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Experimental and Analytical Assessment of Waste-Derived Particleboards for Scaled Roof-Beam Applications: Stress, Deflection and Similitude-Based Prediction

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Abstract
The increasing generation of agricultural, wood-processing and plastic wastes has created environmental challenges while also providing opportunities for developing alternative construction materials. This study experimentally and analytically assessed the structural response of particleboards produced from rice husk, sawdust, ground oil-palm fruit fibre, breadfruit seed coating and shredded plastic. Medium-density fibreboard (MDF) was used as the control. Scaled roof-beam models were investigated using experimentally determined modulus of elasticity and a similitude-based analytical procedure derived from Murphy's engineering similitude framework. The model length was 200 mm and the corresponding prototype length was 3600 mm; the prototype width and depth adopted in the analysis were 225 mm and 300 mm, respectively. The measured modulus of elasticity ranged from 0.35 to 5.90 N/mm². The adopted scaling procedure gave predicted prototype loads ranging from 37.21 kN for shredded-plastic particleboard to 193.50 kN for rice-husk particleboard, while the MDF control gave 205.64 kN. Prototype deflection predictions were very large, particularly for the low-stiffness plastic board. The results indicate that the investigated boards, in their present form and under the assumed beam configuration, should not be regarded as qualified primary load-bearing roof members without further optimization and full-scale validation. Among the waste-derived materials, rice-husk and sawdust boards showed the most favourable overall response. The study demonstrates the usefulness of similitude-based modelling as a preliminary assessment tool while emphasizing the importance of dimensional verification and full-scale structural testing.

Keywords: Waste-Derived Particleboard; Rice Husk; Sawdust; Recycled Plastic; Roof Beam; Similitude; Stress; Deflection; Modulus Of Elasticity; Sustainable Construction.

1. Introduction

The construction sector depends heavily on conventional materials and contributes to resource consumption and waste generation. Agricultural residues, sawdust, fruit-processing residues and post-consumer plastics are therefore increasingly investigated as feedstocks for engineered composite products. Particleboard provides a useful route for converting particulate waste into a shaped construction material. Reviews of crop-residue particleboards show that non-wood lignocellulosic materials can produce boards with useful mechanical properties, although moisture sensitivity, bonding and dimensional stability remain important challenges (Kariuki et al., 2020).

Rice husk has received particular attention because of its availability and potential as a substitute for conventional wood particles. Osarenmwinda and Nwachukwu (2007) showed that particle size influences the modulus of elasticity, modulus of rupture, internal bond, water absorption and thickness swelling of rice-husk particleboard. More recent studies have also shown that the mechanical performance of rice-husk boards can be improved through reinforcement and appropriate binder systems (Nicolao et al., 2020; Onu et al., 2022).

Material-level strength alone is insufficient for structural qualification. A board intended for a beam must also be assessed for load response, stress and deflection. Where full-scale testing is impractical, physical modelling and engineering similitude provide a preliminary means of relating model behaviour to a prototype. Murphy's engineering similitude framework provides the theoretical basis

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for relating corresponding model and prototype quantities when the required similarity conditions are satisfied (Murphy, 1950).

The present study therefore focuses on the structural interpretation of five waste-derived particleboards using scaled roof-beam models. The work combines experimentally determined stiffness with model-to-prototype transformations to compare predicted load, stress and deflection among the materials.

2. Aim and Objectives

The aim was to assess the suitability of selected waste-derived particleboards for scaled roof-beam applications through experimental characterization and similitude-based analytical prediction.

1. manufacture and characterize particleboards from selected agricultural, wood and plastic wastes;
2. determine the modulus of elasticity of the developed boards;
3. investigate scaled roof-beam response using the supplied model geometry and loading data;
4. predict prototype load, stress and deflection using the adopted similitude relationships;
5. compare the waste-derived boards with an MDF control; and
6. Identify the materials requiring further development before structural application.

3. Materials and Methods

3.1 Materials and specimen groups

Five waste-derived boards were investigated: Sample A (rice husk), Sample B (sawdust), Sample C (ground oil-palm fruit fibre), Sample D (ground breadfruit seed coating), and Sample E (shredded plastic). Sample F was a medium-density fibreboard control. The supplied study reports that the specimens were produced and subsequently evaluated for structural behaviour.

