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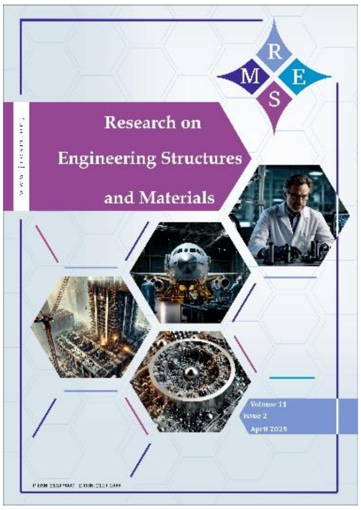

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Research Article

Recycling plastic waste into bricks: A sustainable approach using HDPE, PET, RFA, and PP

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Abstract

Plastic waste poses a significant environmental challenge due to its resistance to degradation. One promising solution is its utilization as a construction material, such as lightweight or floating bricks. This study investigates the feasibility of using High-Density Polyethylene (HDPE), Polyethylene Terephthalate (PET), and Polypropylene (PP) combined with Recycled Fine Aggregate (RFA) to produce sustainable bricks. A total of 39 specimens and 3 control samples (100% HDPE) were tested through three experimental series. The first series examined HDPE–RFA mixtures (100–70% HDPE; 0–30% RFA). Increasing RFA content significantly improved the compressive and shear strengths, reaching maximum values of 47.43 MPa and 0.700 MPa, respectively. The second series evaluated HDPE–PET blends (90:10 to 70:30). Although pure HDPE showed the highest compressive strength (30.43 MPa), the 80:20 ratio provided an optimal balance between performance and efficiency. The third series analyzed HDPE–PP mixtures, with the 90:10 ratio yielding the highest strength (30.13 MPa), while the 80:20 ratio demonstrated more stable overall performance. All specimens met lightweight brick criteria and exhibited low water absorption. Increased PET content improved moisture resistance, making HDPE–PET blends suitable for water-sensitive applications. Density values ranged from 0.088 to 0.101 g/cm^3, with HDPE–RFA mixtures showing the highest density. Overall, the results indicate that incorporating PET or RFA enhances mechanical strength, while PP improves stability. These findings demonstrate the strong potential of HDPE-based composite bricks as sustainable and eco-friendly alternatives for construction and floating applications.

1. Introduction

Plastic is a very dangerous substance that is incredibly difficult to degrade, making it a major concern worldwide. Plastic is widely used in our everyday lives for items like polythene bags, disposables, furniture, food packaging, and other accessories. Plastic varies greatly in kind and composition based on their chemical makeup. Separating plastic garbage is a significant challenge [1,2]. The UN said that over 11.2 billion tons of solid trash are collected globally, mostly from human activities [3,4]. Plastic is a major contributor to the world's solid waste, with its usage steadily rising each year, leading to a corresponding growth in plastic garbage [5]. It is important to highlight that

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over 300 million metric tons of plastic are generated yearly, with around 20% of this garbage not properly handled. Additionally, most plastic is discarded within a year of production [6,7]. According to data from the Indonesian Plastics Industry Association (INAPLAS) and the Central Statistics Agency (BPS), Indonesia produces 64 million tons of plastic garbage annually, with 3.2 million tons of it ending up in the sea [8]. Plastic waste is a significant global issue due to its non-biodegradable nature, taking hundreds of years to degrade and being long-lasting, as studies have shown that plastic can persist for up to 4,500 years without breaking down. So, the issue of plastic trash must be resolved and handled more sensibly. Trash recycling is a beneficial approach that helps safeguard the ecosystem from the negative impacts of trash. Issues with waste management are connected to overproduction [9,10].

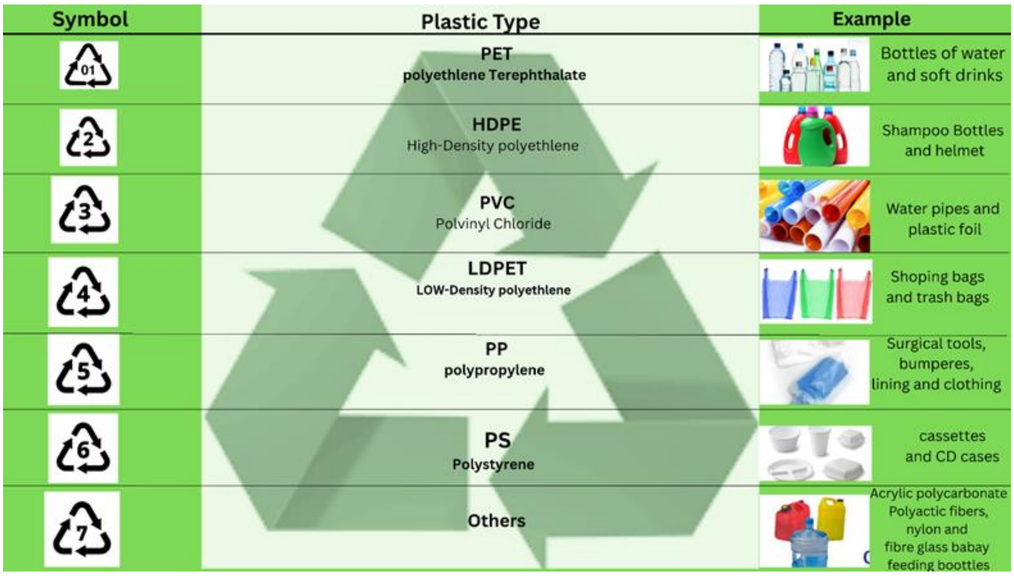


Fig. 1. Type of plastic

Based on reports published by various sources and experts related to climate change and global warming, one of which is the United Nations (UN) UN-Habitat's New Urban Agenda, published in 2020, predicts that 90% of the largest cities in the world will be exposed to rising sea levels in 2050. Most towns and settlements in coastal areas will be affected by erosion and flooding, which can damage homes and infrastructure, so millions of residents must be displaced [11,12]. Plastic waste can be categorized into several types based on their properties and recyclability. PET (Polyethylene Terephthalate), commonly used in beverage bottles and food containers, is lightweight and highly recyclable [13]. HDPE (High-Density Polyethylene), found in items like milk jugs, detergent bottles, and toys, is strong, durable, and widely recycled [14]. PVC (Polyvinyl Chloride), used in pipes, window frames, and vinyl flooring, is resistant to chemicals but challenging to recycle [15]. LDPE (Low-Density Polyethylene), often used in plastic bags, cling wraps, and squeezable bottles, is moderately recyclable. PP (Polypropylene), present in food containers, bottle caps, and automotive parts, is tough, heat-resistant, and recyclable [16]. PS (Polystyrene), which includes Styrofoam cups, food trays, and packing peanuts, is lightweight but difficult to recycle [17]. Multilayer plastics, such as snack wrappers and Tetra Pak, are hard to recycle due to their mixed materials [18]. Microplastics, tiny particles from degraded plastics or synthetic fibers, are not recyclable and pose significant environmental risks19]. Bioplastics, made from renewable resources like corn starch, are sometimes compostable under specific conditions. Lastly, mixed plastics (Code 7) include diverse materials like polycarbonate and acrylic, with varying recyclability depending on the specific type. Understanding these categories is crucial for effective waste management and recycling efforts [20].

This project paper focuses on utilizing PET and HDPE [21] to produce plastic bricks, as these types of plastic are widely available and commonly discarded as waste [22]. PET, often used in water bottles and food packaging, is lightweight and highly recyclable, making it suitable for reuse in construction materials. Similarly, HDPE [13,23], found in containers such as milk jugs and detergent bottles, is durable, resistant to moisture and chemicals, and easily recyclable [24]. By targeting these abundant and recyclable plastic types, the research seeks to reduce environmental waste while providing an innovative solution for sustainable construction [25]. The Ministry of Environment and Forestry reported that of Indonesia's daily waste production of 189 thousand tons, plastic waste reached 15% (28.4 thousand tons per day) [26]. Of the waste products produced daily, only 10-15% of worldwide plastic waste is recycled, while 60-70% is disposed of in landfills. The remaining 15-30% are disposed carelessly of the environment, especially in water areas such as rivers, lakes, beaches, and oceans. This is exacerbated by the increasing number of packaging products circulating in the community [8]. Therefore, plastic recycling becomes very important and a solution that can be implemented [26].

