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Characteristics of Wall Panels From Thin Plastic Packaging Waste

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Abstract - **Plastic waste has increased following the spike in plastic use as a result of population growth in Indonesia. Approximately 61.37% (21.670 million tons) of plastic waste per year goes unreported, including 7.68 million tons of plastic waste which has a high level of urgency. Thin plastic packaging waste, which has low economic value, is a major contributor to environmental pollution. Meanwhile, the construction sector consumes substantial natural resources, highlighting the need for alternative sustainable materials. This study assesses the wall panels made from thin plastic packaging waste, including plastic bags, non-plastic-bags and non-aluminum plastics, and aluminum-laminated plastics. The research methods include literature study and laboratory testing, with production stages consisting of shredding, washing, drying, melting, and pressing using hot press and cold press machines. The panels were tested for density, moisture content, thickness swelling, Modulus of Rupture (MoR), Modulus of Elasticity (MoE), and tensile strength. The results indicated that MoR values of panels made from plastic bags, non-plastic bags and non-aluminum plastics, and aluminum-laminated plastics were 392.3; 338.231; and 227.323 kgf/cm^2, respectively. MoE values were 9,793.83; 14,664.19; and 9,942.72 kgf/cm^2, while tensile strength values were 1.95; 1.67; and 1.27 kgf/cm^2. Overall, the panels meet the minimum requirements of the Indonesian National Standard-INS 03-2105-2006, except for the MoE parameter, indicating their suitability as non-structural particle boards for sustainable construction.**

Keywords - modulus of rupture (MoR), modulus of elasticity (MoE), plastic waste, tensile strength, wall panels

I. INTRODUCTION

The increasing population growth and rapid infrastructure development in Indonesia have led to a continuous rise in the volume of waste generated annually. The situation is worsening which not only poses serious environmental challenges but also creates a room for innovation in environmentally sustainable construction practices. The construction sector is recognized as one of the major contributors to natural resource consumption [1].

Plastic waste has become one of the most urgent waste management issues that demands immediate attention. Plastic is widely used in daily life due to its strength, lightweight nature, and durability [2]. However, the growing population in Indonesia has also contributed to a significant rise in waste generation. According to data from the Indonesian National Statistics Centre, approximately 12% or 7.68 million tons of the 64 million tons of annual waste generated in Indonesia consists of plastic waste [3]. In addition, The Indonesian National Waste Management System, reported as of September 21, 2025, nearly 61.37% or about 21.670 million tons of waste per year in Indonesia remains unmanaged [4]. Among various plastic waste types, thin plastic waste from used packaging was selected as the primary material in this study due to their high daily consumption and relatively low recycling value.

One innovation that may support sustainable construction development is the production of wall panels from thin plastic waste. Wall panels are non-structural building components made of several partial wall blocks integrated into a single structural unit [5]. Conventional wall construction generally uses materials such as red bricks, concrete blocks, or lightweight bricks combined with mortar finishes including plaster and skim coating. Although widely used, these conventional materials present several limitations, including higher construction costs, longer installation periods, and greater structural weight. Along with the advancement of modern construction systems, framed structures such as reinforced concrete and steel buildings increasingly rely on non-structural wall components. Therefore, lightweight, thin, and durable wall panels made from waste materials may offer a more efficient and sustainable alternative.

Several previous studies have examined the use of waste materials in construction products. For instance, a study utilized HDPE plastic combined with coconut fiber; although it did not evaluate mechanical or physical performance [6]. Similarly, the other study investigated plastic waste mixed with oil palm frond waste [7], while the next study combined plastic with bamboo fiber [8]. Another study employed similar waste materials in the form of wall masonry blocks mixed with used oil and reported encouraging results [9]. The increasing number of studies involving plastic waste and natural fibers suggests that further research is still needed to explore broader applications of waste-based waste materials.

