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Utilization of Plastic Waste and Rice Husk Ash in Polyethylene-Based Composites for Ceiling Applications

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Abstract

This study aims to analyze the effect of polyethylene (PE) and rice husk ash (RHA) composition variations on the mechanical properties of recycled composites developed as environmentally friendly ceiling materials. Composite specimens were prepared through a systematic process involving shredding PE plastic waste into 3–5 mm particles, burning rice husks at 600–700 °C followed by sieving through a 200-mesh screen, melting the plastic at 160–170 °C, and mixing with RHA at three composition ratios: 80:20, 70:30, and 60:40 (PE:RHA). The mixtures were molded into 50 × 50 mm specimens and tested in accordance with ASTM D695 for compressive properties and ASTM D792 for density. The results show that composition variation significantly influences compressive strength, elastic modulus, and strain behavior. The 80:20 composition exhibited the highest elasticity, with a compressive strength of 15.59 MPa and an elastic modulus of 463.50 MPa; however, it fractured shortly after exceeding the elastic limit. The 60:40 composition achieved the highest compressive strength of 125 MPa with a strain of 56.6%, but showed brittle behavior due to its very low elastic modulus (7.5 MPa). The 70:30 composition demonstrated the most balanced mechanical performance, with a compressive strength of 61.65 MPa, a strain of 18.20%, and stable ductile behavior. Based on the overall mechanical performance, the 70:30 PE–RHA composition is recommended as the optimal formulation, as it provides the best balance between strength, stiffness, and deformation resistance. This composition is therefore considered the most suitable for non-structural ceiling applications requiring lightweight, mechanically stable, and environmentally sustainable materials.

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1. Introduction

Plastic waste has become an urgent environmental issue at both global and national levels. Polyethylene (PE) plastic is one of the largest contributors to domestic waste due to its widespread use and its resistance to natural degradation. Large quantities of PE waste are commonly found in household garbage, traditional markets, and public facilities [1]. In Sikka Regency, the 2023 report from the local Environmental Agency recorded a waste generation volume of approximately 57,600 m^3 per year, with plastic waste constituting the dominant component and remaining inadequately managed. This condition highlights the urgent need for innovative approaches to convert plastic waste into useful and environmentally friendly products [2].

On the other hand, rice husk is an abundant agricultural byproduct that remains underutilized despite its wide availability in rice-producing regions [3]. Rice husk ash (RHA), obtained from the combustion of rice husks, contains a high silica content and has been widely used as a filler in concrete, mortar, and polymer-based composite materials. Previous studies have demonstrated that RHA can improve compressive strength, stiffness, and dimensional stability when incorporated into composite systems [4]. Several studies have investigated composites based on plastic waste and RHA; however, most applications have focused on lightweight structural elements, paving blocks, thermal insulation materials, or general composite processing techniques rather than specific building components [5].

To date, research that specifically evaluates the performance of PE–RHA composites for residential ceiling applications remains very limited. Ceiling materials require distinct mechanical characteristics, such as adequate compressive strength, sufficient stiffness, and controlled flexibility, to

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prevent cracking, sagging, or permanent deformation during service. Studies that thoroughly analyze the mechanical behavior of PE–RHA composites tailored to ceiling requirements are still lacking, particularly those employing standardized testing procedures [6]. Moreover, systematic comparisons of different PE–RHA mixture compositions based on recognized standards, such as ASTM methods, are rarely reported, making it difficult to identify the most effective formulation.

Several related studies have examined polypropylene (PP)–rice husk composites with various mixture ratios (50:50, 60:40, 70:30, and 80:20). While most compositions satisfied density and moisture content requirements, not all met water absorption and mechanical strength criteria. Other studies involving recycled HDPE plastics combined with maleic anhydride (MAH) as a compatibilizer reported improved interfacial bonding between the polymer matrix and filler, leading to enhanced mechanical performance [7]. However, these findings cannot be directly applied to PE–RHA ceiling materials without further investigation, particularly under tropical environmental conditions such as those found in Sikka Regency [8].

The novelty of this research lies in the utilization of locally sourced plastic waste and rice husk ash from Sikka Regency to produce PE–RHA composite materials specifically designed for ceiling applications—an area that has not been previously explored. This study adopts a structured experimental approach by evaluating three composition ratios (80:20, 70:30, and 60:40) using ASTM-based mechanical testing to provide a reliable assessment of material performance. The research is directed toward identifying a composite formulation that offers optimal mechanical behavior while remaining lightweight and environmentally friendly for non-structural ceiling applications.