Plastic waste, especially PET plastic, has become rampant as a dangerous global emergency challenge. PET plastic materials, such as drinking water bottles, food packaging, and other products, are often found in the environment [27,28]. The specialty of PET lies in its light, sturdy, flexible, and easy-to-color nature. However, despite its advantages, PET still dominates the waste piles, disturbing the environment. PET is also a type of plastic that is difficult to decompose, and the decomposition period of this type of plastic can take up to 1,000 years. Polyethylene Terephthalate (PET) is a type of food-grade plastic that makes it easy to recycle. But unknowingly, the more often PET is used, the lower its quality. This can affect the quality of the recycling results if you want to reuse it for food packaging [12,29,30].

A series of experimental tests were conducted to evaluate the physical and mechanical properties of the plastic brick specimens, including compressive strength, water absorption, and thermal conductivity. The results indicated that the plastic bricks exhibited significantly lower water absorption rates (ranging from 0 to 0.35%) compared to conventional clay bricks, thereby enhancing their durability. The compressive strength also varied considerably among samples, with the PET/sand composite achieving a maximum strength of 76.85 MPa—substantially exceeding that of traditional bricks. It has been reported that plastic bricks manufactured from recycled materials can effectively replace conventional bricks, thereby reducing dependence on natural resources [27]. The casting process involved melting the plastic waste and pouring it into moulds measuring 190 × 90 × 90 mm, in accordance with the IS 1077 standard. The physical properties assessed included soundness, hardness, efflorescence, and impact resistance. Compression tests on brick masonry models were conducted following the IS 1905 standard, using wall specimens with dimensions of 50×11×50 cm. The results demonstrated that plastic bricks possess advantageous characteristics—such as reduced weight, lower water absorption, and higher compressive strength—rendering them suitable for load-bearing structural applications [31,32].

Numerous studies have explored the incorporation of plastic waste as a binder, aggregate, or as a partial replacement for cement and sand in brick production [30]. Research has shown that the inclusion of recycled HDPE waste in construction materials enhances mechanical performance [31], improves compressive strength [32], and decreases water absorption [33]. Several investigations have further highlighted the potential of using various types of plastic waste, particularly HDPE, in sustainable brick manufacturing [34,35].

The proposed research addresses the problem of plastic waste accumulation by utilizing it in the production of floating house bricks. This study aims to establish a theoretical foundation for sustainable development by exploring innovative recycling techniques that convert Polyethylene Terephthalate (PET), Low-Density Polyethylene (LDPE), and High-Density Polyethylene (HDPE) waste into construction materials [7]. The problem-solving approach involves identifying the main challenges associated with using plastic waste for floating house applications—specifically, material quality, production cost, and environmental impact.

In parallel, investigations have examined the influence of temperature and humidity on salt crystallization in fired clay bricks exposed to saline environments. Research indicates that moisture facilitates the transport of salts into the pores of masonry materials, with the crystallization process being strongly dependent on ambient temperature and humidity. Experimental studies on uniaxial salt crystallization in burned clay bricks conducted at various temperatures (20 °C, 30 °C, and 40

°C) and humidity levels (70%, 80%, and 90%)—while keeping other variables constant—led to the derivation of two predictive equations describing the effects of temperature and humidity, respectively. The findings revealed that salt crystallization intensity increases with higher temperatures of both the brick samples and the sodium sulphate (Na_2SO_4) solution, but decreases with lower relative humidity [36].

To enhance the performance of recycled plastic bricks, additives can be incorporated to improve material properties, optimize the production process, and support recycling programs as a sustainable plastic waste source. Continuous evaluation and improvement of the plastic brick manufacturing process are essential to ensure that the final product meets both structural and environmental standards. Plastic waste, particularly HDPE and PET, poses a major environmental threat due to its persistence and particle size (below 50 μm), which adversely affects soil fertility and marine ecosystems. Therefore, effective and sustainable solutions are urgently required.

This research proposes the utilization of HDPE and PET waste to produce plastic bricks designed as modular components for floating structures. In addition to mitigating plastic pollution, the approach reduces construction costs by minimizing the use of natural materials such as cement and clay. The use of plastic bricks for floating houses offers an innovative and sustainable response to recurrent flooding and tidal inundation in several Indonesian regions—combining environmental responsibility with practicality and economic efficiency.

The proposed modular design employs interlocking plastic bricks, similar to LEGO-like systems, where individual bricks act as both structural and binding elements. HDPE- and PET-based plastic bricks were fabricated in customized shapes and bonded to form modular wall units. These were subsequently evaluated through diagonal shear testing and numerical simulations to assess structural performance. Data analysis was performed using OriginPro 2023 for both statistical and graphical evaluations. The software enabled the visualization and correlation of multiple parameters, including density, compressive strength, water absorption, and shear strength, to identify trends and assess the influence of varying plastic waste ratios on the overall performance of interlocking plastic bricks [37].

This study forms part of a long-term research initiative aimed at developing environmentally friendly and sustainable floating houses within the next five years. The novelty of this work lies in its focus on the performance and interconnectivity of plastic bricks for enhanced strength and structural efficiency in floating house applications—an area with limited prior research. The key contributions of this study include: (1) advancing plastic recycling applications in construction engineering, and (2) developing lightweight, high-strength, low-absorption plastic bricks suitable for floating structures. These bricks exhibit high compressive strength, reduced water absorption compared to conventional bricks, and low density, enabling buoyancy and structural adaptability for coastal and flood-prone regions.

2. Materials and Methods

2.1 Materials

2.1.1 Recycled Fine Aggregate (RFA)

Recycled Fine Aggregate (RFA) is a material obtained from the processing and crushing construction and demolition waste, such as concrete, bricks, tiles, and asphalt. It is an eco-friendly alternative to natural sand, reducing the demand for natural resources and promoting sustainable construction practices [33], [34]. Typically, finer than 4.75 mm, RFAs are well-suited for use as fine aggregates in construction. Due to the crushing process, they have angular particle shapes and rough surface textures [35]. RFA is shown in Figure 2. Recycled Fine Aggregate (RFA), which consists of crushed fine particles obtained from processed construction and demolition waste. To further understand the material behavior of RFA when mixed with HDPE in plastic bricks.

Fig. 2. Recycled Fine Aggregate (RFA) Waste

2.1.2 Waste Plastic HDPE and PET

Waste Plastic PET and HDPE are three of the most recycled plastics, offering significant potential for reuse in construction and other applications. Polyethylene Terephthalate (PET) is a lightweight, strong, and transparent thermoplastic widely used in beverage bottles, food containers, and packaging. Recycling PET and HDPE involves collecting, cleaning, shredding, and melting the waste plastic into pellets or flakes [36]. These recycled plastics can be used as additives or substitutes in construction materials to improve properties like durability and water resistance. Due to its high tensile strength and thermal stability, PET is often incorporated into lightweight composites or reinforcing materials and is commonly used in structural elements or as a filler material in SNI 7974:2013 [37]. PET (Polyethylene Terephthalate) waste is shown in Figure 3(a), and HDPE (High-Density Polyethylene) waste is shown in Figure 3(b).

(a) (b)

Fig. 3. (a) PET Plastic Waste, (b) HDPE Plastic waste

PET plastic waste typically originates from post-consumer products such as beverage bottles, food containers, and packaging materials. The waste is usually processed through cleaning, shredding, and flake production, resulting in angular and glossy flakes with smooth surfaces. HDPE plastic waste is commonly sourced from items such as detergent bottles, milk jugs, plastic crates, and industrial containers. After collecting and cleaning, the waste is granulated into coarse chips or flakes with a dull and waxy appearance [38,39]. HDPE has a lower melting point (approximately 130°C).

2.1.3 Waste Plastic PP

PP (Polypropylene) plastic waste used in this study was obtained from food and detergent packaging waste, which had been shredded before use. PP (Polypropylene) plastic waste can be seen in Figure 4. Polypropylene (PP) plastic waste is widely sourced from household and industrial items such as food containers, automotive components, packaging films, and woven bags. After collecting, PP waste is cleaned and shredded into flakes or granules, often exhibiting a semi-glossy surface with relatively smooth and rounded edges compared to HDPE.