Based on the studies described above, a research gap can be identified. In particular, few investigations have compared different thin plastic waste types including plastic bags, aluminum-laminated plastic, and non-plastic-bag and non-aluminum plastics. Therefore, this study aims to analyze the characteristics of wall panels produced from thin plastic waste and evaluate their potential as sustainable construction materials, including their possible application in post-disaster housing. Each plastic type was processed separately without additional material mixtures to better understand its individual characteristics and performance.

This study is expected to contribute to the development of alternative wall panel materials from low-value waste while also examining their technical feasibility. Since different variations in thin plastic waste types are expected to influence testing outcomes. The research focuses not only on waste utilization but also on evaluating the characteristics of the resulting wall panels according to the requirements of INS 03-2105-2006 [10], which serves as the quality standard reference for particleboard products.

II. METHODOLOGY

A. *Experimental procedure*

a) Material proportions

Material requirements were calculated based on the density of each plastic type and the mold volume measuring 200 × 150 × 16 mm (480 cm^3). The calculation was run by material density times sample volume and adding a 50% waste factor to anticipate material loss during the molding process and to ensure better compaction of the panel.

b) Plastic shredding process

Plastic waste was separated and shredded to smaller pieces. The shredding process was done about four to five times until most of the plastics reached a size approximately 1–2 cm. Figure 1 presents the plastic shredding machine together with the shredded plastic produced after the shredding process.

Fig 1. Plastic shredding process

c) Material grouping

The shredded plastics was grouped and processed according to their respective types to maintain homogeneity. This process was particularly necessary for plastic bags, which vary in color, material quality, and thickness, in order to produce wall panels with uniform properties throughout the specimen.

d) Material placement method in the mold

The mold surface was coated with thin oil coating. The prepared material was weighed and divided into several portions and placed into polyethylene (PE) plastic bags measuring 20 × 35 cm, followed by manually pressed and sealed, as shown in Figure 2, to simplify placement into the mold and minimize material loss. A manual spreading method (by hand) was used for the remaining material, as illustrated in Figure 3. Each panel consisted of three PE bags containing approximately 150 g each, combined with manual spreading performed at 15-minute intervals. This takes an overall molding process approximately 75 minutes per panel.

Fig 2. Manual pressing and sealing method and the result

Fig 3. Manual spreading method (by hand)

e) Melting process using a hot press machine

The plastic materials were melted using a hot press machine (Figure 4), with operating temperature determined through a trial-and-error process. Initial trials applied at temperature of 200°C, as the plastics did not melt completely. Therefore, the temperature was increased to 250°C to ensure effective melting without causing material combustion. Since the hot press machine lacked of pressure monitoring system, compaction consistency was achieved by pressing the material firmly until the mold was completely pressed without visible gaps.

Fig 4. Hot press machine

f) Cooling and demolding process

Following the pressing stage, the panels were cooled using a cold press machine and removed from the mold at approximately 70°C, which was considered suitable to facilitate demolding and prevent the risk of deformation to the panel shape.

g) Testing and results evaluation

Six tests were conducted, namely density, moisture content, thickness swelling, modulus of rupture (MoR) (ASTM D790-17), modulus of elasticity (MoE) (ASTM D790-17), and tensile strength (ASTM D638-14) as shown in Figures 5–7. The results were compared with the 2006 Indonesian National Standard (INS) No 03-2105-2006 to determine the feasibility of wall panels produced from post-consumer flexible plastic packaging waste.

