

Research Article



Assessment of the Structural Properties of Waste-Derived Particleboards Using SolidWorks Finite Element Modelling

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ABSTRACT

This study assessed the physical, mechanical and simulated structural properties of particleboards produced from selected waste materials using SolidWorks finite element modelling. Five particleboard materials were produced from rice husk, sawdust, ground oil-palm fruit chaff, ground breadfruit seed coating and shredded plastic waste, while commercially available medium-density fibreboard (MDF) was used as the control. Physical properties including density, moisture content, ash content, water absorption and thickness swelling were determined, while mechanical properties including compressive strength, impact energy, modulus of rupture (MOR) and modulus of elasticity (MOE) were evaluated. The SolidWorks simulations were performed using static finite element analysis with solid meshes and experimentally derived material properties. The maximum simulated von Mises stresses were 0.0359, 0.0278, 0.0248, 0.0263 and 0.0139 MPa for samples A–E, respectively, while the corresponding maximum displacements were 0.102, 0.083, 0.161, 0.100 and 0.601 mm. The results indicated that rice-husk particleboard exhibited the most favourable overall structural behaviour among the biodegradable-waste particleboards, whereas the shredded-plastic board exhibited the largest displacement and poorest simulated response. Nevertheless, the biodegradable-waste boards generally showed inferior structural performance compared with the MDF control. The study therefore concludes that the investigated materials have greater potential for non-load-bearing applications than for primary structural members. The integration of experimental testing with SolidWorks modelling provides a useful approach for preliminary assessment and optimization of waste-derived composite materials.

1. INTRODUCTION

Particleboard is a manufactured wood-based composite produced by consolidating lignocellulosic particles with a suitable binder under controlled pressure and temperature. (Ezeagu et al., 2022; Şahin & Kaymakçı, 2024) However, conventional particleboards are predominantly manufactured from wood particles, creating concerns regarding deforestation, resource depletion, and the long-term sustainability of raw-material supply. Consequently, increasing research attention has been directed towards the development of particleboards from agricultural residues and other biodegradable wastes as alternative raw materials. (Sawawi et al., 2018; Ezeagu et al., 2022)

The structural behaviour of particleboard is strongly influenced by the characteristics of its constituent particles, including particle size, orientation. (Ezeagu et al. 2022; Şahin and Kaymakçı 2024; Sawawi et al., 2018)

Although experimental testing provides essential information about material behaviour, it can be complemented by numerical modelling to obtain a more detailed understanding of structural response. (Zienkiewicz et al., 2013; Elobuiké et al., 2023). Computer-Aided Engineering (CAE) tools provide researchers with the ability to develop three-dimensional representations of engineering materials and simulate their behaviour under

different loading conditions (Ugboaja et al., 2018). SolidWorks provides an effective environment for three-dimensional modelling and Finite Element Analysis (FEA) simulation, which enables the Finite Element evaluation of stress, strain, displacement, deformation, and other structural parameters. Zienkiewicz et al. (2014)

The Finite Element Method is a well-established numerical technique for solving complex engineering problems by discretising a continuous material or structural domain into a finite number of smaller elements connected at nodes. The method is particularly useful for structural analysis because it permits the behaviour of materials under specified loading and boundary conditions to be investigated numerically. Zienkiewicz et al. (2013) provided a comprehensive treatment of the theoretical foundations and applications of the Finite Element Method, while Zienkiewicz et al. (2014) demonstrated its application to solid and structural mechanics. The application of FEA to biodegradable particleboard can therefore provide valuable information on stress distribution, deformation patterns, strain development, and potential critical regions within

The integration of experimental material characterization with SolidWorks Finite Element modelling is therefore particularly relevant to the development of sustainable particleboard. Experimental properties obtained using standardized procedures can be incorporated into Finite Element models to simulate the response of the material under defined loading conditions. The resulting Finite Element predictions can then be compared with experimental behaviour to assess the reliability of the model. Such an approach can reduce the dependence on extensive physical testing and provide a framework for investigating different material configurations, dimensions, loading conditions, and potential engineering applications. (Zienkiewicz et al. 2014)

Against this background, this study focuses on the assessment of the structural properties of particleboard produced from biodegradable waste using SolidWorks modelling and Finite Element Analysis. The study combines the evaluation of relevant physical and mechanical properties with three-dimensional computer modelling and numerical structural analysis. The experimental results provide the material parameters required for the numerical model, while the SolidWorks/FEA simulation is used to investigate the structural response of the developed particleboard under specified loading conditions.

2. MATERIALS AND METHODOLOGY

2.1 Materials Collection and Preparation

Sawdust was collected from the timber market at Nkwo Nnewi, Anambra State, Nigeria. Breadfruit seed coating was obtained from Eke Awka Market, while rice husk and palm fruit chaff were sourced from rice and oil mills at Oba Ofemmili and Amansea, respectively. Plastic waste was collected from the premises of Nnamdi Azikiwe University, Awka. The lignocellulosic materials were air-dried for seven days and subsequently oven-dried at 60 °C for 24 h. The materials were ground where necessary and sieved through 2.56 and 1.18 mm

BS sieves to obtain relatively uniform particle sizes. The plastic waste was washed, dried, and shredded before use.