Fig. 4. PP Plastic Waste

2.2 Material Testing

Performing tests on the materials utilized in manufacturing test items is a prerequisite for the procedure. Activities such as the following are included in the material testing that is carried out: Density measures the mass of each unit volume of an object. Normal bricks have a density of around 2200-2400 kg/m^3. Measuring the density of bricks using the Archimedes method refers to the ASTM C134-95 standard (ASTM, 2013) and is calculated using Eq 1.

$$\rho_{pc} = \frac{mb - ms}{mb} x100 \quad (1)$$

where, ρ_{pc} = density (kg/cm^3), ms= mass of dry sample (kg), mb= mass of wet sample (kg).

Evaluation of specific gravity and water absorption of fine aggregates in accordance with SNI 1970:2008 (BSN, 2008a) for fine aggregates. The definition of dry bulk specific gravity refers to the comparison of the condition of the aggregate dried in an oven. The surface dry bulk specific gravity (SSD) compares the aggregate's condition in a dry saturated state [41]. Meanwhile, apparent specific gravity refers to comparing the aggregate's condition when saturated with water. Calculations of specific gravity and water absorption of Sand and fine aggregate are in Eq (2) to Eq (5).

$$Dry\ bulk\ density = \frac{Wk}{Wb + SSD - Wt} \quad (2)$$

$$Surface\ dry\ bulk\ density = \frac{SSD}{Wb + SSD - Wt} \quad (3)$$

$$Apparent\ specific\ gravity = \frac{Wk}{Wb + Wk - Wt} \quad (4)$$

$$Water\ absorption = \frac{SSD - Wk}{Wk} \quad (5)$$

where, WK = oven dry weight (grams), Wb = weight of Erlenmeyer flask containing water (grams), Wt = weight of Erlenmeyer flask containing water-sand (grams), SSD = weight of surface dry fine aggregate.

Based on SNI ASTM C117:2012, mud is a lump or layer that covers the surface of the aggregate and passes through sieve No. 200. Mud and fine dust from rock breaking are particles measuring between 0.002 mm and 0.006 mm (2 to 6 microns). The mud content can be calculated using the following Eq (6).

$$Mud\ Level = \frac{W_1 - W_2}{W_1}\ x\ 100\% \quad (6)$$

where, W1= initial oven dries aggregate weight (grams), W2= oven dries aggregate weight after washing (grams).

Based on SNI ASTM C136:2012, Fine aggregate gradation testing also functions to determine the Fine Grain Modulus (FGM) value. The MG value indicates the fineness or coarseness index of aggregate grains, which ranges from 1.5 to 3.8. The greater the MG value, the MG value can be calculated using Eq (7).

$$FGM = \frac{\Sigma A}{100} \tag{7}$$

where, A= cumulative retained percentage (%).

Compressive strength testing on bricks made using plastic waste can be done by referring to the concrete brick compressive strength testing method according to the SNI 1974:2011 standard. The compressive strength test can be calculated using the following Eq (8).

$$Compressive\ Strength = \frac{Maximum\ Load\ (N)}{Cross{-}sectional\ Area (mm2)} \tag{8}$$

Measure the dimensions of the specimen to calculate its cross-sectional area. where = the highest load the material can withstand before failure, measured in Newtons (N), Cross-sectional Area (mm^2) = surface area under compression. The diagonal shear strength test assesses the ability of plastic bricks and mortar to withstand maximum shear force. Based on ASTM E519/E519M-22 on Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages, there are several requirements for shear strength testing, including the size of the test specimen. In addition, this study also refers to SNI 03-4166-1996 on Shear Strength Testing Method for Red Brick Walls. The minimum size of the test object is 1.2 m x 1.2 m, with a permissible dimension measurement limit of 6 mm. However, this study used a test object size of 30 cm x 30. specimens with dimensions of 300 x 300 mm^2. The calculation formula for the shear strength of brick walls can be seen in Eq (9).

$$Shear\ Stress = \frac{0{,}707\ P}{An} \tag{9}$$

where, Ss= diagonal shear strength of brick (MPa), P =load maximum test (kg), A= cross-sectional area pressure (cm^2). Where A_n is calculated using the formula in Eq (10).

$$A = \left(\frac{(b+h)}{2}\right) tn \tag{10}$$

where, B = specimen width, mm (in), h = specimen height, mm (in), t = total thickness of specimen, mm (in), n Percentage of gross area of solid units. If necessary, the shear strain is calculated using the formula in Eq (11).

$$\gamma = \left(\frac{(\Delta V + \Delta H)}{g}\right) \tag{11}$$

where, γ = shear strain, or (mm/mm), ΔV=vertical shortening (mm), ΔH =horizontal extension (mm), g =vertical measuring length (mm). The Stiffness modulus can be calculated as in Eq (12).

$$G = \frac{Ss}{\gamma} \tag{12}$$

where, G=stiffness modulus (MPa), Ss =shear stress on area, MPa, γ =shear strain, or (mm/mm).

3. Methodology

A control variable is required to be used to conduct this study [35], [42]. In addition, experimental research is carried out to test hypotheses that are prepared in a strict manner and are typically carried out for specific fields [43], [44], [45]. This study uses HDPE, PET, and PP plastic waste recycling techniques as the main basis, which are combined with secondary materials such as Recycled Fine Aggregate Waste (RFA). All waste was collected from urban waste around

Yogyakarta and laboratory waste. After collecting, all materials were washed to remove contamination from other particles, and RFA and GWP were first screened to ensure particle sizes were in the range of 4.75-0.075 mm. Solid plastic waste was shredded to a size of ±30 mm and categorized based on the type of plastic. A series of physical tests was applied to the materials using ASTM standards (C128, C117, C136, and F1312). Since there is no official mix design for plastic bricks, the calculation of brick proportions is based on the weight ratio to 1 volume of the brick specimen. The control specimens in this study were 100% HDPE and 100% PET. There were 21 variations, including the control specimens that would be tested for the effect of each material, as stated by the experimental method. according to SNI 15-2094-2000 (BSN, 2000), For Plastic bricks dimensions 23 x 11 x 5 cm with a certain thickness tolerance. According to SNI, Compressive strength is one of the main parameters that determines the ability of bricks to withstand loads.

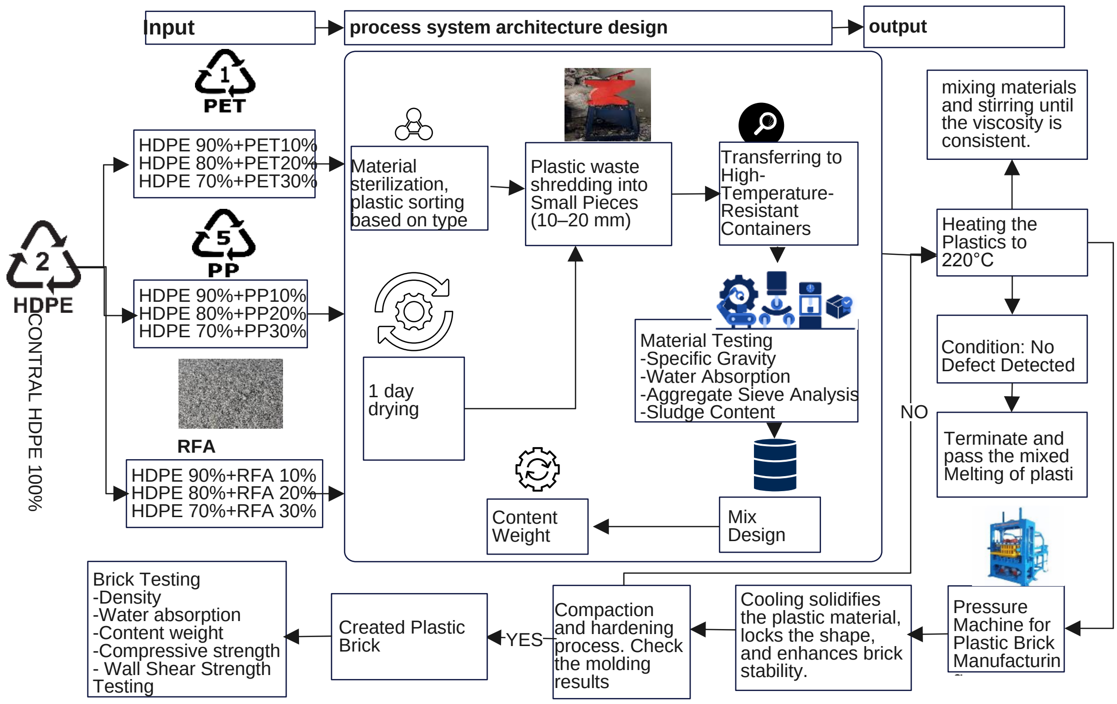


Fig. 5. Experimental methods

The test was conducted to analyse the specifications of the materials used. The test specimen was conducted as follows:

3.1 Density or Solidity Test

The first step to test the density of plastic bricks according to SNI 15-2094-2000 is to prepare measuring instruments and scales. Next, the dimensions of the test object are measured (length, width, and height). Then, the test object is weighed using a digital scale to find the dry mass. After that, the volume of the test object and density were calculated using the specified formula [46].