Accordingly, the objectives of this study are to investigate the effect of varying polyethylene (PE) and rice husk ash (RHA) compositions on the compressive strength, elastic modulus, and strain behavior of the resulting composites. In addition, this study aims to compare the mechanical performance of the three compositions and determine the most suitable formulation for use as an alternative ceiling material based on standardized mechanical testing results.

2. Methods

2.1. Research approach

This study employed an experimental material development approach aimed at producing and evaluating polymer-based composite materials derived from plastic waste and rice husk ash. Although the process involves product development, the methodology is framed as a laboratory-scale experimental investigation rather than an educational Research & Development (R&D) model. The focus of this approach is to systematically process materials, fabricate composite specimens, and evaluate their physical and mechanical properties using standardized testing methods [8].

2.2. Materials preparation

Polyethylene (PE) and polypropylene (PP) plastic waste were collected from a temporary solid waste disposal facility (TPS) in Maumere City, Sikka Regency. The collected plastics were manually sorted to ensure material homogeneity based on physical characteristics such as density, flexibility, and color. Selected plastics were thoroughly washed to remove surface contaminants, dried under ambient conditions, and subsequently shredded into particle sizes of approximately 3–5 mm. Particle size uniformity was controlled in accordance with ASTM E11. Prior to processing, the moisture condition of the plastic flakes was stabilized following ASTM D618 requirements.

Rice husks were obtained from a local rice mill in Alok District, Sikka Regency. The husks were combusted using a waste oil stove at a controlled temperature range of 600–700°C for approximately two hours to produce rice husk ash (RHA). The resulting ash was then sieved using a 200-mesh sieve (≤75 µm) in accordance with ASTM E11 to ensure uniform particle size distribution. The chemical composition of the RHA was referenced from previous studies, indicating a silica (SiO_2) content in the range of 85–95%.

2.3. Composite fabrication process

Figure 3 shows shredded PE/PP flakes that were melted at a temperature of 160–170°C using a waste oil stove. This temperature range was selected to ensure sufficient melting while preventing thermal degradation of the polymer matrix.

Rice husk ash was gradually added to the molten plastic to achieve uniform dispersion. Mechanical mixing was carried out using a heat-resistant stirrer at a rotational speed of 350–400 rpm for 5–7 minutes to obtain a homogeneous composite mixture, as shown in Figure 4.

Three composition ratios of PE to RHA were prepared and evaluated, as shown in Figure 5:

- Specimen 1 - 80:20 (PE:RHA)
- Specimen 2 -70:30 (PE:RHA)
- Specimen 3 - 60:40 (PE:RHA)

The homogenized mixture was poured into steel molds with dimensions of 50 × 50 mm and a thickness of 8–10 mm, as shown in Figure 2. Manual compaction was applied using a press tool to reduce air voids and improve material density. After molding, specimens were allowed to cool at room temperature until fully hardened. All samples were then conditioned for 24 hours in accordance with ASTM D618 to ensure stable moisture content and consistent testing conditions.

2.4. Testing methods

Compressive testing was performed using a Universal Testing Machine (UTM) HK 2B FST with a maximum capacity of 20 tons, as shown in Figure 1. The test parameters were as follows:

- Loading speed: 5 mm/min
- Test mode: compressive loading
- Specimen geometry: solid specimens according to mold dimensions

The parameters evaluated included maximum compressive strength (MPa), elastic modulus (MPa), strain at failure (%), and elastic–plastic deformation behavior. The test results were recorded in the form of load–displacement and stress–strain curves.

Density measurements were conducted using the water displacement method in accordance with ASTM D792. A digital electronic balance with an accuracy of 0.01 g was used to measure specimen mass. The density (g/cm^3) and specific gravity values were calculated to assess the lightweight characteristics of the composite material. These results were used to evaluate the suitability of the PE–RHA composites as lightweight ceiling materials and to analyze the effect of RHA addition on overall composite density.