Fig 5. UTM (Universal Testing Machine) for MoR, MoE, tensile strength test

Fig 6. Oven for moisture content test

Fig 7. Container and water setup used for thickness swelling test

B. *Characteristics of waste-based wall panels*

Characteristics refer to the specific properties that differentiate one material from another through testing and evaluation procedures, including observation and experimental analysis. In this study, the characteristics of wall panels were evaluated through these tests which are density, moisture content, thickness swelling, and modulus of rupture (MoR), modulus of elasticity (MoE), and tensile strength testing.

a) Density

Density refers to the mass per unit volume, representing the relationship between the weight and volume of a particleboard. The thickness of each specimen was measured at four corners, 25 mm from each corner (at the intersection points of length and width measurements) with an accuracy of 0.05 mm. Higher particleboard density requires greater pressing pressure during manufacturing [7]. The density value was calculated using the Equation 1 [10].

$$\text{Density (gr/cm}^3\text{)} = \frac{B}{I} \qquad (1)$$

Where:

B = specimen weight (g)
V = specimen volume (length × width × thickness) (cm³)

b) Moisture Content

Moisture content refers to the amount of water removed from particleboard after oven drying. Specimens were first weighed under air-dried conditions and subsequently dried in an oven at 103 ± 2°C until a constant weight was achieved [10]. The drying process was repeated at 6-hour intervals until the weight difference did not exceed 0.1%, indicating oven-dry weight. Moisture content was calculated using Equation 2 [10].

$$\text{MC(\%)} = \frac{Initial\ Mass\ (gr) - Final\ Mass\ (gr)}{Initial\ Mass\ (gr)} \times 100\% \qquad (2)$$

c) Thickness swelling

One of the major weaknesses of particleboard in terms of dimensional stability is its tendency to swell in thickness [8]. Thickness swelling testing was conducted by immersing specimens in water for approximately 24 hours, after which the samples were removed, wiped dry, and measured again. Thickness swelling was calculated using Equation 3 [10].

$$\text{TS (\%)} = \frac{T2 - T1}{T1} \times 100\% \qquad (3)$$

Where:
TS = thickness swelling (%)
T_1 = thickness before immersion (mm)
T_2 = thickness after immersion (mm)

d) Modulus of rupture (MoR)

Modulus of rupture (MoR) represents the ability of a particleboard to resist bending stress applied perpendicular to its surface. Increased particleboard density generally leads to greater toughness and bending resistance [7]. During testing, the load was applied at the center of the specimen at a loading rate of approximately 10 mm/min. Deflection and applied load were recorded until the specimen reached maximum load or failure. MoR was calculated using Equation 4 [10].

$$\text{MoR} = \frac{3.B.S}{2.L.T^2} \qquad (4)$$

Where:
MoR = modulus of rupture (kgf/cm²)
B = maximum applied load (kgf)
S = support span (cm)
L = specimen width (cm)
T = specimen thickness (cm)

e) Modulus of elasticity (MoE)

Modulus of elasticity (MoE) describes the ability of a particleboard to resist deformation under bending load and represents the stiffness of the board. MoE is an important parameter reflecting the ability of a board to maintain its shape [11]. The MoE test followed the same procedure as the MoR test using ASTM D790-17 with specimen dimensions of 12.7 ×

1.27 × 0.32 cm [12]. The modulus of elasticity was calculated using Equation 5 [10].

$$\text{MoE} = \frac{S^3}{4\,L\,T^3} \times \frac{\Delta B}{\Delta D} \qquad (5)$$

Where:

MoE = modulus of elasticity (kgf/cm²)
S = load before proportional limit (kgf)
L = support span (cm)
T = specimen width (cm)
D = deflection (cm) resulting from the load difference ($B_1 - B_2$)
B = load difference ($B_1 - B_2$) obtained from the load–deflection curve (kgf)

f) Tensile strength

In the tensile strength test, both ends of the specimen were clamped, with one end connected to a tensile loading device. Tensile strain was applied through a motor-driven crosshead, causing specimen elongation [13]. The main parameter observed was the maximum tensile load sustained by the specimen, referred to as maximum tensile strength. The test specimens were prepared according to ASTM D638-14 Type IV specifications [14]. Tensile strength was calculated using Equation 6 [10].

$$\text{Tensile Strength (kgf/cm}^2\text{)} = \frac{B}{P \times L} \qquad (6)$$

Where:

B = maximum load (kgf)
P = specimen length (cm)
L = specimen width (cm)

C. *Standard values according to INS 03-2105-2006*

Table I presents the standard values used as references for evaluating the characteristic test results of wall panels based on INS 03-2105-2006 [10].