3.2 Water Absorption Test

The first step taken to test the water resistance of bricks, according to SNI 15-2094-2000, is to prepare the necessary tools and materials, such as scales and containers filled with water. Then, the test object is weighed in a dry state to obtain the dry weight. Furthermore, the test object is soaked for 24 hours in a container filled with water. After soaking, the brick is dried and weighed using a cloth on its surface. The data obtained is then processed with a predetermined formula. Based on SNI, the maximum water absorption in bricks must be 20% [47], [48].

3.3 Mix Design

The data generated from the density and water absorption tests are then used to plan the plastic brick mixture [49,50]. The control specimen used is the HDPE Control Brick, with a ratio of 100%. In addition, there are several types of mixed bricks consisting of HPE1, using a mixture of 90%

HDPE and 10% PET, HPE2 utilizing a mixture of 80% HDPE and 20% PET, and HPE3, using a mixture of 70% HDPE and 30% PET. The planned ratio is used to determine the plastic waste mixture's effect on the brick's characteristics and properties. HPP1 uses a mixture of 90% HDPE and 10% PP, HPP2 uses a mixture of 80% HDPE and 20% PP, and HPP3 uses a mixture of 70% HDPE and 30% PP. HR1 uses a mixture of 90% HDPE and 10% RFA, HR2 uses a mixture of 80% HDPE and 20% RFA, and HR3 uses a mixture of 70% HDPE and 30% RFA. The mix design can be seen in Table 3.

Table 1. Brick specimens mix ratio

Test Object Code	HDPE (%)	PET (%)	PP (%)	RFA (%)
HDPE Control	100	-	-	-
HPE1	90	10	-	-
HPE2	80	20	-	-
HPE3	70	30	-	-
HPP1	90	-	10	-
HPP2	80	-	20	-
HPP3	70	-	30	-
HR1	90	-	-	10
HR2	80	-	-	20
HR3	70	-	-	30

3.4 Preparation of Test Objects

The making of test objects begins with preparing the tools and materials. The shredded plastic waste is then put into a melting machine at a temperature of 250°-300° based on the planned ratio. After melting, the plastic is weighed at high temperature and moulded using a hydraulic press machine with a rectangular block mould measuring 23 cm x 11 cm x 5 cm for approximately 10 minutes so the plastic does not shrink [51]. Furthermore, the plastic bricks shaped like rectangular blocks are soaked in a container filled with water to lower the temperature. The shape of the mould can be seen in Figure 6.

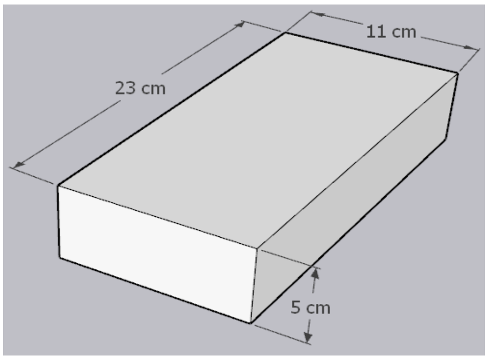


Fig. 6. Rectangular block-shaped mould

4. Results and Discussion

This study was performed at many Universitas Muhammadiyah Yogyakarta (UMY) Labs, namely the Lab Structure, and the UMY Computing Lab. The facilities provide the requisite equipment and expertise for experimental procedures and analysis. The research sought to assess the density, compressive strength, and water absorption characteristics of plastic bricks formulated with diverse compositions and supplementary materials, including plastic waste like HDPE (High-Density Polyethylene), PET (Polyethylene Terephthalate), PP, and recycled fine aggregate (RFA).

4.1 Gradation of Fine Aggregate

Fine aggregate gradation testing also functions to determine the Fine Grain Modulus (FGM) value. The MG value indicates the fineness or coarseness index of aggregate grains which range from 1.5

to 3.8. The greater the MG value, the coarser and larger the gradation, and if the FGM is smaller, the finer the grain gradation. The FGM value can be calculated using Equation (7).

Table 2. Gradation Analysis of Fine Aggregate

Filter Number	Size	Retained Weight (grams)	Retained Weight (%)	Cumulative Retained Weight (%)	Cumulative Pass Weight (%)
No. 4	4.8	16	1.6	1.6	98.4
No. 8	2.4	56	5.6	7.2	92.8
No. 16	1.2	151	15.1	22.3	77.7
No. 30	0.6	158	15.8	38.1	61.9
No. 50	0.3	279	27.9	66	34
No. 100	0.15	277	27.7	93.7	6.3
Pan		63	6.3	100	0
Total		1000	100		371.1
Cumulative Retained Weight (%)				228.9	
Fineness Modulus (FM)				FM= 228.9/100= 2.289	

The gradation study of the fine aggregate indicated a cumulative retained weight of 228.9%, yielding a fineness modulus (FM) of 2.289. As per ASTM C136, this number signifies that the fine aggregate utilized in this study is categorized as medium fine sand, offering appropriate workability and adhesion properties for plastic brick manufacturing. The gradation analysis of the fine aggregates (D1, D2, D3, and D4) was conducted in accordance with ASTM C136 to ascertain the particle size distribution within the samples.