2.5. Optional visual and morphological analysis

Macroscopic visual observations were conducted to assess surface quality and structural uniformity of the composites. The analysis focused on filler distribution within the polymer matrix, the presence of air voids formed during mixing or molding, and overall surface homogeneity. These observations provided qualitative insight into mixing effectiveness and composite integrity [11].

2.6. Standards referenced

The following international standards were used in this study:

- ASTM D695 – Standard Test Method for Compressive Properties of Rigid Plastics [9]
- ASTM D792 – Standard Test Methods for Density and Specific Gravity of Plastics by Displacement [10]
- ASTM E11 – Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves
- ASTM D618 – Standard Practice for Conditioning Plastics for Testing

Figure 1. Compressive and tensile testing of composite specimens using a double-column universal testing machine with a 20-ton capacity

Figure 2. Cross-sectional view of the composite mold used for specimen fabrication

Figure 3. PE plastic waste and rice husk ash (RHA) used as raw materials for composite production

Figure 4. Melting of PE plastic waste and mixing with rice husk ash during the composite fabrication process

Figure 5. Fabricated PE–RHA composite specimens with composition ratios of 80:20, 70:30, and 60:40

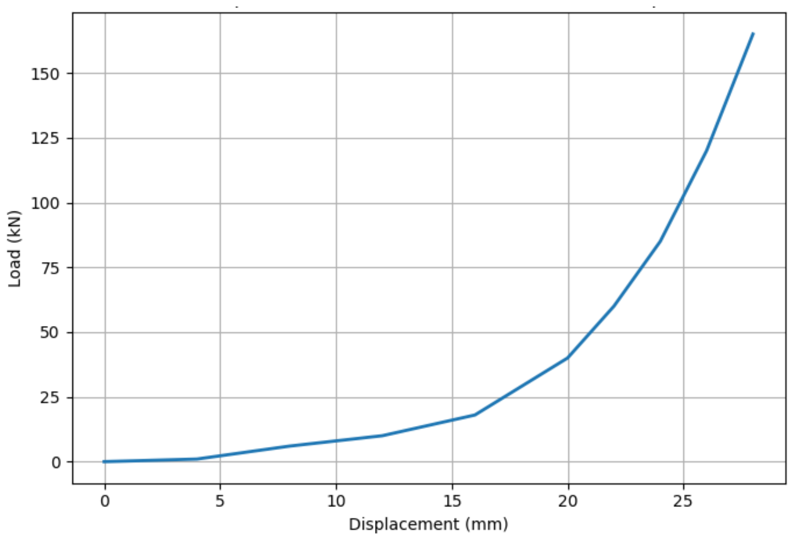

Figure 6. Load–displacement response obtained from the compression test of the PE–RHA composite with an 80:20 composition

3. Results and Discussion

This section presents the experimental results obtained from compressive testing of composite specimens fabricated from polyethylene (PE) plastic waste and rice husk ash (RHA) with different composition ratios. Three mixture variations were evaluated, as summarized in Table 1. All mechanical test data were obtained using a Universal Testing Machine (UTM) Double Column HK 2B FST with a maximum capacity of 20 tons. The results are presented in the form of load–displacement and stress–strain curves, supported by tabulated mechanical parameters.

3.1. Specimen 1 (80:20) results

Figure 6 presents the load–displacement response obtained from the compressive test. The relationship between load (stress) and strain exhibits a typical deformation behavior for polymer-based composites. At the initial loading stage, the curve increases linearly, indicating elastic deformation in which the material can recover its original shape upon unloading. As the applied load increases, the curve gradually deviates from linearity, marking the transition from elastic to plastic deformation. The peak of the curve represents the ultimate compressive strength that can be sustained by the PE–RHA composite. Beyond this peak, the curve shows a downward trend, indicating internal structural damage, crack initiation, and a progressive reduction in load-bearing capacity.

The results indicate that the composite specimen can withstand a maximum load of 165 kN, as shown in Table 1, corresponding to a compressive stress of 66 MPa at a displacement of 28 mm. The material exhibits good elastic behavior at low displacement, followed by a prolonged plastic deformation phase, reaching a strain of approximately 93% before failure. This response reflects the ductile nature of the polymer-dominant matrix.