TABLE I. WALL PANEL CHARACTERISTICS

Physical and Mechanical Properties	Value of SNI 03-2105-2006
Density (gr/cm³)	0,4 -0,9
Moisture Content (%)	<14
Thickness Swelling (%)	Maks 12
MoR (kgf/cm²)	Min 82
MoE (kgf/cm²)	Min 20.400
Tensile Strength (kgf/cm²)	Min 1,5

D. MATERIALS

Wall panel specimens were manufactured using three types of plastic materials, namely plastic bags, non-plastic-bag and non-aluminum plastics, and aluminum-laminated plastics. Accordingly, three homogeneous specimen variations were obtained.

A. Plastic bags (LDPE & HDPE)

Plastic bags mainly consist of low-density polyethylene (LDPE) and high-density polyethylene (HDPE). LDPE is characterized by its soft and flexible properties, with a melting point ranging from 105–115°C [15]. Meanwhile, HDPE, identified by resin code number 2, is commonly used in the production of plastic bags, plastic sheets, plastic cups, shampoo bottles, and similar products. HDPE is characterized by its rigid, strong, and opaque characteristics.

B. Non-plastic-bag and non-aluminum plastics (PE)

Polyethylene (PE) is widely used in transparent packaging materials and contains several types, particularly LDPE and linear low-density polyethylene (LLDPE).

C. Aluminum-Laminated Plastics (PETE)

Polyethylene terephthalate (PETE) is generally categorized as a single-use plastic and is identified by resin code number 1 [16]. PETE is widely used in food and beverage packaging due to its ability to maintain airtight conditions and preserve product quality.

E. RESULTS AND DISCUSSION

A. Plastic material inspection results

The specific gravity test conducted on each plastic material produced the results presented in Table II.

TABLE II. SPECIFIC GRAVITY OF PLASTIC

Material Type	Specific Gravity
Plastic Bags	0,890
Non-Plastic-Bag and Non-Aluminum Plastics	0,877
Aluminum-Laminated Plastics	0,893

B. Plastic melting temperature and material proportions

TABLE III. CALCULATION OF MATERIAL VOLUME REQUIREMENTS

Sample	Volume (cm³)	Specific Gravity (cm³)	SG 100% & Waste Factor 50%	Sample Mass (gr)
A1 & A2	480	0,890	1,335	641
B1 & B2	480	0,877	1,316	631
C1 & C2	480	0,893	1,340	643

Description:
Sample A = Plastic bags
Sample B = Non-plastic-bags and non-aluminum plastics
Sample C = Aluminum-laminated plastics

The material proportions presented in Table III. The results indicate that the optimum melting temperature for plastic bags and non-bag, non-aluminum plastics was 190°C, whereas 200°C was required for aluminum-laminated plastics.

The compacted panels produced using the hot press machine are illustrated in Figures 8–10.

Fig 8. Plastic bags panels

Fig 9. Non-plastic-bags and non-aluminum plastics panels

Fig 10. Aluminum-laminated plastics panels

C. *Density test results*

Based on the test results presented in Figure 11, wall panels made from aluminum-laminated plastic exhibited the highest density value (0.878 g/cm³). The test results indicate that the density of wall panels made from thin plastic packaging waste complies with the requirements of INS 03-2105-2006, which specifies a density range of 0.4–0.9 g/cm³ [10].