2.2 Mould Preparation and Particleboard Production

A plywood mould measuring 200 × 200 × 50 mm internally was fabricated, with a 15 mm-thick cover. The required quantity of particles for each panel was determined by filling and weighing the mould. The specified proportion of adhesive was measured and thoroughly mixed with the particles to achieve a homogeneous distribution. The mould was lightly oiled before the mixture was placed and compacted to approximately 50 mm thickness. The filled mould was covered, placed in a manual compression machine, and subjected to sustained pressure for 24 h. The compressed panels were subsequently oven-dried at 80 °C for 1 h, cooled, demoulded, and sun-dried for seven days. Five panels were produced and cut into specimens for physical, mechanical, and structural evaluation.

2.3 Physical Properties

The density of the particleboard specimens was determined from their measured mass and volume in accordance with EN 323 (CEN, 1993). Moisture content Water absorption and thickness swelling ash content were determined following ASTM D1037

2.4 Structural Properties

The Structural performance of the particleboards was evaluated through static bending, impact, and compression tests. Static bending tests were conducted in accordance with ASTM D1037 to determine the modulus of rupture (MOR) and modulus of elasticity (MOE) from the applied load, specimen dimensions, span, and measured deflection. Impact resistance was determined in accordance with ASTM D256 using an instrumented Avery Denison testing machine. Compressive strength was similarly evaluated following the procedures specified in ASTM D1037.

2.5 SolidWorks Modelling and Finite Element Analysis

The experimentally determined material properties were used as input parameters for SolidWorks modelling. Three-dimensional particleboard specimens were developed in SolidWorks, incorporating the actual specimen dimensions and relevant material properties. The models were subsequently subjected to Finite Element Analysis (FEA) under loading and boundary conditions corresponding to the experimental tests. The simulations were used to evaluate stress distribution, deformation, strain, and overall structural response. The modelling procedure involved:

- creating the three-dimensional geometry;
- assigning the material properties;
- defining the fixtures;
- applying the appropriate external force;
- generating the solid finite element mesh;
- solving the static analysis;
- Extracting stress, displacement and strain results.

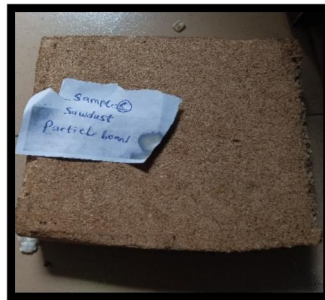
3. RESULT AND DISCUSSIONS

Table 3.1: Coding of Samples

Composite Code	Particles Used	Mass of Particles used (g)	% Adhesive used (%)	Mass of Adhesive used (g)	Total mass used(g)
A	Rice Husk	214	230	492.2	706.2
B	Sawdust	214	230	492.2	706.2
C	Grinded Palm fruit Chaff	214	230	492.2	706.2
D	Grinded Breadfruit seed Coating	214	230	492.2	706.2
E	Shredded Plastics	114	300	342	456
F (Control)	Medium Dense Fiberboard	-	-	-	-



Sample A



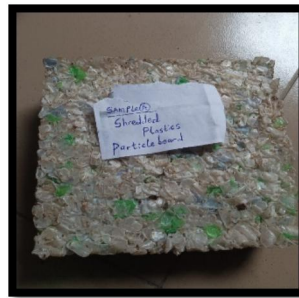
Sample B



Sample C



Sample D



Sample E



Sample F

Table 3.2: Physical Properties of the Particleboard Samples

Sample	Density (kg/m ³)	Ash Content (%)	Moisture Content (%)	T.S (%) – 2 h	T.S (%) – 24 h	W.A (%) – 2 h	W.A (%) – 24 h
A	0.543	6.11	21.81	7.89	18.75	36.14	89.40
B	0.485	5.72	22.63	8.50	19.05	59.97	109.80
C	0.455	4.95	38.23	9.38	25.00	32.97	106.30
D	0.475	4.80	39.68	10.77	27.78	61.03	121.25
E	0.240	2.49	69.39	38.46	66.67	119.94	219.60
F (Control)	0.648	9.55	16.08	5.88	5.88	19.24	29.25

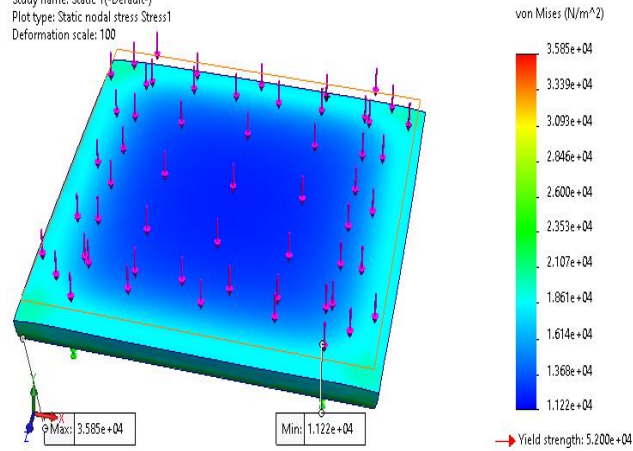
Table 3.3: Structural Properties of the Particleboard Samples

Sample	Compressive Strength (N/mm ²)	Impact Energy (J)	MOR (N/mm ²)	MOE (N/mm ²)
A	0.405	38	10.69	5.35
B	0.353	29	10.37	5.05
C	0.330	43	4.65	2.33
D	0.462	48	4.50	2.33
E	0.176	14	0.69	0.35
F (Control)	0.878	44	11.67	5.90