The deformation behavior of Specimen 1 can be divided into three stages. In the initial stage (0–10 mm displacement), the composite remains in the elastic region, with a nearly linear load–displacement relationship and stress values not exceeding 6.2 MPa. In the intermediate stage (10–20 mm), the material enters an elastic–plastic transition zone, where load and deformation increase significantly, and stress values range from 6.2 to 29.6 MPa. In the final stage (20–28 mm), the composite undergoes fully plastic deformation, sustaining loads up to 165 kN and stresses up to 66 MPa before failure. This progression demonstrates that the composite possesses good initial elasticity followed by extensive plastic deformation prior to reaching its ultimate strength.

Figure 7 shows the stress–strain curve of the PE–RHA composite with an 80:20 composition ratio. The curve exhibits a clear elastic region at the early stage of loading, represented by a linear increase in stress with strain. After exceeding the elastic limit, the material enters the plastic deformation region and continues to carry load until reaching the maximum stress (σ_{max}), which defines the compressive strength of the composite. The dominance of the polyethylene matrix contributes to the ductile behavior of the material, while the presence of rice husk ash provides additional stiffness. This combination results in a composite that exhibits moderate stiffness with good deformation capability.

Table 1. Load–displacement test results of Specimen 1 (80:20)

Transfer (mm)	Load (kN)	Compression (MPa)	Pressure (MPa)
0	0	0	0
2	0.8	0.32	0.067
4	4	2	0.133
6	8	3	0.200
8	11	4	0.267
10	16	6	0.333
12	20	8	0.400
14	28	11	0.467
16	37	15	0.533
18	50	20	0.600
20	74	30	0.667
22	95	38	0.733
24	120	48	0.800
26	142	57	0.867
27.5	160	64	0.917
28	165	66	0.933

The compressive strength of 15.59 MPa indicates that the material has relatively low strength compared to structural materials but remains adequate for non-structural applications, as the summary presented on Table 2. The elastic modulus of 463.50 MPa reflects moderate stiffness, while the absence of Poisson's ratio data is due to the lack of lateral strain measurements during testing.

Based on the mechanical parameters obtained from the compressive stress–strain test, the PE–RHA composite with an 80:20 composition exhibits relatively low compressive strength, with a maximum stress (σ_m) of only 15.59 MPa. This value indicates that the material has limited load-bearing capacity compared to conventional engineering materials and is therefore unsuitable for structural applications. The yield stress (σ_Y) and yield strain (ε_Y) coincide with the maximum stress and strain values ($\sigma_m = \sigma_Y$ = 15.59 MPa; $\varepsilon_m = \varepsilon_Y \approx$ 5.4%), suggesting that the material yields immediately upon reaching its maximum stress without exhibiting a distinct plastic hardening region.

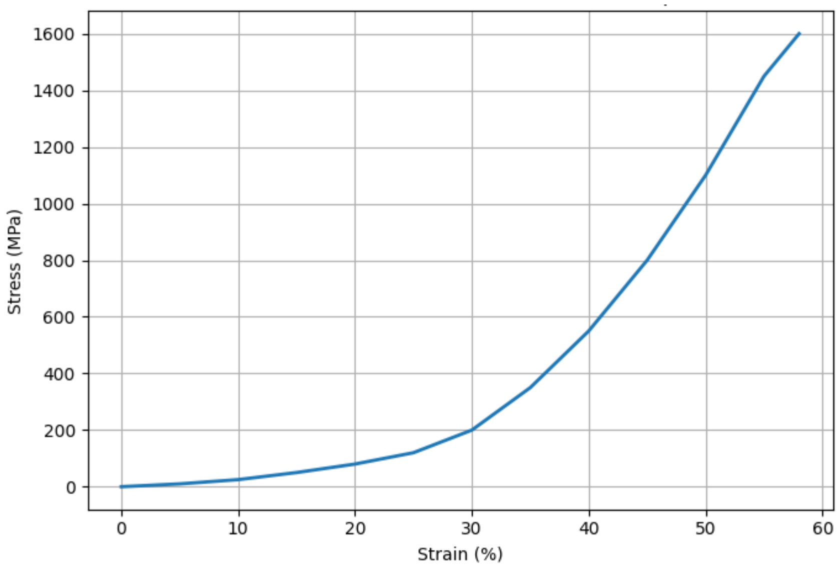

Figure 7. Stress–strain curve of the PE–RHA composite with an 80:20 composition under compressive loading

Table 2. Summary of compression test results of PE–rice husk ash composites (80:20)