Table 1. Model dimensions, applied flexural force and modulus of elasticity.

Sample	Material	Length (cm) (L)	Width (cm) (b)	Thickness (cm) (h)	Model load (kN) (P)	MOE (N/mm^2) (q)
A	Rice husk	20.00	5.00	2.10	0.86	5.35
B	Sawdust	20.00	5.00	2.20	0.80	5.05
C	Oil-palm fruit fibre	20.00	5.00	2.25	0.50	2.33
D	Breadfruit seed coating	20.00	6.00	2.30	0.65	2.33
E	Shredded plastic	20.00	5.00	2.20	0.20	0.35
F	MDF control	20.00	5.00	1.80	0.74	5.90

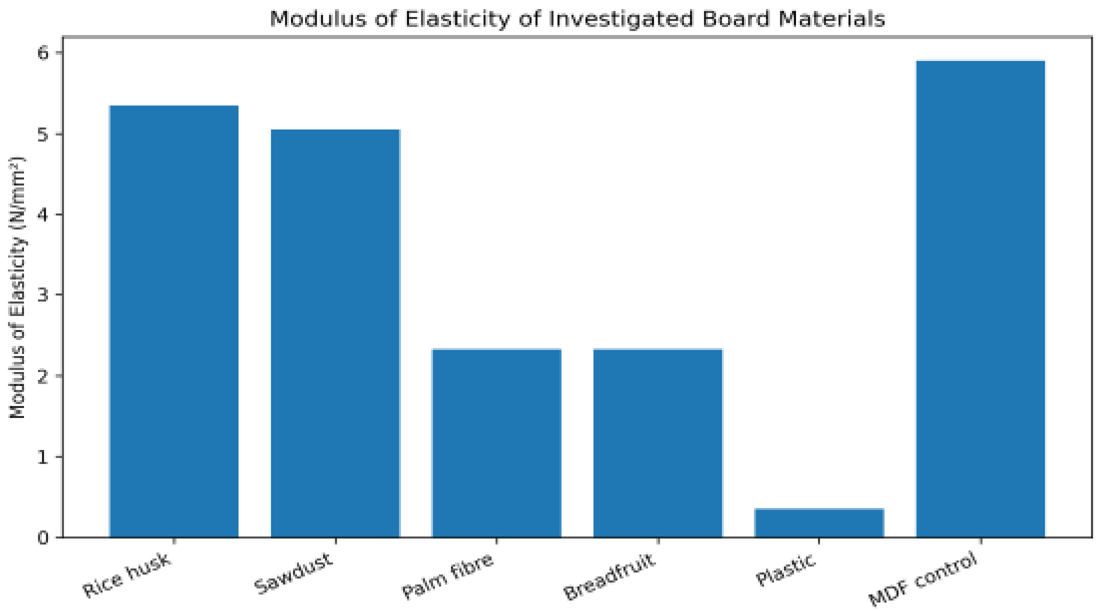

Figure 1. Modulus of elasticity of the investigated board materials.

3.2 Prototype and scale model

The model length was 200 mm, while the prototype length was 3600 mm. The prototype width and depth adopted in the supplied analytical model were 225 mm and 300 mm, respectively. The scale factor was determined from the corresponding prototype and model dimensions. Because the manufactured board thickness differed among samples, the resulting scale factor also varied.

3.3 Analytical formulation

The adopted geometric relationship was:

$n = L_p / L_m$ (1)

and the corresponding depth relationship was:

$d_p = n\, d_m$ (2)

The prototype load was estimated from the model load using the relationship:

$P_p = P_m\, n^2$ (3)

For the stress analysis, the supplied study evaluated stresses at critical cross-sectional locations using the bending-stress relationship involving moments about the two principal axes. The second moments of area for rectangular sections were obtained from the conventional expressions

$I_x = bh^3/12$ (4)

$I_y = b^3h/12.$ (5)

For the cantilever idealization used in the supplied simulations, free-end deflection was calculated from $\delta = PL^3/(3EI)$ (6)