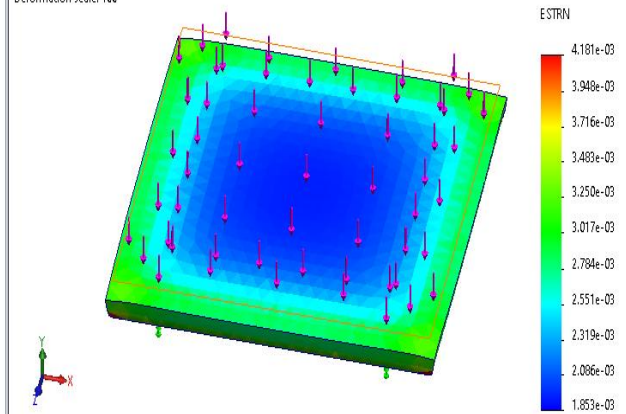
4.2.4 Simulations using Solid works modelling

Simulation of Sample A_

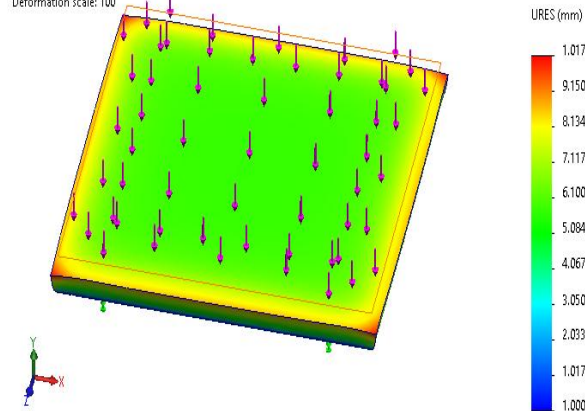
Model name: Particle Board A
Study name: Static 1(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 100



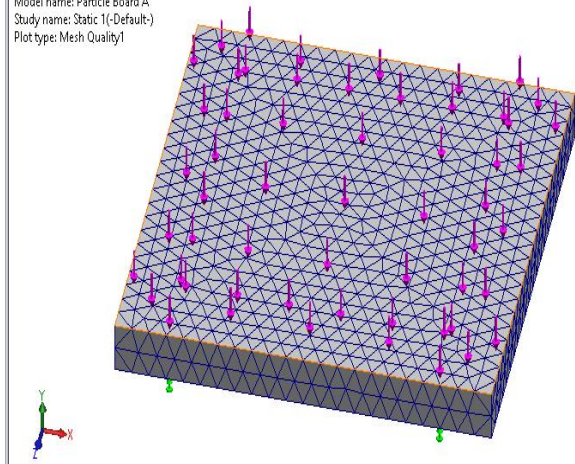
Model name: Particle Board A
Study name: Static 1(-Default-)
Plot type: Static strain Strain1
Deformation scale: 100



Model name: Particle Board A
Study name: Static 1(-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 100



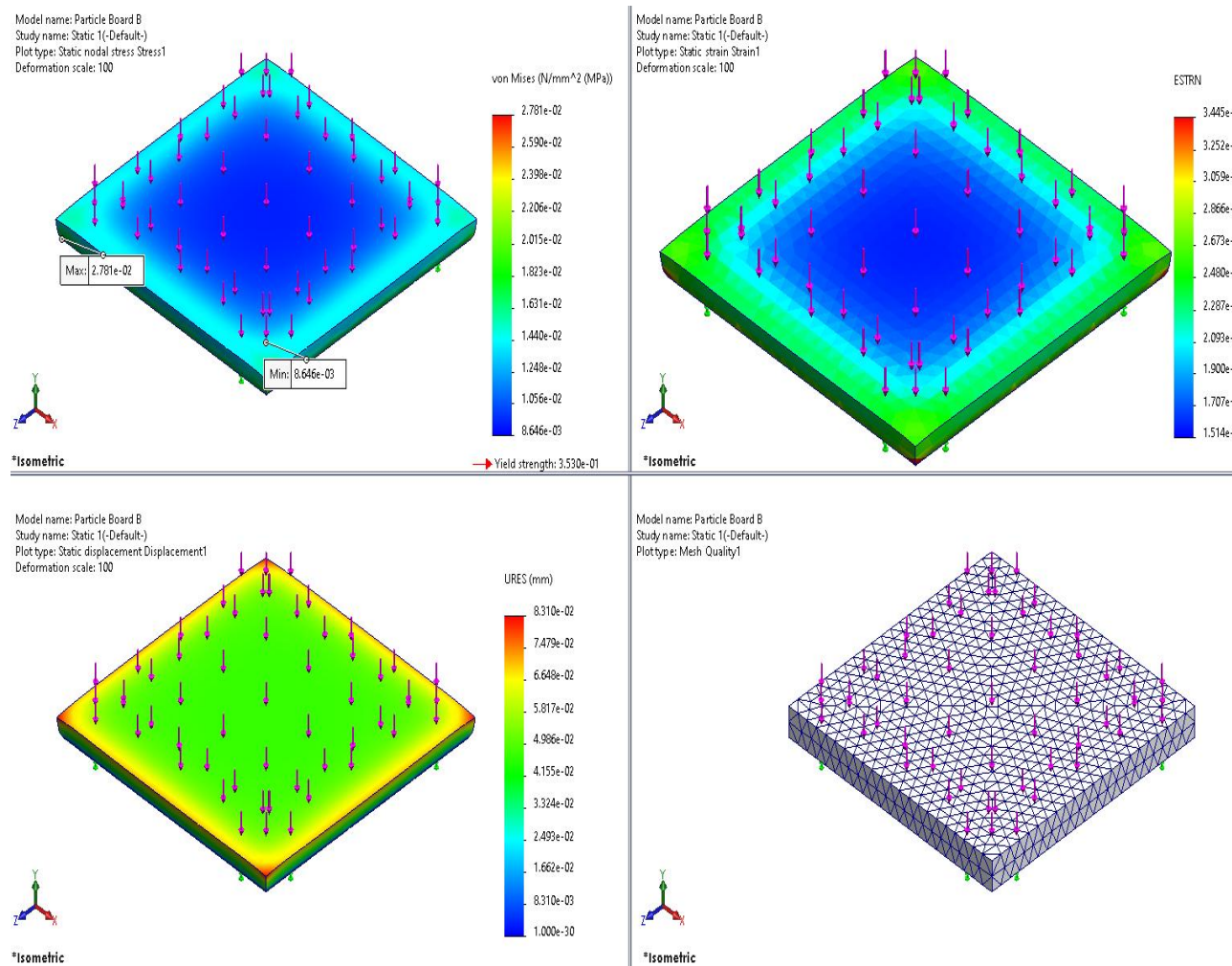
Model name: Particle Board A
Study name: Static 1(-Default-)
Plot type: Mesh Quality1