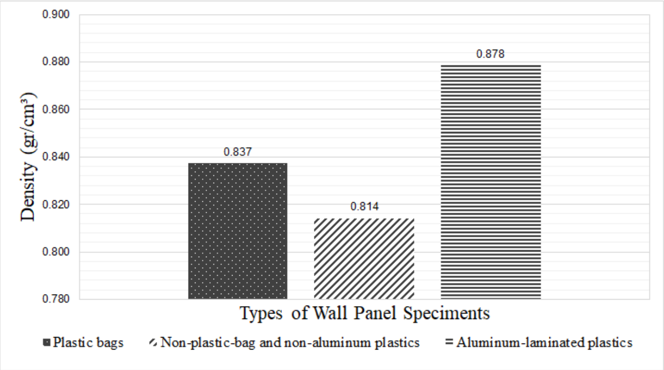

Fig 11. The density test graph

Additionally, laboratory testing conducted on February 24, 2026, produced density values of 0.617 g/cm³ for Albizia wood and 0.338 g/cm³ for plywood. These findings suggest that the utilization of thin plastic packaging waste as wall panel material can achieve physical performance comparable to, or even exceeding, certain commercially available materials. Furthermore, higher wall panel density generally indicates greater pressure applied during the hot-pressing process.

D. *Moisture content test results*

Based on the moisture content test results Figure 12, wall panels made from non-plastic-bag and non-aluminum plastics exhibited the lowest moisture content percentage (0.06%), while aluminum-laminated plastic wall panels showed the highest value (0.13%). The low moisture content values indicate that wall panels manufactured from post-consumer flexible plastic packaging waste possess excellent hydrophobic properties compared to conventional wood-based materials.

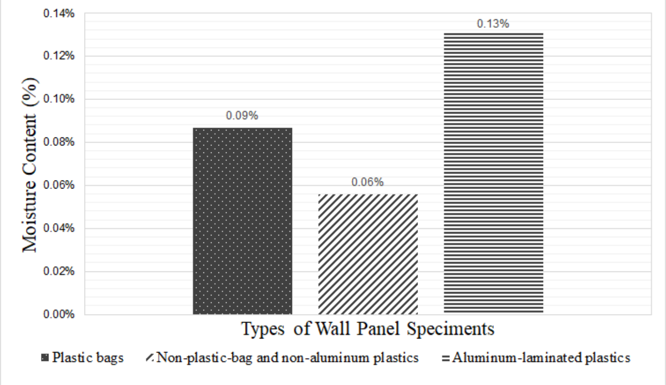

Fig 12. The moisture content graph

Overall, the moisture content results of the plastic wall panels satisfied the requirements of INS 03-2105-2006, which specifies a maximum moisture content of 14%. Previous studies reported moisture content values of 10.76% for Albizia wood [17] and 10.4% for plywood [18]. Additionally, laboratory testing conducted on February 24, 2026, obtained moisture content values of 5.89% for Albizia wood and 9.39% for plywood. These findings demonstrate that wall panels produced from post-consumer flexible plastic packaging waste exhibit superior dimensional stability against environmental humidity.

E. Thickness swelling test results

Based on the test results, all wall panel specimens showed 0% thickness swelling after 24 hours of water immersion. This result indicates that the wall panels did not undergo dimensional expansion due to water absorption. The obtained values were substantially lower than the requirements of INS 03-2105-2006, which specifies a maximum thickness swelling value of 12%.

Laboratory testing of comparison materials showed thickness swelling values of 8.326% for plywood and 4.101% for Albizia wood. Although both materials exhibited relatively higher swelling percentages, they still complied with the INS requirements. Therefore, wall panels manufactured from post-consumer flexible plastic packaging waste demonstrate a competitive advantage as moisture-resistant materials, particularly under high-humidity conditions and direct water exposure, when compared with wood-based materials.

F. Modulus of rupture (MoR) test results

As shown in Figure 13, the MoR test results indicated values of 392.300, 338.231, and 227.323 kgf/cm² for wall panels made from plastic bags, non-plastic-bag and non-aluminum plastics, and aluminum-laminated plastics, respectively. Among these materials, wall panels made from plastic bags exhibited the highest MoR value, whereas aluminum-laminated plastic panels showed the lowest bending strength.