The model-to-prototype prediction factor was then determined as $K\delta = \delta p/\delta m$. (7)

Prediction factor for stress $= S_p / S_m$ (8)

$S_p =$ Stress in the prototype (9)

$S_m =$ Stress in the model (10)

$S_p = (M_x\, y / I_x) \ {}^{+}/_{-}\ (M_y x / I_y)_p$ (11)

$S_m = (M_x\, y / I_x) \ {}^{+}/_{-}\ (M_y x / I_y)_m$ (12)

Where y and x are the location of the points at which the stress is evaluated in the model and prototype.

These equations were retained from the original analytical framework; however, the unusually large prototype deflection values reported below require dimensional and unit verification before they are used for design.

4. Results and Discussion

4.1 Modulus of elasticity

The modulus of elasticity ranged from 0.35 to 5.90 N/mm². The MDF control recorded the highest value, followed by rice-husk and sawdust particleboards. Samples C and D recorded equal values of 2.33 N/mm², while the shredded-plastic board had the lowest stiffness. The relatively high stiffness of the rice-husk board is encouraging because previous research has demonstrated that rice husk can be converted into particleboard with useful mechanical properties when particle size and binder conditions are controlled (Osarenmwinda & Nwachukwu, 2007; Kariuki et al., 2020).

4.2 Predicted prototype load

Table 2. Predicted prototype loads.

Sample	Material	Scale factor (n)	Predicted prototype load (kN) (P_p)
A	**Rice husk**	**15.00**	**193.50**
B	**Sawdust**	**13.60**	**147.97**
C	**Oil-palm fruit fibre**	**13.30**	**88.445**
D	**Breadfruit seed coating**	**13.04**	**110.53**
E	**Shredded plastic**	**13.64**	**37.21**
F	**MDF control**	**16.67**	**205.64**

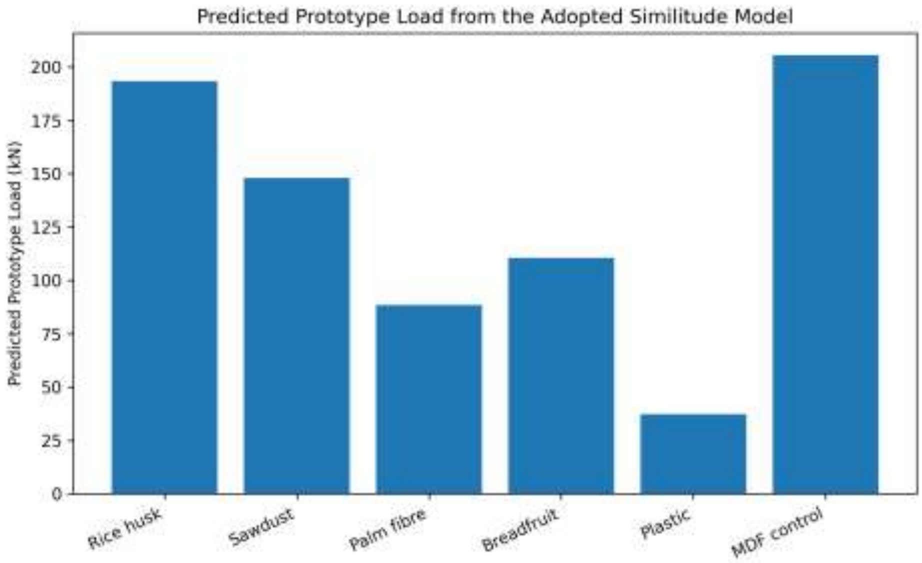

Figure 2. Predicted prototype load obtained from the adopted similitude relationship.

The MDF control gave the highest predicted prototype load at 205.64 kN, followed by the rice-husk board at 193.50 kN. The shredded-plastic board gave the lowest predicted prototype load at 37.21 kN. Among the waste-derived boards, rice husk therefore gave the strongest predicted response under the adopted model-to-prototype transformation.

4.3 Stress prediction

Table 3. Model and prototype stress predictions and stress prediction factors.