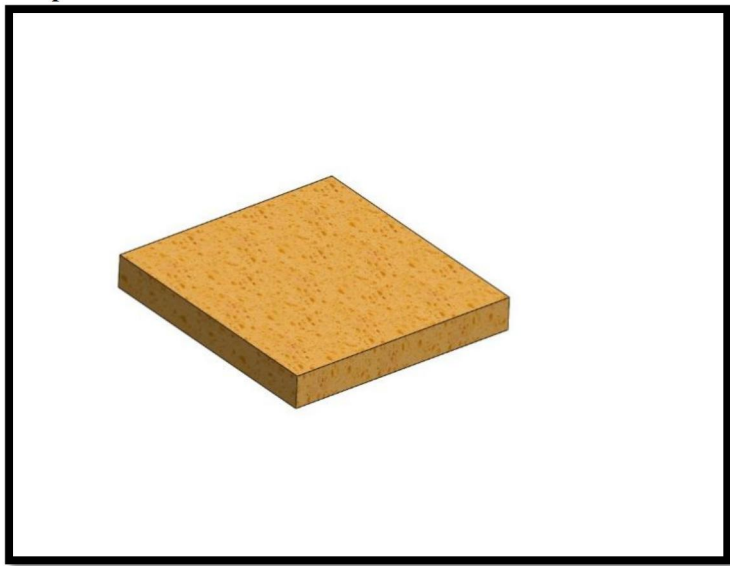
Sample A Model



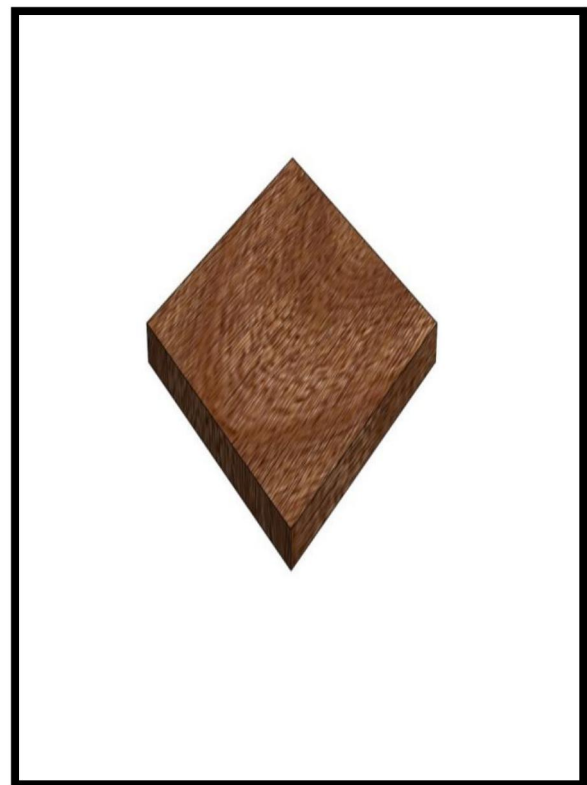
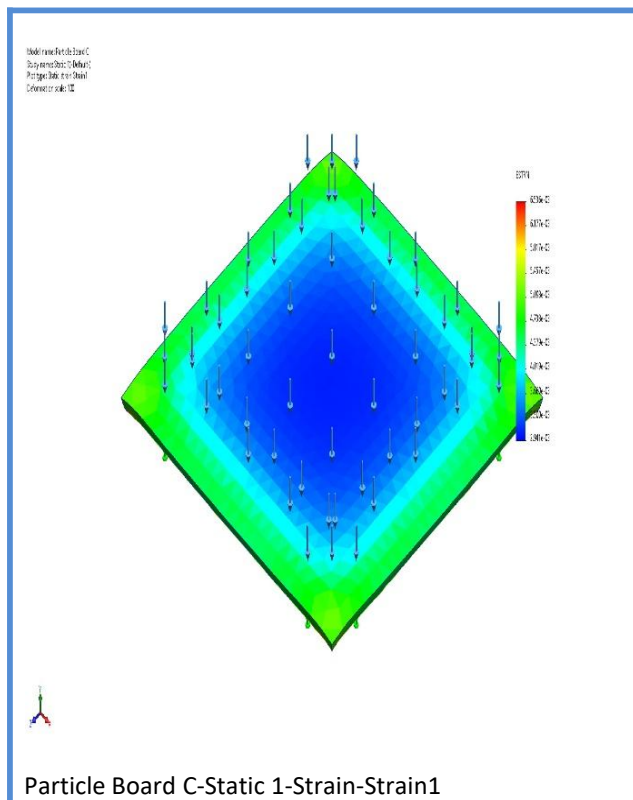
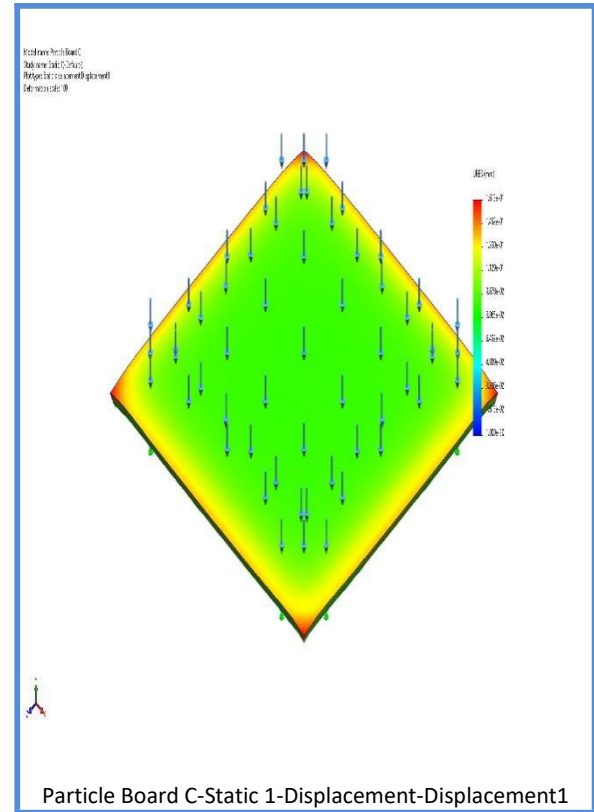
