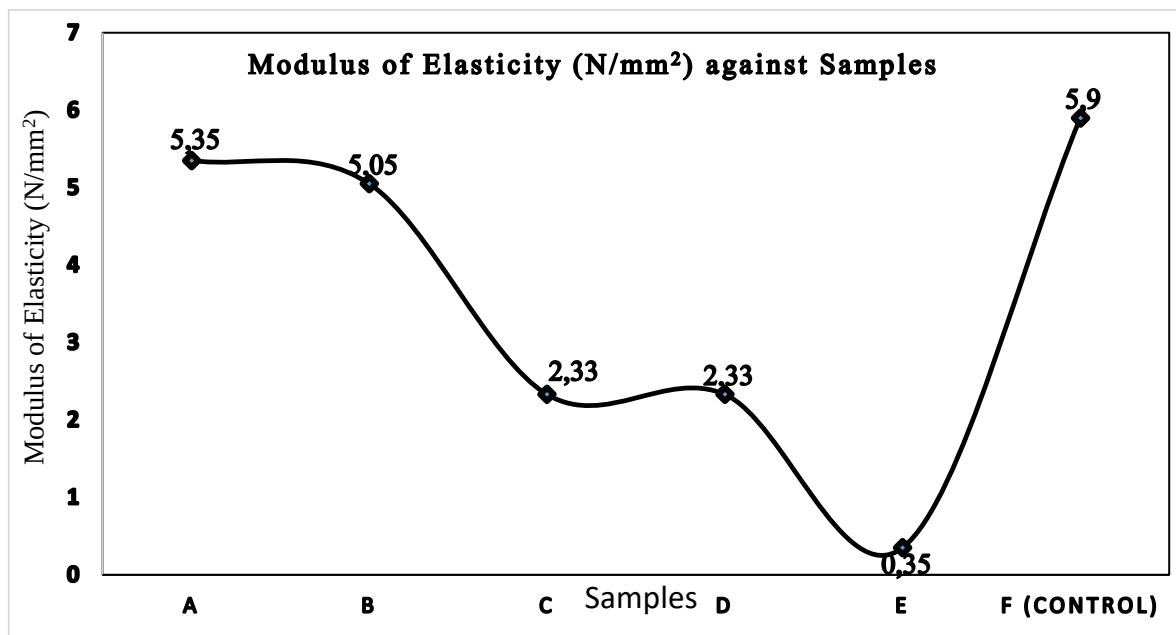
Figure 2 Energy Absorbed during Impact (J) against Samples



Sample D recorded the highest impact energy at 48 J, followed by Sample C at 43 J and the control MDF at 44 J. Rice-husk particleboard recorded 38 J, while sawdust particleboard recorded 29 J. The shredded-plastic board exhibited the lowest impact energy of 14 J. The results indicate that impact resistance did not follow the same ranking as density or bending strength. This is important because impact behaviour depends not only on density but also on particle morphology, interfacial bonding, defects and the ability of the composite structure to dissipate energy. The relatively high impact energy of the breadfruit seed-coating board suggests that its particle morphology may have allowed greater energy dissipation before failure. However, this observation requires further investigation using controlled particle-size distributions and microscopic examination of the fracture surfaces.