Sample	Prototype stress—add	Prototype stress—subtract	Model stress—add	Model stress—subtract	Factor—add	Factor—subtract
A	**631.50**	**82.50**	**119.70**	**78.30**	**2.70**	**1.05**
B	**483.75**	**63.45**	**153.67**	**115.17**	**3.15**	**0.55**
C	**291.00**	**39.00**	**94.95**	**85.05**	**3.07**	**0.45**
D	**361.35**	**47.25**	**49.475**	**33.775**	**7.30**	**1.40**
E	**121.575**	**15.825**	**17.045**	**11.995**	**7.10**	**1.32**
F	**673.50**	**88.50**	**114.56**	**75.16**	**5.88**	**1.18**

The stress results vary substantially among the materials. Under the stress-addition condition, the MDF control recorded the highest prototype stress, followed by rice husk and sawdust. The highest stress prediction factor was recorded for Sample D. These factors describe the model-to-prototype transformation and should not be interpreted as direct measures of material quality.

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4.4 Deflection prediction

Table 4. Predicted model and prototype deflections.

Sample	Prototype δy (m)	Prototype δx (m)	Model δy (m)	Model δx (m)	Ky	Kx
A	1709.20	555.82	1.79	2.47	954.86	225.02
B	1384.00	450.30	1.60	4.75	865.40	94.80
C	1793.80	1010.40	2.16	5.97	830.50	169.23
D	2241.70	1262.64	1.56	6.10	1436.99	169.30
E	5024.01	2829.73	3.33	14.32	1508.71	197.61
F	1647.08	927.70	1.54	6.88	1069.53	134.84

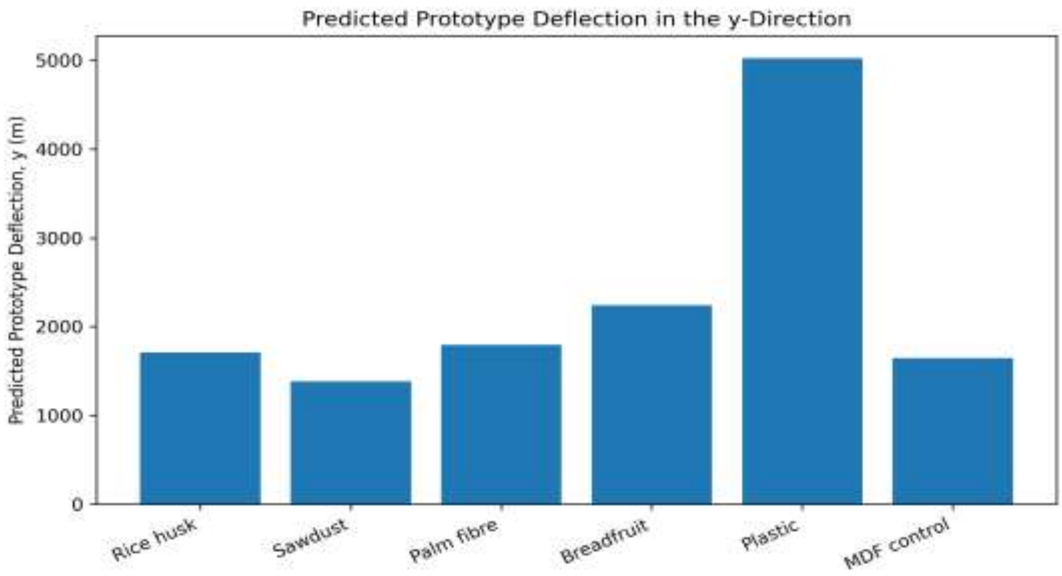

Figure 3. Predicted prototype deflection in the y-direction.

Sample E produced the largest predicted prototype deflection, which is consistent with its very low modulus of elasticity. Sample B produced the lowest predicted y-direction deflection among the waste-derived boards.

4.5 Overall performance assessment

Considering stiffness, predicted prototype load and predicted deflection together, the rice-husk and sawdust boards were the most promising waste-derived materials in the present dataset. The oil-palm and breadfruit boards showed intermediate performance, while the shredded-plastic board consistently showed the least favourable stiffness and deformation response. The MDF control generally performed best overall, as expected for a conventional engineered board.