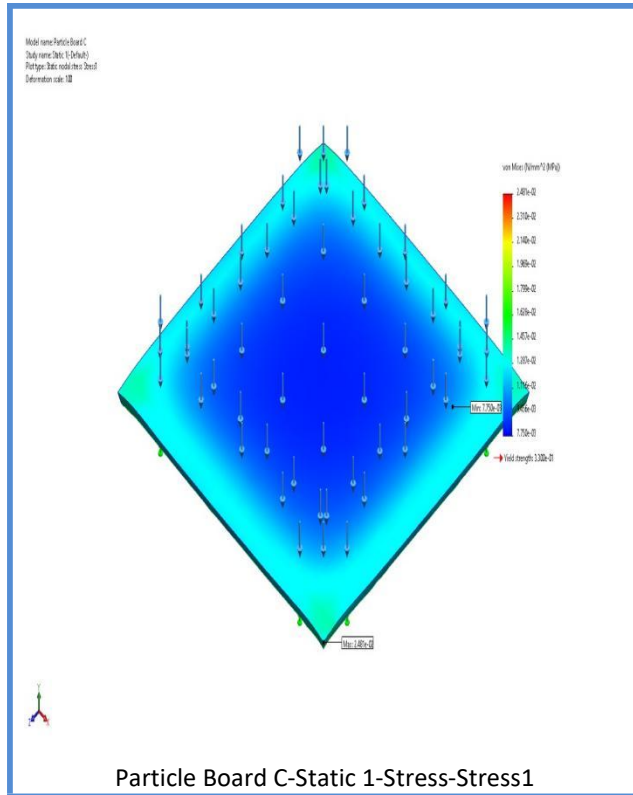
Simulation of Sample B



Sample B Model

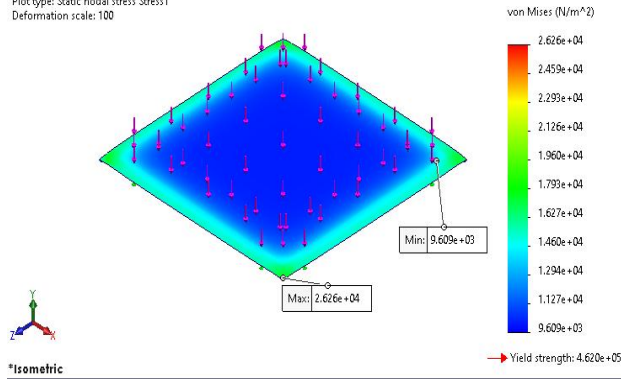


Simulation of Sample C

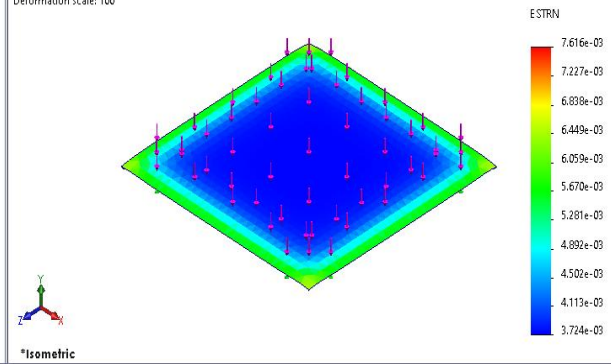


Simulation of Sample D.