Parameter	Value
Maximum load	7.80 kN
Compressive strength	15.59 MPa
Axial strain	6.80%
Elastic modulus	463.50 MPa
Poisson's ratio	Not measured

After surpassing the maximum stress, the composite experiences a rapid reduction in stress, with the fracture stress (σ_b) decreasing sharply to approximately 0.92 MPa at a fracture strain of 7.6%. This abrupt loss of load-carrying capacity indicates brittle post-peak behavior despite the material's ductile response prior to failure. The elastic modulus (E_t) of 463.50 MPa reflects moderate stiffness, placing the material in the medium-to-low stiffness category. While this stiffness level is sufficient for non-structural applications that primarily experience elastic loading, it is inadequate for components subjected to significant mechanical demands.

The calculated Poisson's ratio (μ) of 2.15 is significantly higher than the theoretical range for solid materials (typically 0.2–0.5). This abnormal value suggests inaccuracies in measurement or calculation, likely arising from the absence of direct lateral strain measurement during testing. Consequently, Poisson's ratio values for this specimen should be interpreted with caution and are not considered reliable for mechanical characterization.

3.2. Specimen 2 (70:30) results

Figure 8 presents the stress–strain response of the PE–RHA composite with a composition ratio of 70:30 under compressive loading. The vertical axis represents stress (MPa), while the horizontal axis represents strain (%). The curve shows a gradual increase in stress with strain, indicating a stable deformation process characterized by an initial elastic region followed by plastic deformation prior to failure.

The results indicate that the 70:30 composite achieves a moderate compressive strength of 61.65 MPa, which is adequate for non-structural building applications, as the summary presented on Table 3. The high axial strain of 18.20% demonstrates good ductility, reducing the likelihood of brittle failure during service. The elastic modulus of 339.71 MPa reflects moderate stiffness, indicating a flexible yet sufficiently load-bearing material. Poisson's ratio is not reported because lateral strain was not measured during the compression test.

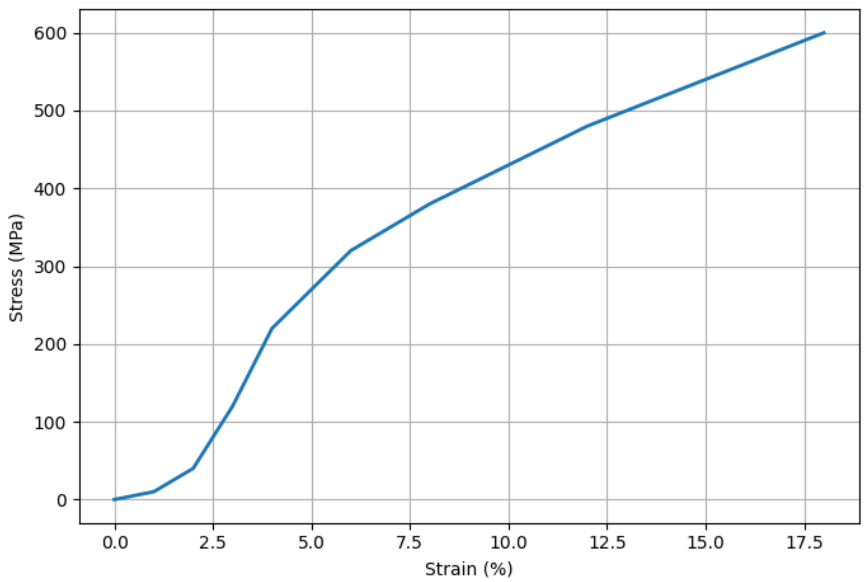

Figure 8. Stress–strain curve of the PE–RHA composite with a 70:30 composition under compressive loading

Table 3. Summary of compression test results of PE–rice husk ash composites (70:30)

Parameter	Value
Maximum load	30.82 kN
Compressive strength	61.65 MPa
Axial strain	18.20%
Elastic modulus	339.71 MPa
Poisson's ratio	Not measured

The stress–strain behavior confirms that the 70:30 PE–RHA composite exhibits a favorable balance between strength and ductility. The material sustains increasing stress beyond the elastic region without abrupt failure, indicating a tough deformation response. Fracture occurs near the maximum stress level, suggesting that the composite can absorb significant energy prior to failure. This combination of moderate strength and high ductility makes the 70:30 composition particularly suitable for non-structural applications where controlled deformation and damage tolerance are required.