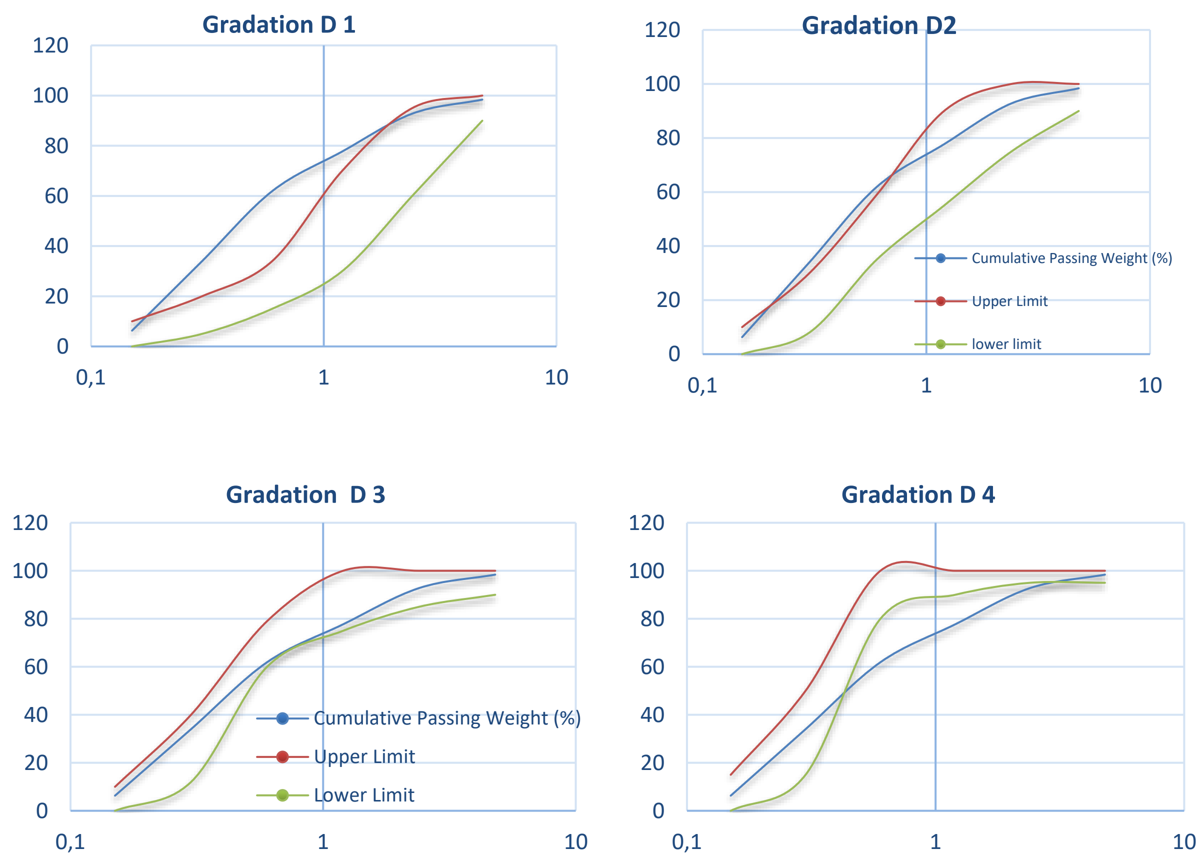


Fig. 7. Analysis of fine aggregate granules gradation

The outcomes were illustrated as cumulative % passing against sieve size on a semi-logarithmic scale, as depicted in Fig. 7. Each gradation curve was evaluated against the established upper and lower limits of fine aggregate gradation to determine compliance and appropriateness for brick manufacture. The Gradation D1 curve approaches the upper limit within the fine particle spectrum, signifying a comparatively finer sand. This gradient enhances the workability and surface texture of the plastic brick mixture. Excessive fine content may marginally diminish permeability and elevate plastic requirements while mixing. Gradation D2 exhibits a balanced particle distribution that lies within the top and lower thresholds, indicating well-graded sand. This gradation improves density, interlocking, and adhesive strength between sand and plastic materials. The fineness modulus (FM = 2.289) indicates that D2 is classified as medium fine sand, optimal for attaining homogeneous compaction and an excellent surface finish in the product. The Gradation D3 curve exhibits a minor tilt towards the coarser end while remaining within acceptable parameters. This signifies a relatively gritty sand that can enhance the drainage and structural integrity of the interlocking plastic bricks. Nonetheless, when utilized in excessive amounts, it may diminish surface cohesiveness during the melding process. The D4 curve nears the lower threshold at smaller filter sizes, indicating a coarser aggregate composition. This gradation improves compressive strength and dimensional stability, while it may somewhat diminish workability.

4.2 Plastic Bricks Measurements

Upon completion of the curing time, the dimensions of the bricks were assessed using calibrated measuring instruments to identify any discrepancies. Variations in size may signify irregularities in the composition of the mixture, compaction force, or curing conditions.

Table 3. Plastic bricks measurements

No.	Code Test Object	Ratio	Length (cm)	Width (cm)	Height (cm)	Volume (cm^3)	Initial Weight (grams)
1	HDPE1	100%; 0%	22.26	10.79	5.79	1390.673466	1.22
2	HDPE2		22.375	10.845	5.95	1443.808406	1.2
3	HDPE3		22.25	10.7	5.9	1404.6425	1.27
Average	HDPE		22.295	10.778	5.88	1413.041457	1.23
4	HP A1	90%; 10%	22.41	10.936	5.61	1374.875014	1.27
5	HP A2		22.47	10.83	5.57	1355.460057	1.255
6	HP A3		22.45	10.91	5.5	1347.11225	1.28
Average	HP A		22.443	10.892	5.56	1359.149107	1.268
7	HP B1	80%; 20%	22.235	10.855	5.66	1366.102836	1.300
8	HP B2		22.36	10.05	5.64	1267.40952	1.265
9	HP B3		22.33	10.75	5.76	1382.6736	1.205
Average	HP B		22.308	10.552	5.687	1338.728652	1.257
10	HP C1	70%; 30%	22.24	10.73	5.37	1281.471024	1.265
11	HP C2		22.25	10.97	5.315	1297.298488	1.285
12	HP C3		22.245	10.86	5.5	1328.69385	1.195
Average	HP C		22.245	10.85	5.395	1302.487787	1.248

Compliance with standardized brick dimensions facilitates comparison testing, guaranteeing that mechanical parameters like compressive strength, density, and water absorption are assessed under consistent circumstances. In conclusion, ensuring accurate measurements in plastic brick production is crucial for quality assurance, structural integrity, and adherence to ASTM C67-05 and SNI 15-2094-2000 requirements. It drawing attention to their dimensions, volume, and weight. The bricks are 100% HDPE and 90:10, 80:20, and 70:30 HDPE-PET blends. As PET content rises, brick volume and mass vary somewhat. In the HP B1 sample, the 80:20 HDPE to PET ratio resulted in the greatest starting weight (1.300 grams) while having a smaller volume (1366.10 cm^3), suggesting a denser and more compact structure. This shows that the 80:20 ratio may be best for lasting plastic bricks since it balances material density and structural integrity.

4.3 Test of Plastic Bricks

In this investigation, three significant laboratory tests were conducted. For every test, three specimens were made. To ascertain the specimens' density, compressive strength, and water absorption, a brick compression test was conducted according to ASTM C67-05, and the Indonesian Standard SNI 15-2094-2000 was followed when conducting the testing procedure. To determine the flexural characteristics, the three-point bending flexural test was conducted in accordance with Indonesian Standard SNI 03-6458-2000. The testing procedure is shown in Figure 8. The plastic bricks were cast and cured for hours after the completion of the curing period, and the bricks were further tested. The following are a few tests that were performed on plastic bricks.

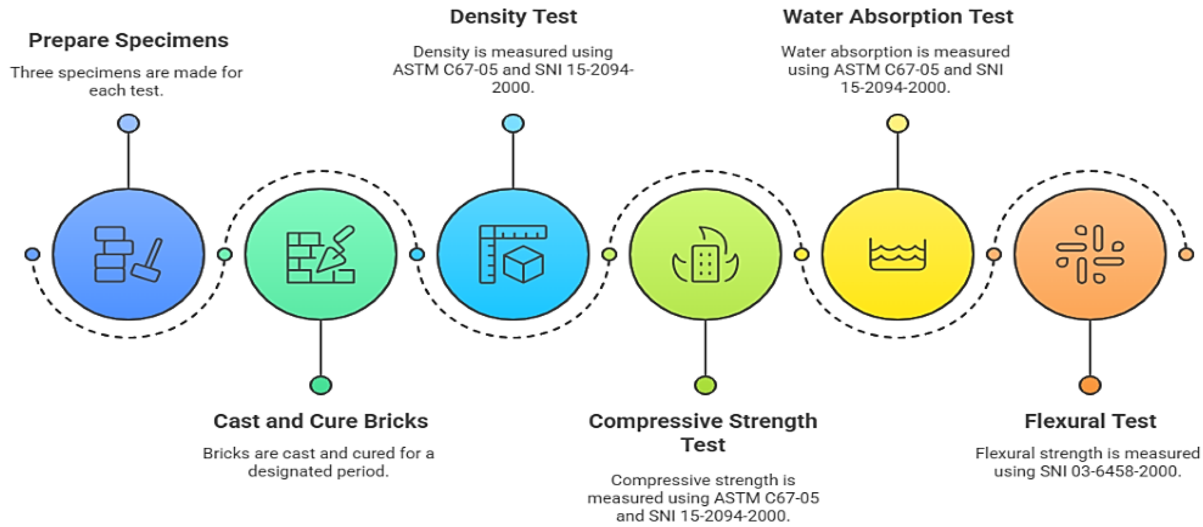


Fig. 8. Testing process plastic bricks

4.3.1 Compressive Strength Test

Compressive strength testing is carried out on cube-shaped test specimens that a curing period of 7 days. This test refers to SNI 15-2094-2000 concerning Solid Red Bricks for Wall Pairs. It was conducted using the Compression Testing Machine in the Structure and Construction Materials Laboratory, Civil Engineering Study Program, Muhammadiyah University of Yogyakarta. The compressive strength test results are shown in Figure 9.