3.3 Static Bending Test

Figure 3 Modulus of Elasticity (N/mm²) against Samples



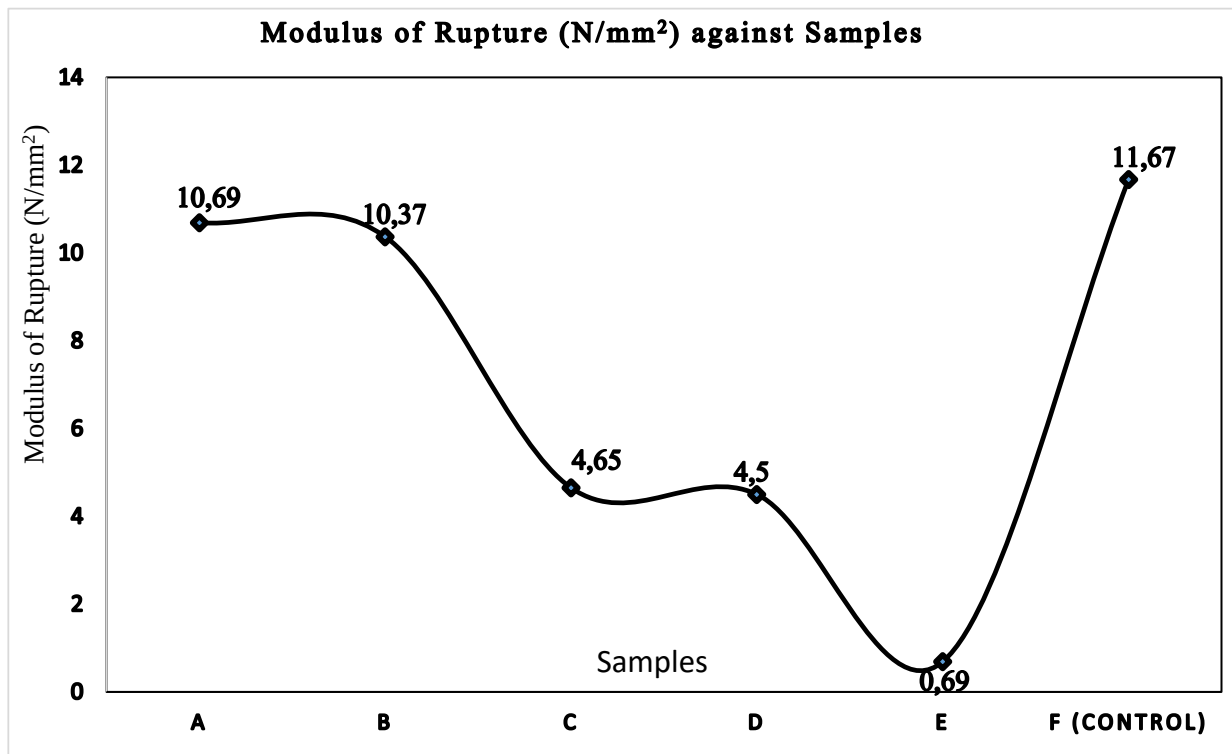
The commercial MDF recorded the highest MOE of 5.90 N/mm². Rice-husk particleboard followed closely with 5.35 N/mm², while sawdust particleboard recorded 5.05 N/mm². Oil-palm fibre and breadfruit seed-coating boards each recorded 2.33 N/mm², while the shredded-plastic board recorded the lowest MOE of 0.35 N/mm².

The comparatively high stiffness of the rice-husk and sawdust boards suggests that these materials developed better load transfer through the board matrix than the other waste materials. The result is consistent with the general observation that particle geometry, density and adhesive distribution affect the stiffness of particleboard. Astari et al. (2018) reported that particle size and adhesive content significantly affected the mechanical properties of waste-derived particleboards.

The very low MOE of Sample E indicates that the plastic particles did not form an effective load-transfer network under the production conditions employed. This may have resulted from poor compatibility between the plastic surface and the adhesive or insufficient consolidation.

However, the reported MOE values are unusually low compared with many commercial particleboard products. Therefore, the testing configuration, specimen dimensions, units, load-deflection measurements and calculation procedure should be rechecked before publication. This is particularly important because some commercially manufactured particleboards meeting ANSI A208.1 requirements have MOE values in the order of thousands of N/mm² rather than single-digit N/mm² values.

Figure 4. Modulus of Rupture (N/mm²) against Samples



The MOR results demonstrate a clear difference in bending performance among the boards. The commercial MDF exhibited the highest MOR at 11.67 N/mm². Rice-husk particleboard recorded 10.69 N/mm², followed by sawdust particleboard at 10.37 N/mm². Oil-palm fibre and breadfruit seed-coating boards recorded 4.65 and 4.50 N/mm², respectively, while the shredded-plastic board recorded only 0.69 N/mm². The relatively strong performance of the rice-husk board is particularly significant. Its MOR was approximately 91.6% of the MOR recorded for the commercial MDF control. Similarly, the sawdust board achieved approximately 88.9% of the control MOR. These results suggest that properly processed agricultural residues can provide a useful reinforcing phase in low-density composite panels.