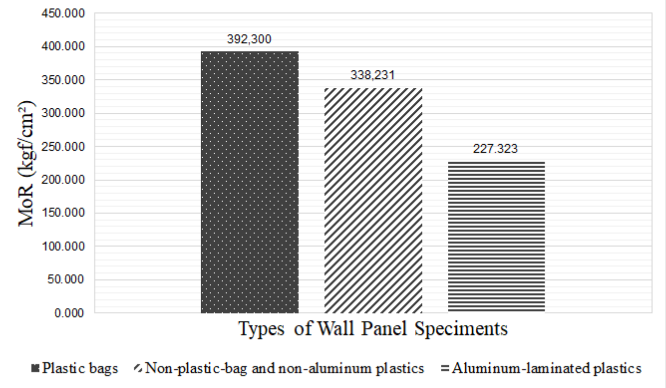

Fig 13. The MoR graph

For comparison, MoR testing was also conducted on commercially available materials. Albizia wood demonstrated the highest MoR value among all tested materials, reaching 450.557 kgf/cm², while plywood exhibited a value of 233.967 kgf/cm², which was relatively comparable to that of the plastic wall panels. Based on the calculated MoR values, all wall panels manufactured from post-consumer flexible plastic packaging waste satisfied the minimum requirement of SNI 03-2105-2006, which specifies a minimum MoR value of 82 kgf/cm². In comparison with previous literature, HDPE plastic showed an MoR value of 230.048 kgf/cm² [19].

G. Modulus of elasticity (MoE) test results

As illustrated in Figure 14, the MoE values of wall panels made from plastic bags, non-plastic-bag and non-aluminum plastics, and aluminum-laminated plastics were 9,793.83 kgf/cm², 14,664.19 kgf/cm², and 9,942.72 kgf/cm², respectively. These values represent the stiffness of the wall panels, where higher MoE values indicate greater rigidity and lower deformation under loading conditions.

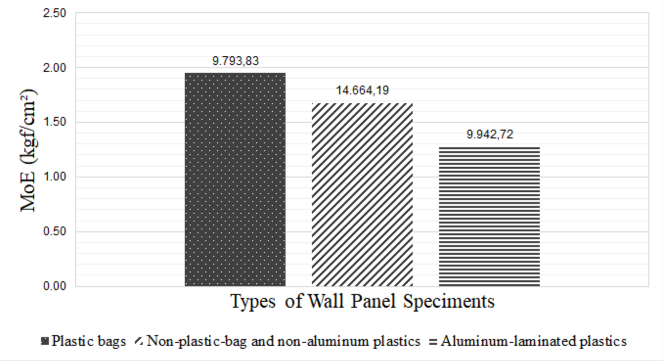

Fig 14. The MoE graph

The results showed that the flexural modulus (MoE) values of all post-consumer flexible plastic wall panel specimens did not meet the minimum requirement specified in INS 03-2105-2006, namely ≥ 20,400 kgf/cm². Consequently, the developed wall panels are considered unsuitable for structural wall applications and are more appropriate for non-structural wall panels.

These findings are consistent with previous studies in which MoE values also failed to meet the INS minimum requirement. For instance, composites made from PET plastic waste and bamboo powder exhibited an MoE value of 750.174 kgf/cm² [20], while bamboo fiber composite materials achieved 7,015.607 kgf/cm² [8]. Laboratory testing of comparison materials further showed MoE values of 19,200.06 kgf/cm² for Albizia wood and 12,207.50 kgf/cm² for plywood, indicating stiffness values that were not substantially different from those of the recycled plastic wall panels.