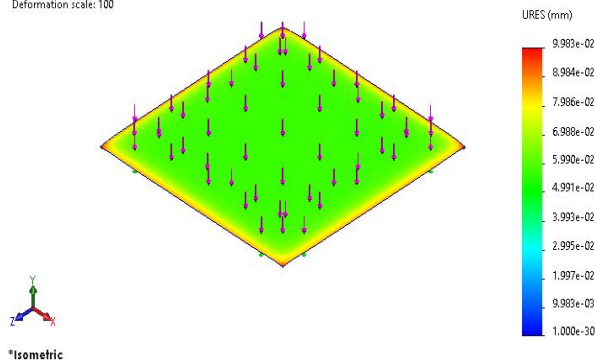
Model name: Particle Board D
Study name: Static 1(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 100



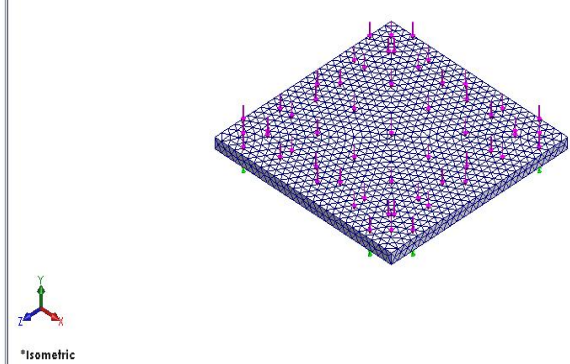
Model name: Particle Board D
Study name: Static 1(-Default-)
Plot type: Static strain Strain1
Deformation scale: 100



Model name: Particle Board D
Study name: Static 1(-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 100



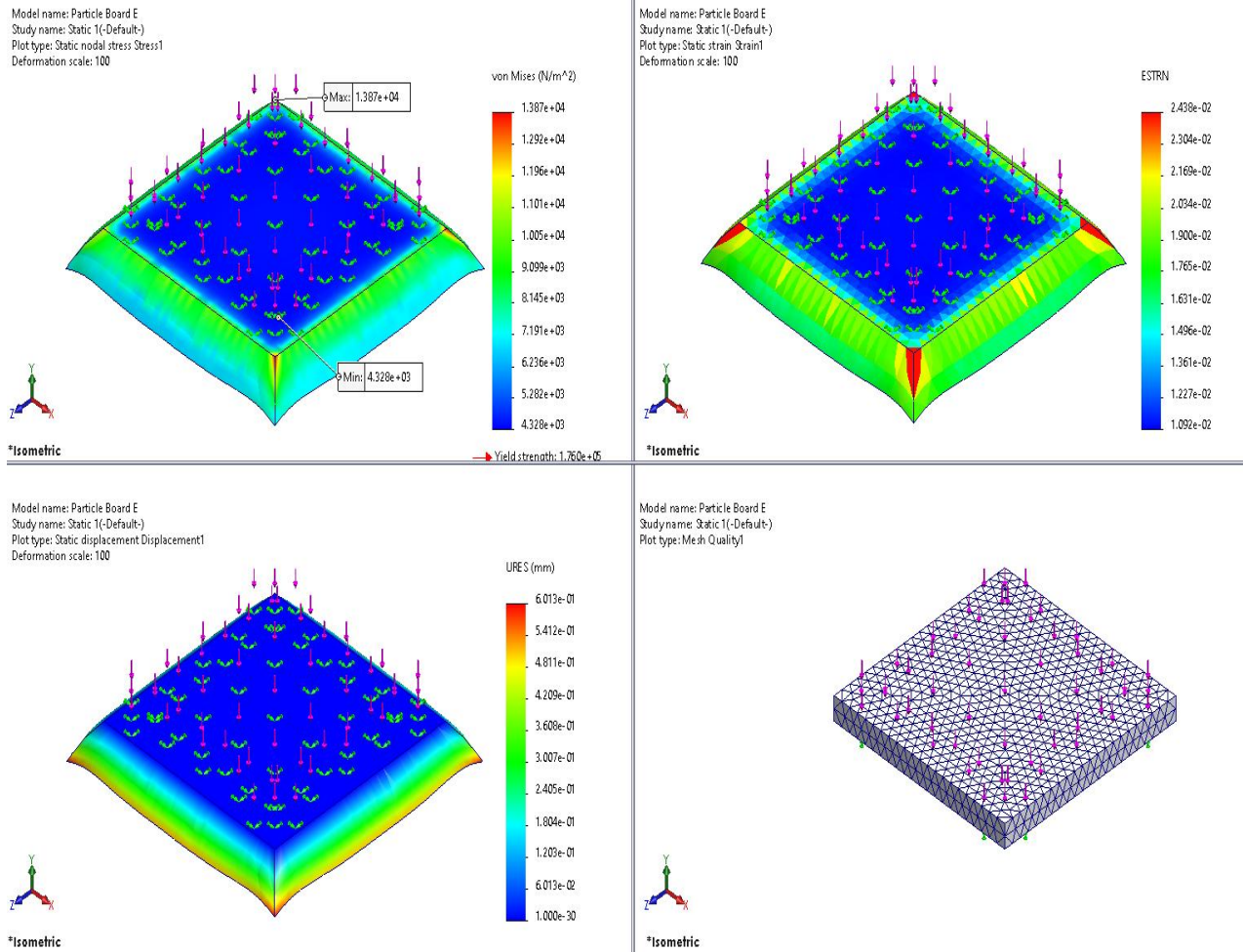
Model name: Particle Board D
Study name: Static 1(-Default-)
Plot type: Mesh Quality1