Figure 9 shows the load–displacement curve obtained from the compression test of the 70:30 composite. The curve can be divided into three distinct deformation stages. At low displacement levels (0–2 mm), the load increases rapidly and almost linearly, indicating elastic deformation where the material tends to recover its original shape upon unloading. As displacement increases to approximately 2–6 mm, the slope of the curve decreases, signifying a reduction in stiffness due to the onset of plastic deformation. Despite this reduction, the material continues to carry additional load.

In the advanced deformation stage (6–9 mm), the applied load continues to increase until reaching a peak value of approximately 63 kN at a displacement of around 9 mm, representing the maximum load-bearing capacity of the composite. Beyond this peak, further loading would be expected to result in a decline in load, marking the initiation of material failure mechanisms such as cracking, interfacial debonding, or localized structural collapse due to excessive compressive stress.

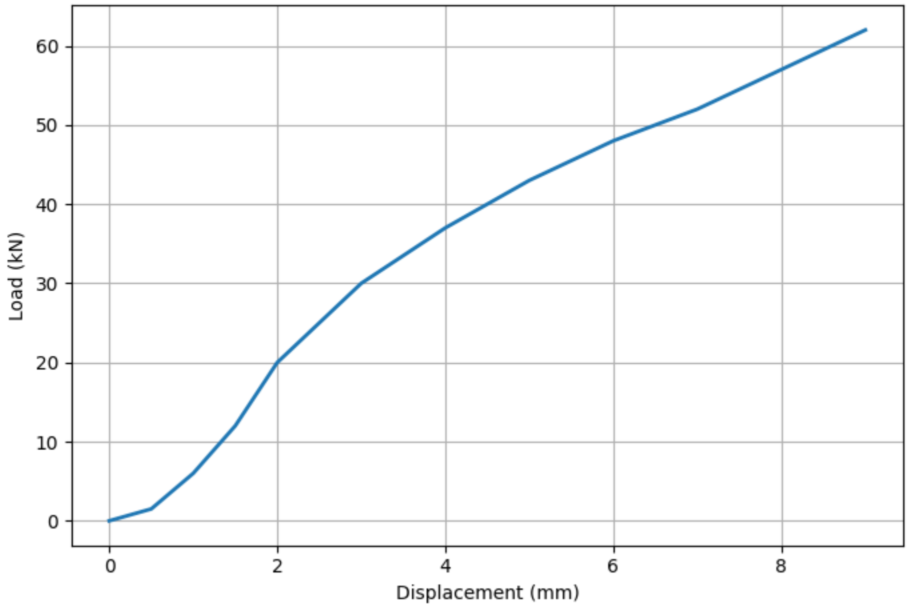

Figure 9. Load–displacement response of the PE–RHA composite with a 70:30 composition obtained from the compression test

3.3. Specimen 3 (60:40) results

Figure 10 presents the stress–strain curve obtained from the compressive test of the PE–RHA composite with a composition ratio of 60:40. The curve demonstrates the mechanical response of the composite under compressive loading, characterized by a pronounced deformation capability prior to failure.

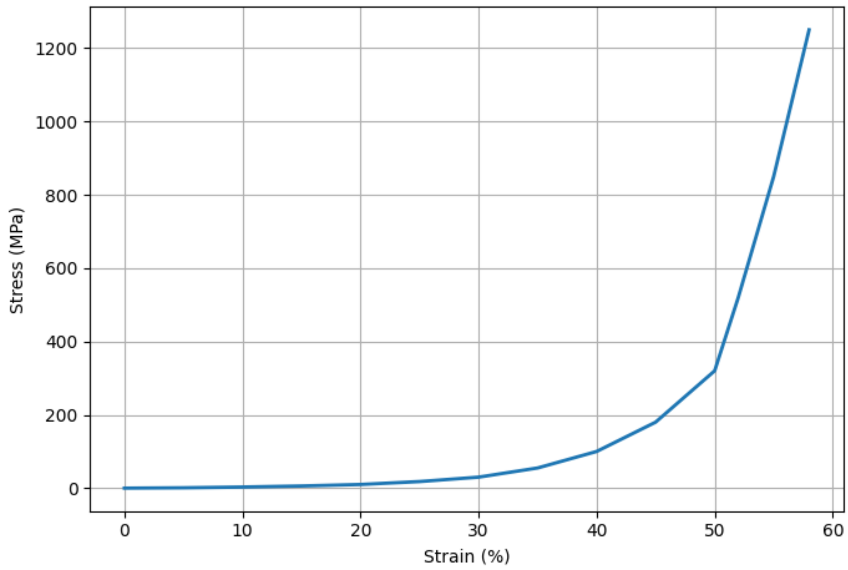

Figure 10. Stress–strain curve of the PE–RHA composite with a 60:40 composition under compressive loading