From the results of the compressive strength test in Figure 8, there is an increase in the compressive strength value of the plastic bricks with 90% HDPE and 10% PP variations compared to the plastic bricks with 100% HDPE variations, with a difference in increase of 5.81 MPa. However, there is a decrease in the compressive strength value as the variation of the PP plastic mixture increases in the plastic bricks. This can be caused by the two materials being inhomogeneous between HDPE and PP, which reduces the bonds between molecules in the mixture. In addition, the difference in melting temperature between the two materials can cause non-uniformity in the brick structure, thus affecting the stress distribution during the compression test.

Compressive strength that controls the brick variation of 100% HDPE produces an average compressive strength of 30.43 MPa. Meanwhile, bricks with a variation of 10% PET mixture produce an average compressive strength of 26.7 MPa, bricks with a mixture of 20% PET produce an average of 18.1 MPa, and bricks with a mixture of 30% PET produce an average of 14.5 MPa. The difference in compressive strength results in each variation due to the large number of PET proportion levels that can affect the ability of the brick to withstand loads. The graph of the compressive strength test results of plastic bricks is shown in Figure 10. From the results of the compressive strength test of plastic bricks shown in Figure 10, it is known that bricks with a proportion of HDPE have the highest average compressive strength compared to bricks with a mixture of 10%, 20%, and 30% PET. This is due to the flexible nature of HDPE whichs high mechanical resistance. HDPE can form a solid structure when melted and molded using a mold to increase durability. The addition of 10% PET causes a decrease in compressive strength due to the difference in physical properties of HDPE and PET, where PET is more fragile when compared to HDPE.

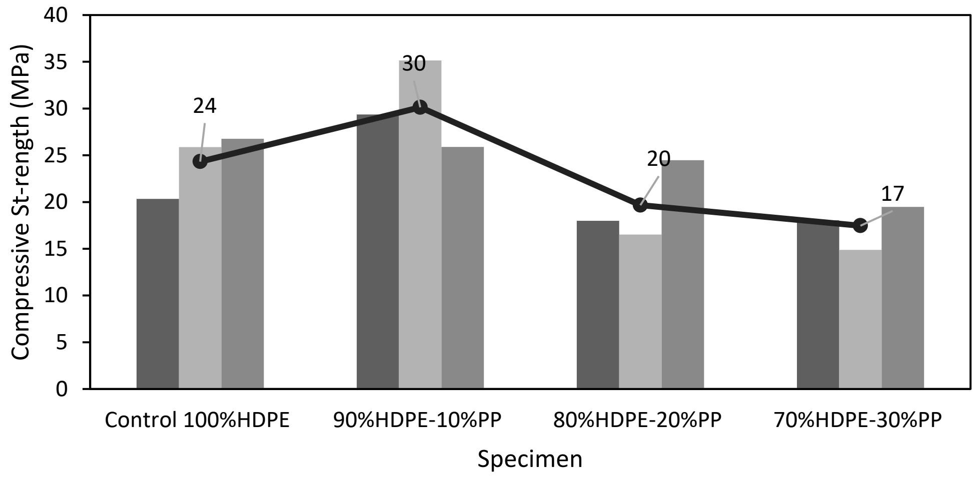


Fig. 9. Brick Compressive strength

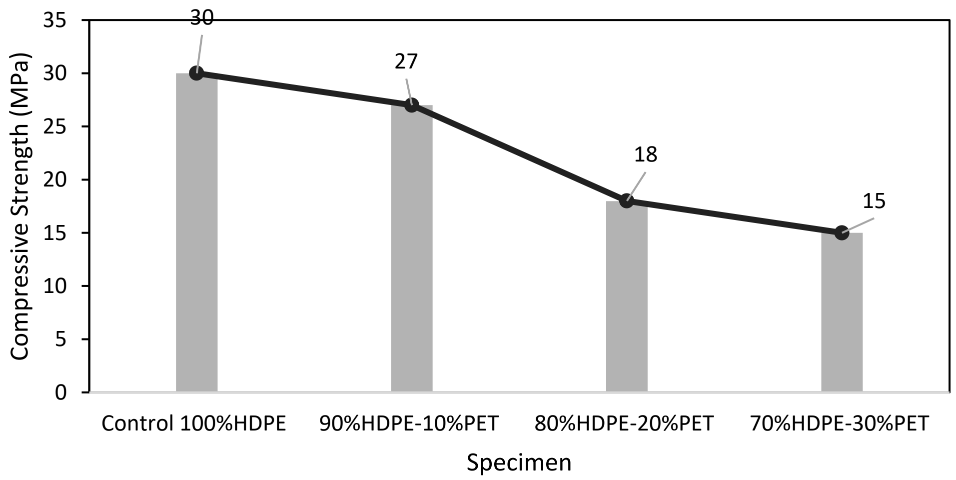


Fig. 10. HDPE-PET plastic brick compressive strength test result graph

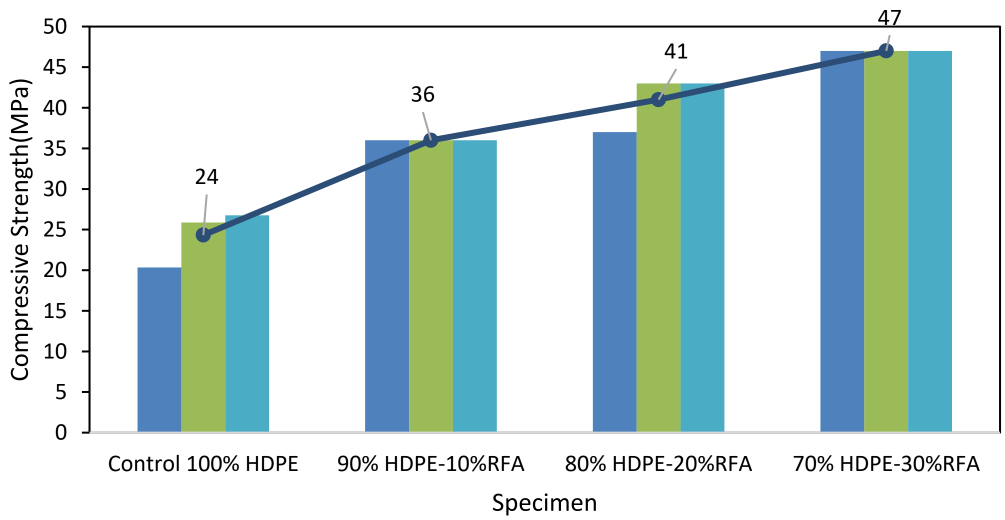


Fig. 11. Brick compressive strength diagram

Brick compressive strength testing refers to the provisions of SNI 15-2094– 2000b [46] about solid red bricks for wall masonry. Compressive strength testing using a Compression Testing Machine at the Structure and Construction Materials Laboratory, Civil Engineering, Muhammadiyah University of Yogyakarta. Brick compressive strength testing is carried out when the mortar used as capping is 7 days old [52]. The results of the red brick compressive strength test can be seen in Figure 11. The maximum compressive strength results on the SPW HDPE D specimen, with variations of 70% HDPE and 30% RFA, with an average of 47.43 MPa, and shows the compressive strength of PW HDPE A brick with 100% HDPE variation, which is lower than SPW HDPE with additional RFA content.

4.3.2 Relationship between Characteristics and Compressive Strength

The relationship between brick characteristic testing and brick compressive strength for quality evaluation. Using polynomial regression, the relationship between brick characteristic testing and brick compressive strength is represented in Figures 12 and 13. The results of the linear regression analysis in Figure 12 show a coefficient correlation value of 0.9999. There is a positive correlation between the percentage of water absorption and compressive strength. The results of the analysis show that the higher the compressive strength, the greater the water absorption. In a study with HDPE as a substitute for sand in bricks, the compressive strength was observed to decrease with a higher percentage of HDPE, indicating that the material's compressive strength was not increased by water absorption. Research results showed that HDPE bricks exhibit superior mechanical properties, including higher compressive strength and lower water absorption compared to traditional clay bricks.