Sample D Model



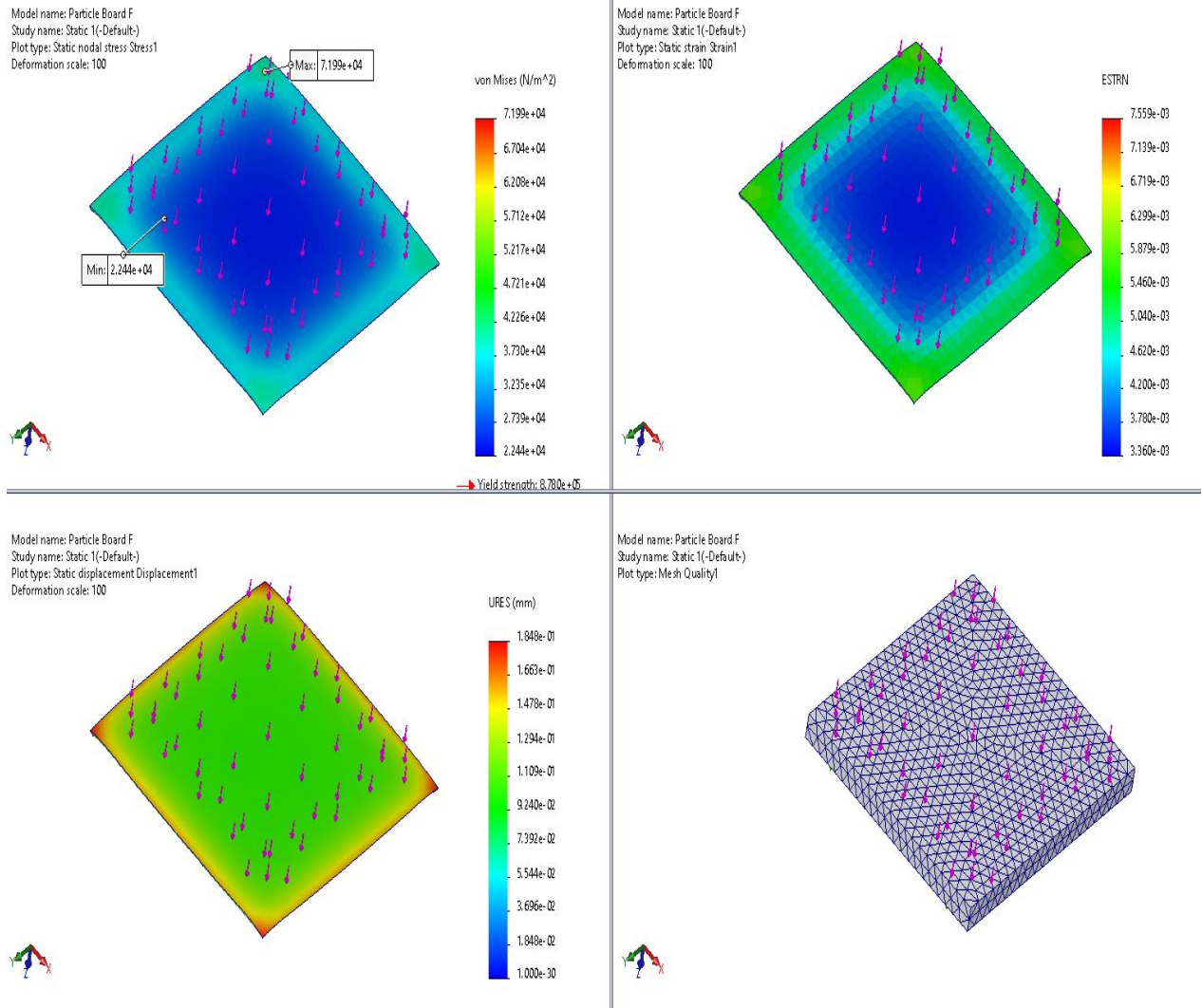
Simulations of Sample E



Sample E Model



Simulations of Sample F (Control)