The results indicate that the 60:40 composite achieves a relatively high compressive strength of 125 MPa, accompanied by a very large axial strain of 56.60%, which reflects high ductility and the ability to undergo substantial deformation before failure. However, the elastic modulus of only 7.50 MPa indicates very low stiffness, suggesting that the material behaves in a highly flexible manner under compressive loading.

The stress–strain response of the 60:40 PE–RHA composite confirms that increasing the rice husk ash content enhances compressive strength while significantly reducing stiffness. Although the material is capable of sustaining high compressive stress and large deformation without immediate fracture, its low elastic modulus makes it unsuitable for structural ceiling applications where dimensional stability is required. The high flexibility of the composite increases the risk of sagging and long-term deformation under sustained loads. Consequently, this composition is more appropriate for non-structural or decorative ceiling panels, particularly when installed on rigid supporting frames and supplemented with additional treatments such as fiber reinforcement, fire-resistant coatings, and moisture protection.

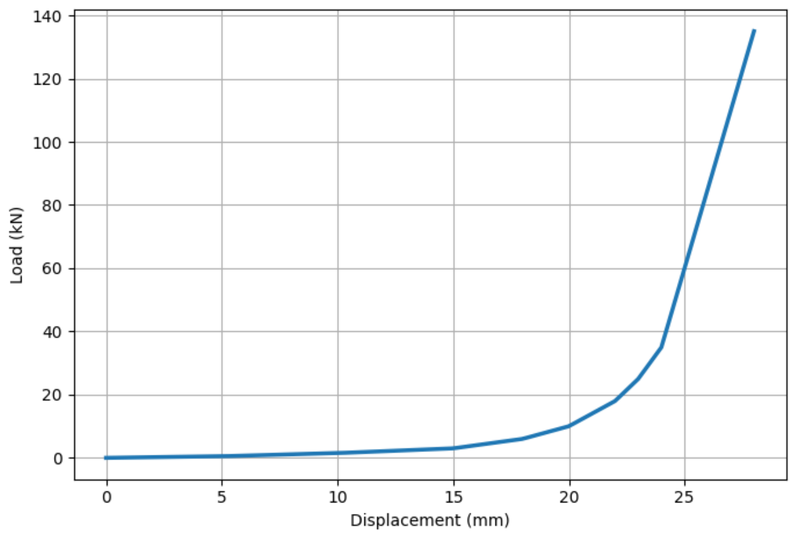

Figure 11. Load–displacement response of the PE–RHA composite with a 60:40 composition obtained from the compression test

Figure 11 shows load–displacement curve obtained from the compression test of the 60:40 composite. The curve indicates a gradual increase in load with displacement during the early loading stage, followed by a substantial increase in deformation as the material approaches its maximum load. The absence of a sharp load drop prior to failure suggests that the composite undergoes extensive plastic deformation, confirming its ductile behavior. However, the pronounced displacement at relatively moderate load levels further emphasizes the low stiffness of the material.

Table 4. Summary of compression test results of PE–rice husk ash composites (60:40)

Parameter	Value
Maximum load	62.40 kN
Compressive strength	125.0 MPa
Axial strain	56.60%
Elastic modulus	7.50 MPa
Poisson's ratio	Not measured

Overall, the PE–RHA composite with a 60:40 composition exhibits a combination of high compressive strength and high ductility, as evidenced by a maximum compressive stress of 125 MPa and a strain at failure of approximately 56.6%. Despite these favorable strength characteristics, the very low elastic modulus ($E_t \approx 7.5$ MPa) limits its suitability for structural applications. With appropriate design modifications and further evaluation—particularly regarding long-term stiffness, flexural capacity, fire resistance, and moisture durability, this material has potential for use as an environmentally friendly non-structural or decorative panel material.