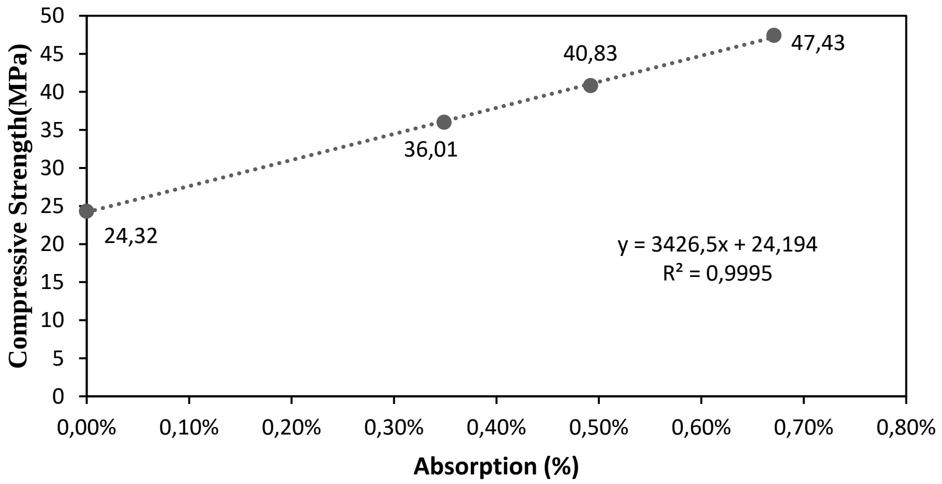


Fig. 12. Graph of the relationship between brick absorption and brick compressive strength

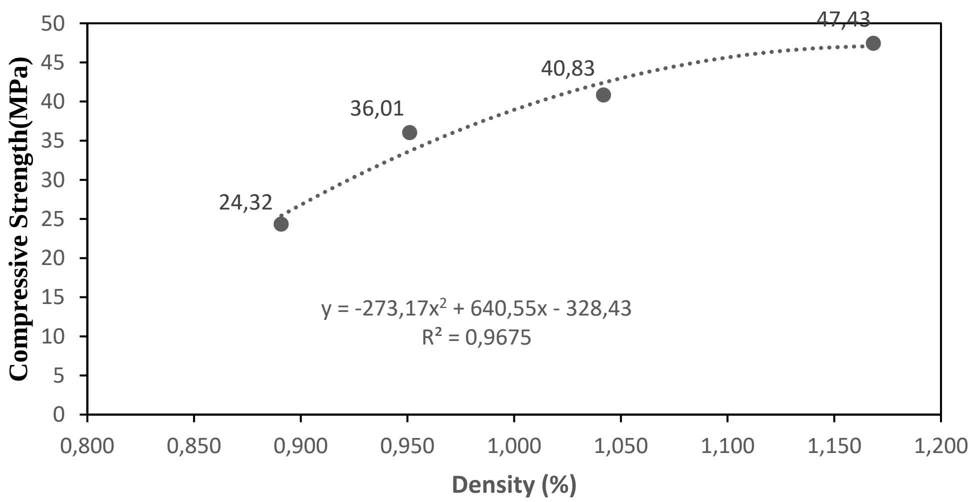


Fig. 13. Graph of the relationship between brick density and brick compressive strength

The results of the polynomial regression analysis in Figure 13 show a correlation coefficient value of 0.9675, and there is a positive correlation between the percentage of density and compressive strength. The relationship between the apparent density of HDPE-based bricks with RFA mixtures with RFA mixtures shows that these two tests provide parameters in evaluating the quality of bricks that are close to the same. The inclusion of HDPE in construction materials generally results in a reduction in density. HDPE is less dense than traditional aggregates such as sand and gravel. For example, when HDPE is used as a partial replacement for natural coarse aggregate, the resulting concrete is lighter, as evidenced by a 2.97% reduction in density compared to the control sample without HDPE.

4.3.3 Wall Shear Strength Testing

Shear strength testing of brick walls refers to ASTM E519/E519M-10(ASTM, 2002) about the standard test method for diagonal compressive strength (shear strength) on brick masonry walls. The brick wall shear strength test was taken as much as 1 test sample in each variation. The brick composition material consists of different HDPE, namely 100%, 90%, 80%, and 70%, with different RFA variations, namely 0%, 10%, 20% and 35%. The brick masonry wall shear strength test results can be seen in Figure 14. The polynomial regression analysis in the Figure shows the compressive strength coefficient and RFA content value of 0.9232. This indicates that the value of the shear strength coefficient and RFA content is close. The optimal compressive strength results on the SPW HDPE C specimen with a variation of 80% HDPE and 20% RFA are 0.700 MPa.

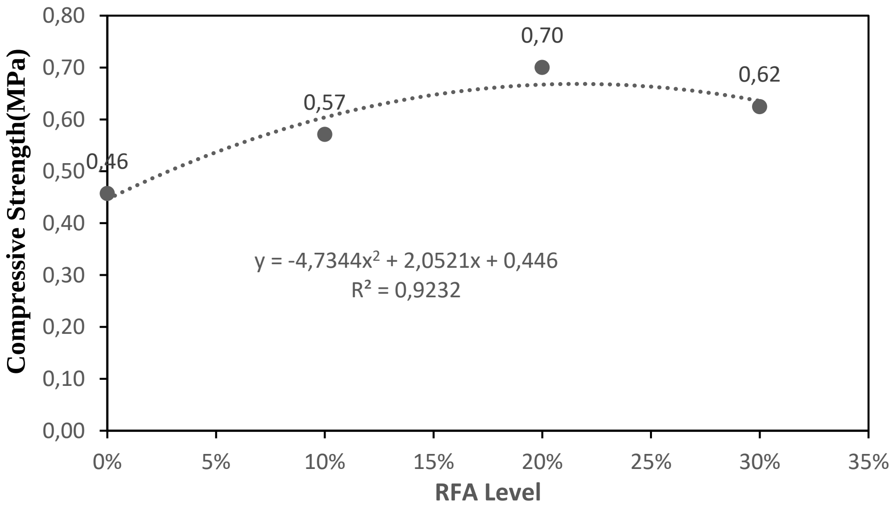


Fig. 14. Comparison graph of shear strength results of brick walls with varying RFA content

4.3.4 Wall Shear Strength Crack Pattern

The specimens tested for wall shear strength are then monitored for their crack patterns to determine how each pair of bricks with different mixtures behave when given an axial load. The crack pattern of the plastic brick's compressive strength usually differs. This occurs because of differences in the texture and characteristics of the materials used or the material content of the test object. According to [54], there are five types of wall shear strength failure modes, namely, horizontal sliding, steps (Step-Stairs Sliding), diagonal cracks (Diagonal Crack), multiple cracks (Multi Crack), and detachment. The shear strength test process for brick wall pairs can be seen in Figure 15. Based on the crack patterns of the test specimens in Table 4, it can be concluded that the visually visible crack patterns are the step-stairs sliding failure mode and the horizontal sliding failure mode. Crack patterns can occur because the mechanical properties of the materials used in masonry, such as mortar and plaster, significantly affect the shear strength and internal friction coefficient.