Sample F Model

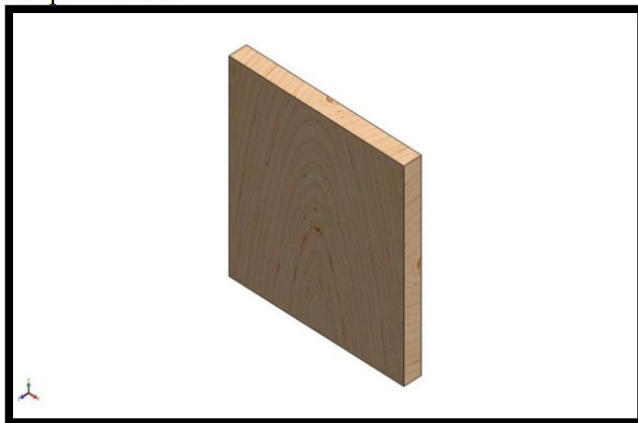


Table 3.3 The summarized principal SolidWorks results

Sample	Material	Maximum von Mises stress (MPa)	Maximum displacement (mm)	Maximum equivalent strain
A	Rice husk	0.0359	0.102	0.00418
B	Sawdust	0.0278	0.083	0.00345
C	Palm fruit chaff	0.0248	0.161	0.00654
D	Breadfruit seed coating	0.0263	0.100	0.00762
E	Shredded plastic	0.0139	0.601	0.02438
F	MDF control	0.0720	0.185	0.00756

Sample A, manufactured from rice husk, exhibited a maximum displacement of approximately 0.102 mm. This was substantially lower than the displacement of sample E and indicates comparatively greater stiffness under the modelled loading condition.

Sample B, manufactured from sawdust, produced the lowest displacement among the five waste-derived particleboards, approximately 0.083 mm. This is consistent with its relatively high MOE of 5.05 N/mm².

Sample C exhibited a maximum displacement of approximately 0.161 mm, indicating greater deformation than samples A and B.

Sample D exhibited approximately 0.100 mm displacement, despite its relatively low MOE. This indicates that numerical response is influenced not only by the experimentally measured elastic modulus but also by geometry, loading, restraints and the material parameters used in the SolidWorks model.

The most significant result was obtained for sample E. Its maximum displacement was approximately 0.601 mm, substantially greater than that of the other waste-derived boards. This result is consistent with its very low experimental MOE of 0.35 N/mm² and compressive strength of 0.176 N/mm².

The MDF control had the highest density, compressive strength, MOR and MOE. Its maximum simulated stress was also greater than those of the waste-derived boards because it was subjected to a substantially higher simulated load of approximately 1,580 N.

Therefore, maximum stress alone should not be used to rank the materials without considering the applied load, geometry and material properties.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusions

- Particleboards can be produced successfully from locally available agricultural and waste materials, including rice husk, sawdust, palm fruit chaff, breadfruit seed coating and shredded plastics.

- The density of the investigated boards ranged from 240 to 648 kg/m³, with the MDF control recording the highest density and shredded-plastic board recording the lowest.
- Rice-husk particleboard demonstrated the most favourable overall combination of physical and mechanical properties among the biodegradable-waste boards.
- The rice-husk particleboard recorded a compressive strength of 0.405 N/mm², MOR of 10.69 N/mm², MOE of 5.35 N/mm² and impact energy of 38 J.
- Sawdust particleboard also demonstrated promising performance, particularly in terms of stiffness, flexural strength and simulated displacement.
- The shredded-plastic particleboard demonstrated poor mechanical performance, recording the lowest MOE (0.35 N/mm²) and the highest simulated displacement (0.601 mm).
- The SolidWorks finite element analysis successfully provided numerical estimates of stress, displacement and strain for all investigated materials.
- The numerical results broadly supported the experimental observation that the rice-husk and sawdust boards were among the better-performing waste-derived materials.
- The MDF control generally exhibited superior mechanical properties and dimensional stability compared with the waste-derived particleboards.
- The investigated particleboards should therefore be considered primarily for non-load-bearing applications unless further testing and material optimization demonstrate sufficient structural capacity for a specific design application.

4.2 Recommendations

- a. Future research should optimize the particle-to-adhesive ratio to improve bonding and mechanical strength.
- b. The particle size distribution should be optimized because particle geometry and orientation can significantly influence mechanical behaviour.
- c. Moisture-resistant treatments should be investigated to reduce water absorption and thickness swelling.
- d. Bio-based adhesives should be investigated as alternatives to conventional synthetic binders.
- e. The numerical models should be developed using experimentally determined orthotropic properties where sufficient data are available.
- f. Mesh-convergence studies should be incorporated into future SolidWorks simulations.
- g. The finite element models should be validated against complete experimental load–displacement curves.
- h. Long-term durability, creep, fatigue, fire resistance and biological resistance should be investigated.
- i. Larger-scale prototype boards should be manufactured and tested before considering structural applications.
- j. Based on the present results, rice-husk particleboard is recommended as the most promising candidate among the investigated waste-derived materials for further development, particularly for non-load-bearing applications.

4.3 Limitations of the SolidWorks Modelling

- a. Particleboards are heterogeneous composites, whereas the SolidWorks models were treated as linear elastic isotropic materials. This simplification does not completely reproduce the actual microstructural behaviour of particleboard.
- b. The Samples displayed variation in moisture content, density and dimensional stability. Such variability can affect the accuracy of the assigned material parameters.
- c. SolidWorks results depend strongly on the boundary conditions and applied loading. Therefore, the results should be interpreted as predictions for the specific loading and support configurations modelled.
- d. A reliable finite element model should ideally be validated against multiple experimental load–displacement curves rather than only comparing isolated maximum values. These limitations do not invalidate the modelling exercise; rather, they define its appropriate use as a comparative and preliminary design tool.

1.

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