The observed ranking is broadly consistent with the literature showing that particle size, adhesive content and board density influence bending strength. Astari et al. (2018) reported MOR values between 11.69 and 26.54 MPa for their wood-waste particleboards and observed improvement with increasing adhesive content and finer particle size.

Ndububa (2013) likewise demonstrated that increasing binder content substantially improved the flexural strength of sawdust/wood-shavings particleboard. The relatively poor performance of Samples C and D may be associated with particle morphology, surface characteristics and bonding efficiency. The very low MOR of Sample E suggests that the plastic particles did not develop adequate adhesion with the selected binder.

3.4 Comparative Assessment of Structural performance of the samples

From the Structural Test Results, It has been shown that no single waste material produced the highest value for every property. Rice-husk particleboard exhibited the best overall balance of bending strength, stiffness and compressive strength among the experimental boards. Breadfruit seed coating produced the highest impact energy and compressive strength among the waste-derived boards, while oil-palm fibre also showed relatively good impact resistance.

The shredded-plastic board exhibited the weakest overall mechanical performance. This result highlights the importance of binder compatibility in the manufacture of hybrid waste-derived panels. Plastic waste cannot necessarily be treated in the same manner as lignocellulosic particles because its surface chemistry and thermal behaviour differ significantly.

4.0 Conclusion and Recommendations

4.1 Conclusion

The commercial MDF control exhibited the highest overall performance, recording MOR of 11.67 N/mm², MOE of 5.90 N/mm² and compressive strength of 0.878 N/mm².

Among the experimental waste-derived boards, the rice-husk particleboard exhibited the best overall mechanical performance, with MOR of 10.69 N/mm², MOE of 5.35 N/mm², compressive strength of 0.405 N/mm² and impact energy of 38 J.

Sawdust particleboard also demonstrated promising bending performance, recording MOR and MOE values of 10.37 and 5.05 N/mm², respectively.

Breadfruit seed-coating particleboard recorded the highest impact energy among the experimental boards at 48 J and the highest compressive strength among the waste-derived boards at 0.462 N/mm².

The shredded-plastic particleboard exhibited the poorest overall mechanical performance, with MOR of 0.69 N/mm², MOE of 0.35 N/mm², compressive strength of 0.176 N/mm² and impact energy of 14 J.

The differences among the boards indicate that raw-material type has a significant influence on particleboard performance.

The experimental boards show potential for selected non-load-bearing and light-duty applications such as interior wall and ceiling, panels, furniture components, cabinet and shelving components, decorative panels, acoustic or thermal panel applications, packaging and protective boards

Rice husk appears to be the most promising of the investigated waste materials for further development because it produced the best combination of bending, stiffness and compressive performance.

The study supports the broader concept of converting agricultural residues into value-added engineered materials, thereby reducing waste disposal problems and potentially reducing dependence on virgin timber resources.

4.2 Recommendation

Based on the findings of this investigation, the following recommendations are proposed:

Future studies should investigate narrower and smaller particle-size distributions to improve particle packing and adhesive contact.

Hydraulic or hot-press equipment should be used to provide controlled pressure, temperature and pressing duration.

Different adhesive contents should be investigated systematically to determine the optimum binder-to-particle ratio.

Because the shredded-plastic board exhibited poor mechanical performance, future studies should investigate appropriate surface treatment and polymer-compatible binders before incorporating plastic waste into structural composites.

Target board densities should be established and controlled during production because density has a strong influence on mechanical performance.

Future work should include internal bond strength, water absorption, thickness swelling, screw withdrawal, dimensional stability, durability and fire-performance testing.

Multiple replicates should be tested for every mixture, and statistical analyses such as analysis of variance (ANOVA) should be employed to determine whether differences among board types are statistically significant.

Before recommending the boards for construction applications, their performance should be assessed against the requirements of the relevant particleboard product standard and the specific intended use.

Because Sample A demonstrated the best overall performance among the experimental boards, future research should investigate the effect of rice-husk particle size, adhesive content, density and pressing pressure on its mechanical properties.

Subsequent research may investigate controlled combinations of rice husk and sawdust to determine whether their complementary characteristics can produce a board with improved strength, stiffness and dimensional stability.

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