H. Tensile strength test results (tensile strength perpendicular to surface)

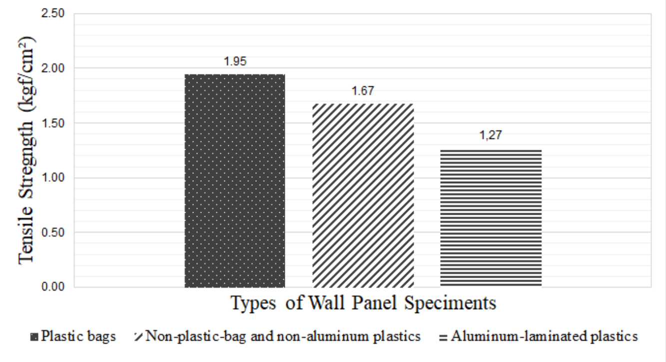

Fig 15. The tensile strength graph

Based on the test results shown in Figure 15, the tensile strength values for wall panels made from plastic bags, non-plastic-bag and non-aluminum plastics, and aluminum-laminated plastics were 1.95 kgf/cm², 1.67 kgf/cm², and 1.27 kgf/cm², respectively. These values reflect the tensile resistance of the wall panels, where higher tensile strength reflects stronger inter-particle bonding within the material.

According on INS 03-2105-2006, the minimum required value is 1.5 kgf/cm². The wall panels produced from plastic bags and Non-plastic-bags and non-aluminum plastics met this requirement, whereas the aluminum-laminated plastic panels showed values slightly below the minimum standard. This result might be caused by the aluminum layer not melting at 200°C. As only the plastic component melted during processing, resulting in weaker inter-particle bonding compared to the other two panel types.

For comparison, the same test was performed on other materials. Albizia wood exhibited the highest tensile strength value at 9.36 kgf/cm², followed by plywood at 3.14 kgf/cm². Previous studies reported tensile strength values of 2.01 kgf/cm² for composites consisting of 50% PP plastic and 50% coconut stem powder/PVAc adhesive mixture [8]. Similarly, composites made from PET plastic waste and bamboo powder demonstrated an average tensile strength of 3.524 kgf/cm²[19], while bamboo fiber composite wood materials reported achieved the highest value of 4.933 kgf/cm² [8].

F. CONCLUSIONS

Based on the experimental results of the three thin plastic packaging waste wall panel samples, it can be concluded that the optimum melting temperature during the hot press process for samples A1, A2, B1, and B2 was 190°C, whereas samples C1 and C2 required a temperature of 200°C.

Based on the characterization analysis through the conducted tests, wall panels made from plastic bags exhibited the following properties, respectively: density, moisture content, thickness swelling, Modulus of Rupture (MoR), Modulus of Elasticity (MoE), and tensile strength were 0.837 g/cm³; 0.09%; 0%; 392.3 kg/cm²; 9,793.83 kg/cm²; and 1.95 kg/cm². Meanwhile, wall panels made from non-bag and non-aluminum plastics showed values of 0.814 g/cm³; 0.06%; 0%; 338.231 kg/cm²; 14,664.19 kg/cm²; and 1.67 kg/cm², respectively. In comparison, aluminum-laminated plastic wall panels demonstrated values of 0.878 g/cm³; 0.13%; 0%; 227.323 kg/cm²; 9,942.72 kg/cm²; and 1.27 kg/cm².

The test results indicated that the thin plastic packaging waste wall panels generally satisfied the requirements of INS 03-2}05-2006, except for the Modulus of Elasticity (MoE) test, in which all panel types failed to meet the specified standard. Furthermore, wall panels made from aluminum-laminated plastic did not satisfy the required limit in the internal bond strength test.

Among the tested materials, wall panels made from plastic bags demonstrated the best overall performance, particularly in the Modulus of Rupture (MoR) and internal bond strength tests. This was followed by wall panels made from non-bag and non-aluminum plastics, which showed superior performance in moisture content and Modulus of Elasticity (MoE) tests. Aluminum-laminated plastic wall panels ranked third in performance, despite having the highest density among all tested samples.

In general, the results suggest that wall panels manufactured from thin plastic packaging waste meet most of the requirements specified in INS 03-2105-2006, indicating their potential for use as alternative and sustainable construction materials.

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