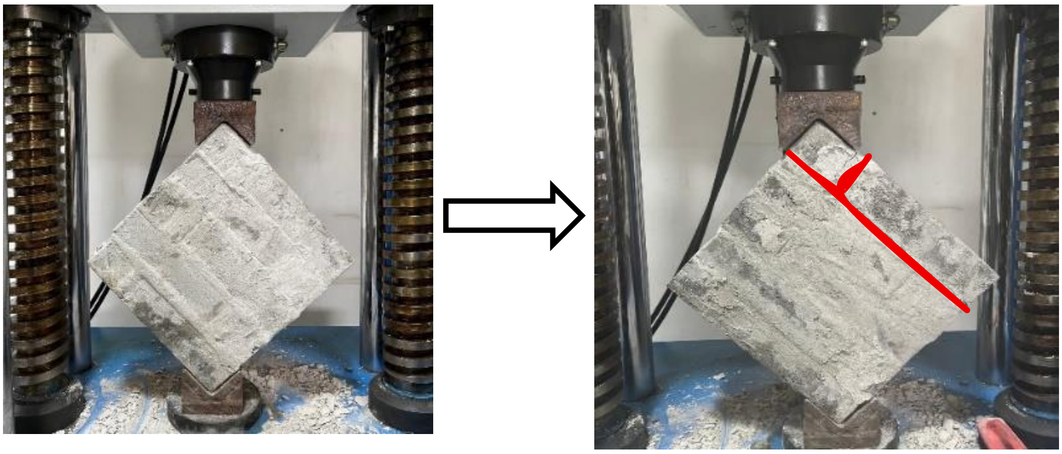
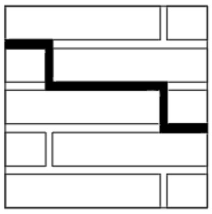
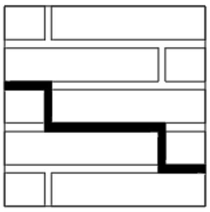
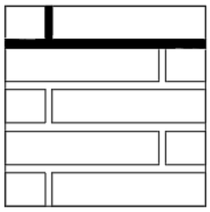
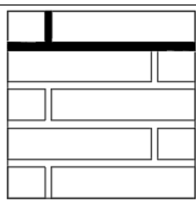


Fig. 15. The process of testing the shear strength of brick wall pairs

Table 4. Crack pattern of shear strength test of brick wall pair

Specimen	Failure mode image	Failure Mode Sketch
PW HDPE A		
SPW HDPE B		
SPW HDPE C		
SPW HDPE D		

The failure modes seen in plastic bricks made of HDPE and different amounts of Recycled Fine Aggregate (RFA) show that the matrix composition has a big effect on how well they hold up. When 100% HDPE specimens break, they do so in a brittle way, with wide fracture planes and abrupt separation under shear stresses. This is because there are no particles to slow down the spread of cracks. The addition of RFA (10% to 30%) changes how failure happens by making the material stiffer and more resistant to internal friction. As the amount of RFA in bricks goes up, they go from being brittle to being more ductile. The cracks become more confined, spread out, and eventually turn into stepwise crushing collapses. This matrix effect is like masonry systems, where (HDPE) layers add shear strength and (RFA) layers make things more ductile by letting more energy escape. RFA works like these stiff inclusions in plastic bricks by making interlocking frictional channels in the HDPE matrix, which makes shear capacity better. If reinforcing fibers were included, such in Fabric Reinforced Cementitious Matrix systems, the shear capacity and ductility may be much better. As the amount of RFA increases, the shear strength and ductility should gradually climb. This will make plastic bricks a more reliable and long-lasting building material that can better resist shear deformation.

4.3.5 Relationship Between Compressive Strength and Shear Strength of Walls

Based on Figure 16, it can be concluded that the addition of RFA to HDPE bricks has been proven to increase the compressive strength value against HDPE bricks at certain levels and increase the shear strength value at but in the SPW HDPE D variation, the shear strength value decreases when applied to brick walls. This can happen because it is less effective in terms of bonding between mortar and bricks on brick walls, even though it has been proven effective for bonding between particles and pores in mortar bricks. In addition, HDPE bricks with RFA mixtures have different properties depending on where the HDPE and RFA come from. RFA in this test has properties that easily absorb water, and HDPE has properties that do not easily absorb water. However, the use of HDPE and RFA with the appropriate levels will still be able to produce quality construction products. From the polynomial regression calculations, it can be concluded that the optimal specimen recommended in this study is SPW HDPE D. At this level, the compressive strength value obtained was 47.43 MPa, and the shear strength value was 47.43 MPa, 0.625 MPa. The relationship graph of the compressive strength of bricks with the shear strength of brick masonry walls can be seen in Figure 16. This shows the values of the shear strength coefficient and shear strength that are close to.

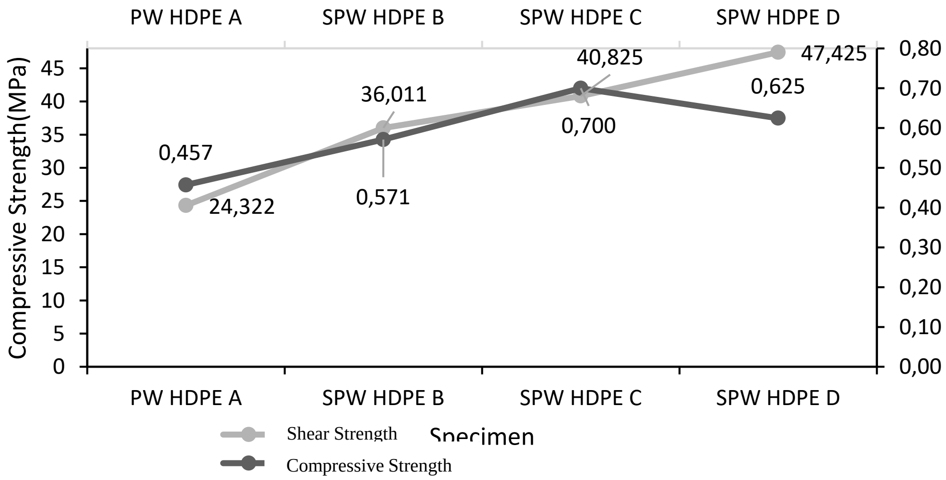


Fig. 16. Graph of the relationship between the compressive strength of bricks and the shear strength of brick wall pairs

Depicts the correlation between the compressive strength of individual plastic bricks and the shear strength of their respective wall pairs. The graph shows a mostly positive connection, suggesting that a rise in the compressive strength of the bricks corresponds with an enhancement in the shear strength of the wall pairs. This tendency indicates that more robust bricks improve interlocking and bonding efficacy within the wall structure, hence augmenting its resistance to lateral stress. The augmentation of shear strength is not always immediately proportionate to the escalation of compressive strength, presumably attributable to other influencing elements like material compatibility, surface roughness, and brick morphology, which impact the cohesion among bricks in a wall assembly. The graph underscores the need to maximize compressive strength to enhance structural performance in brick wall systems.

5. Conclusion

Based on the results of experimental testing and comprehensive data analysis from three investigative studies, plastic waste-based composite bricks have demonstrated considerable potential as lightweight, durable, and sustainable construction materials. These properties make them particularly suitable for floating house applications, where low density and high water resistance are critical performance criteria. The integration of High-Density Polyethylene (HDPE) with other plastic wastes and recycled aggregates presents an innovative, eco-friendly alternative to conventional masonry materials, effectively addressing the dual challenges of construction material demand and plastic waste management.

- Bricks composed entirely of HDPE achieved a compressive strength of 30.43 MPa with zero water absorption, indicating outstanding durability. The optimal blend, designated BP2 (80% HDPE and 20% PET), achieved the best balance between mechanical strength and waste utilization, with the lowest recorded water absorption of 0.3982%. HDPE–PET composites also exhibited the lowest densities among all tested mixtures, rendering them ideal for lightweight and moisture-sensitive applications.
- The incorporation of Recycled Fine Aggregate (RFA) into HDPE matrices significantly enhanced compressive strength, with a maximum value of 47.43 MPa achieved at a 70:30 HDPE–RFA ratio (sample SPW HDPE D). Water absorption decreased as RFA content increased, reaching 0.7508% at 20% RFA. Among all composite types, HDPE–RFA mixtures exhibited the highest densities, thereby improving structural mass and stability—an advantageous property for load-bearing applications.
- The addition of 10% Polypropylene (PP) improved compressive strength to 30.13 MPa; however, higher PP proportions led to a decline in strength due to partial incompatibility between the polymers. Water absorption increased with higher PP content, reaching 1.631% at 20% PP, which limits the suitability of these blends for moisture-exposed environments. The density of HDPE–PP composites rose progressively with PP content, attaining 0.1039 g/cm^3 at 30% PP, situating them as intermediate materials between the HDPE–PET and HDPE–RFA groups.
- Furthermore, shear strength assessments revealed that plastic composite bricks outperformed conventional red clay bricks, achieving shear values of up to 4.3 MPa. Overall, these findings affirm the feasibility of HDPE-based composite bricks as sustainable, high-performance alternatives to traditional construction materials. By transforming plastic waste into structurally reliable and environmentally responsible building units, this research supports the advancement of circular economy principles in the construction industry.

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