These findings agree with the broader literature showing that particleboard performance depends strongly on particle morphology, density, binder compatibility and manufacturing conditions. Kariuki et al. (2020) identified water absorption and thickness swelling as continuing challenges in crop-residue particleboards, while Nicolao et al. (2020) demonstrated that reinforcement can substantially improve the flexural performance of rice-husk particleboards.

5. Engineering Interpretation and limitations

The analysis should be interpreted as a preliminary similitude investigation rather than a direct structural design certification. Two corrections are particularly important before the work is used for engineering design: (1) the beam boundary condition must be stated consistently as either cantilever or simply supported, because the governing deflection equation changes; and (2) the model-to-prototype similarity conditions must be explicitly demonstrated rather than assumed.

Because the reported prototype deflections are extremely large, they should not be presented as realistic service deflections without verification. The safer scientific interpretation is that the adopted

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analytical transformation predicts an unacceptable deformation trend for the assumed prototype configuration.

6. Conclusions

1. The investigated waste streams can be converted into particleboard specimens suitable for preliminary structural characterization.
2. The modulus of elasticity varied considerably, with the MDF control recording 5.90 N/mm^2, rice husk 5.35 N/mm^2, sawdust 5.05 N/mm^2, oil-palm fibre and breadfruit seed coating 2.33 N/mm^2 each, and shredded plastic 0.35 N/mm^2.
3. Under the adopted similitude relationship, the predicted prototype loads ranged from 37.21 kN for shredded plastic to 193.50 kN for rice husk among the waste-derived boards, while the MDF control gave 205.64 kN.
4. Rice-husk and sawdust boards demonstrated the most favourable overall response among the waste-derived materials.
5. The shredded-plastic board showed the lowest stiffness and largest predicted deformation.
6. The very large prototype deflection values demonstrate that the present material formulations and/or analytical assumptions are not adequate for direct qualification as primary load-bearing roof beams.
7. Similitude-based analysis is useful for preliminary screening, but full-scale beam testing and independent dimensional verification are essential before structural application.
8. Further material optimization should focus on increasing stiffness and bending strength while controlling moisture sensitivity and dimensional instability.

7. Recommendations

1. Conduct full-scale bending tests on the most promising rice-husk and sawdust boards.
2. Repeat the analytical calculations using a single, explicitly stated unit system and independently verified geometry.
3. Clarify the structural boundary condition and use the corresponding beam equation consistently.
4. Investigate density, particle size, binder content, pressing pressure and curing conditions as factors controlling stiffness.
5. Evaluate water absorption, thickness swelling, creep, fatigue, fire behaviour and connection performance before structural use.
6. Use finite-element analysis as a complementary tool after the experimental material properties and boundary conditions have been validated.
7. Do not describe the present model-based loads as certified structural capacities.

References

1.Kariuki, S. W., Wachira, J., Kawira, M., & Murithi, G. (2020). Crop residues used as lignocellulose materialsforparticleboardsformulation.Heliyon,6(9),e05025.
https://doi.org/10.1016/j.heliyon.2020.e05025.

2.Murphy, G. (1950). Similitude in Engineering. Ronald Press Company, New York.

3.Nicolao, E. S., Leiva, P., Chalapud, M. C., Ruseckaite, R. A., Ciannamea, E. M., & Stefani, P. M. (2020). Flexural and tensile properties of biobased rice husk-jute-soybean protein particleboards. Journal of Building Engineering, 30, 101261. https://doi.org/10.1016/j.jobe.2020.101261.

4.Osarenmwinda, J. O., & Nwachukwu, J. C. (2007). Effect of particle size on some properties of rice huskparticleboard.AdvancedMaterialsResearch,18–19,43–48.
https://doi.org/10.4028/www.scientific.net/AMR.18-19.43.

5.Onu, C. E., et al. (2022). Effects of sawdust and adhesive type on the properties of rice husk particleboards. Results in Engineering, 16, 100775. https://doi.org/10.1016/j.rineng.2022.100775.