From a practical application perspective, the main advantage of the 60:40 composite lies in its high compressive strength and energy absorption capacity, indicating good toughness. Conversely, its low stiffness makes it susceptible to long-term sagging and creeping, and it may require additional protection against fire and moisture exposure. Therefore, this composite is recommended for non-structural panels, decorative elements, or acoustic components mounted on rigid support systems, rather than for load-bearing ceiling structures without further reinforcement.

Table 5 shows the comparative analysis that clearly indicates that the 70:30 PE–RHA composite provides the most balanced mechanical performance, combining sufficient compressive strength, controlled deformation, and moderate stiffness. This balance makes it the most suitable formulation for non-structural ceiling applications.

Table 5. Comparative analysis of composite specimens for compression tests

Composition (PE:RHA)	σ_{max} (MPa)	ε_{max} (%)	Initial Modulus (MPa)	Mechanical Characteristics
80:20:00	Low	Very high	Low	Highly ductile, low stiffness and strength
70:30:00	Moderate	Moderate	Moderate	Balanced strength and flexibility
60:40:00	High	Very high	Very low	High strength but prone to long-term deformation

3.4. Feasibility of PE–RHA composites as ceiling materials

Ceiling materials must satisfy specific mechanical and functional requirements to ensure safe and durable performance under service conditions. One critical requirement is adequate resistance to bending loads, as ceilings are subjected to vibrations, installation-induced forces, wind pressure—particularly in stilt houses—and minor impacts during maintenance. According to SNI 03-2105 [13], ceiling boards should exhibit a minimum flexural strength of 3–5 MPa and a flexural modulus in the range of 1500–2500 MPa to ensure sufficient structural resistance.

In addition to mechanical strength, ceiling materials should be lightweight to facilitate installation and minimize loads on roof structures. An ideal ceiling material typically has a density not exceeding 1 g/cm^3. Polyethylene, with a density of approximately 0.92 g/cm^3, combined with rice husk ash, which has a porous structure and a density ranging from 0.3 to 0.5 g/cm^3, produces composites with relatively low density. This characteristic makes PE–RHA composites attractive candidates for lightweight ceiling applications [14].

Long-term dimensional stability is another essential requirement, as ceilings must resist sagging throughout their service life. Polyethylene, as a thermoplastic material, is prone to creep when exposed to elevated temperatures. However, the incorporation of rice husk ash into the PE matrix has been shown to enhance stiffness and reduce creep deformation, thereby improving long-term stability. As a result, PE–RHA composites are better able to maintain their shape and functionality when subjected to sustained loads and tropical environmental conditions [15].

4. Conclusion

This study investigated the effect of polyethylene (PE) plastic waste and rice husk ash (RHA) composition on the mechanical properties of recycled composite materials intended for non-structural ceiling applications. Based on standardized compressive and density testing, the results confirm that variations in PE–RHA composition significantly influence compressive strength, elastic modulus, and deformation behavior. The composite with an 80:20 PE:RHA ratio exhibited high flexibility and ductile behavior, allowing it to undergo large deformation without immediate cracking. However, its relatively low compressive strength and stiffness limit its suitability for ceiling applications, particularly over wide spans, where long-term sagging may occur. The 60:40 PE:RHA composite demonstrated the highest compressive strength and the greatest resistance to deformation, indicating improved load-bearing capability. Nevertheless, the increased rice husk ash content resulted in reduced ductility and increased brittleness, making the material more susceptible to cracking during cutting, drilling, or impact loading. Among the tested formulations, the 70:30 PE:RHA composite provided the most balanced mechanical performance. This composition achieved a compressive strength of 61.65 MPa, an axial strain of 18.20%, and moderate stiffness, indicating a favorable combination of strength, deformation resistance, and ductility. These characteristics enable the material to remain stable under load while retaining sufficient flexibility to withstand installation processes and thermal variations without fracture. The 70:30 PE–RHA composite is identified as the optimal formulation for lightweight, non-structural ceiling applications. The findings demonstrate that recycled PE–RHA composites have strong potential as environmentally friendly building materials that reduce plastic and agricultural waste. Future studies should focus on evaluating flexural performance, long-term creep behavior, fire resistance, and moisture durability to further validate the applicability of this material for real-world ceiling systems.

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