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Research article

Melted Polyethylene Terephthalate Plastic Waste as a Binder in the Manufacture of Sand Bricks

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Abstract: In the province of D.I. Yogyakarta, Indonesia, plastic waste reaches 26.37% of the province's total waste. Plastic waste ranks second after food waste. Given this, managing plastic waste for essential building materials, such as sand bricks, is necessary. This study aims to determine the effect of using melted PET waste as a binding material in sand bricks on compressive strength and water absorption. The weight ratios of PET waste to sand used are: 1:2, 1:2.2, 1:2.5, 1:2.9, 1:3.3, 1:4, and 1:5. The test specimen is a 6cm x 6cm x 6cm cube. Each variation consists of 5 test specimens. The tests carried out were absorption testing and compressive strength testing. From the research obtained, the weight ratio of 1:2 to 1:4 is deemed to satisfy the criteria for quality level 3, with a minimum average compressive strength of 4 MPa. The weight ratio of 1:5 meets the requirements of quality level 4 with a minimum average compressive strength of 2.5 MPa. The weight ratio of 1:2 to 1:5 is deemed to satisfy the requisite quality level 1 bricks for walls standards, with a maximum average absorption of 25%. The density of sand bricks with various weight ratios of PET plastic waste to sand is less than that of clay brick masonry, which has a density of 1700 kg/m^3.

Keywords: PET plastic waste; Sand bricks; Compressive strength; Absorption; Density

1. Introduction

Most of the plastic produced is not reprocessed and tends to end up in landfills or become marine waste. Only about 25% of plastic produced globally is reprocessed [1]. Plastic waste can be classified into several types. PET (Polyethylene terephthalate) is used for beverage bottles, LDPE (Low-density polyethylene) is used for trash bags, HDPE (High-density polyethylene) is used for buckets and detergent bottles, PVC (Polyvinyl chloride) is used for plumbing, PP (Polypropylene) is used for food boxes, PS (Polystyrene) is used for toys and disposable tableware, and PE (Polyester) is used for seat belts and conveyor belts [2]. The use of plastic waste in the construction sector aims to overcome environmental issues and to save non-renewable natural resources [3, 4]. Plastic waste can be used as material for making plastic bricks. High-Density Polyethylene (HDPE) and Polypropylene (PP) plastics, which are melted at a temperature of 230 °C, are used as materials for making plastic bricks. The compressive strength of HDPE bricks is higher than that of conventional bricks, and the compressive strength of PP bricks is lower than that of conventional bricks [5].

It is possible to utilise PET waste as both an aggregate and a fibre in the production of concrete. The incorporation of PET waste as an aggregate in concrete does not affect the compressive or flexural strength of the resulting concrete. However, excessive use may impact the quality of the construction [6]. Polyethylene terephthalate (PET) plastic is employed as a coarse aggregate in the production of concrete. The plastic waste derived from PET is melted at a temperature of approximately 300°C to create artificial aggregates. It was observed that as the percentage of coarse aggregate substituted with artificial PET aggregate increased, the compressive strength, flexural strength, and density of the concrete exhibited a corresponding decline. PET aggregate can be employed in the production of lightweight concrete, which is utilized in non-structural or semi-structural applications [7].

Polyethylene terephthalate (PET) waste is employed as a fibre, while low-density polyethylene (LDPE) waste is utilised as a fine aggregate in the production of mortar [8]. The use of shredded PET (polyethylene terephthalate) waste as a substitute for conventional coarse aggregate in the production of concrete is investigated at proportions of 0%, 5%, 10% and 20% by volume [9]. The melted plastic waste, which is a combination of HDPE and LDPE, is employed as a binder in the production of mortar. The use of liquid plastic waste as a binder in mortar has been found to result in superior performance compared to paving with Portland cement [10]. The utilisation of melted plastic waste as a binder represents a contribution to waste reduction. Recycled plastic waste (RPW), including polyethylene bags, sachet water bags, wrappers, and other materials, can be employed as an alternative binder in the production of paving blocks. RPW exhibits thermoplastic properties that permit reforming when melted [11]. The manufacture of sand-plastic composite bricks involves the use of LDPE and HDPE plastic waste in conjunction with sand. LDPE and HDPE plastic waste are melted and combined with sand. The maximum compressive strength achieved was 4.95 MPa, with a plastic waste content of 60% (40% LDPE and 20% HDPE) and a sand content of 40% (25% size 1.18 mm and 15% size 0.5 mm) [12].

Polyethylene terephthalate (PET) is one of the most widely produced polymers globally, with applications in the manufacture of synthetic fibres and bottles. The incorporation of PET fibres into concrete can enhance flexural strength while reducing density, thereby creating a structure that is both lightweight and earthquake-resistant [13]. The utilisation of PET plastic waste and river sand in the production of roof tiles has been demonstrated. Polyethylene terephthalate (PET) waste is employed as a cement substitute in the production of roof tiles. The weight ratio of PET waste to sand employed is 10%:90%, 20%:80%, 30%:70%, 40%:60%, 50%:50%, 60%:40%, and 100%:0%. The PET waste is melted at 230°C and subsequently combined with sand to create roof tiles. The highest compressive strength was observed at a weight ratio of 40%:60%, with a value of 1.5868 MPa. The utilisation of PET waste as a cement substitute has been observed to result in enhanced compressive strength and absorption properties [14]. Polyethylene plastic waste is used as a binder in making sand bricks. The ratio of plastic waste and sand used is 1:3, 1:4, and 1:5 based on weight ratio. Plastic waste is melted at a temperature of 105°C to 115°C, then sand is added and mixed until homogeneous. The highest compressive strength occurred in a ratio of plastic waste and sand of 1:4. Absorption for ratios 1:3, 1:4, and 1:5 is zero [15]. The utilisation of PET plastic waste and sand in the production of plastic sand bricks represents a novel approach to the utilisation of these materials. The weight ratio of PET plastic waste to sand is 1:2, 1:3, and 1:4. The PET plastic waste is melted at a temperature range of 180°C to 200°C and mixed with sand to create plastic sand bricks. The resulting plastic sand bricks exhibit low porosity, a lightweight composition, and a higher compressive strength than conventional clay bricks [16].

The utilisation of PET plastic waste and sand as materials for the production of tiles has been demonstrated. The melted PET plastic waste is combined with sand, agitated, and subsequently shaped into tiles. The proportion of PET plastic waste utilised is 20%, 30% and 40%. The compressive strength of tiles manufactured using PET plastic waste is superior to that of conventional bricks and concrete blocks [17]. Bricks are manufactured from melted PET plastic waste and crushed glass. The mass ratio of PET plastic waste to crushed glass employed is 20%:80%, 30%:70%, and 40%:60%. The findings of the research indicated that the tensile strength of bricks produced from a mixture of melted PET plastic waste and crushed glass was 70.15% higher than that of conventional clay bricks, while the compressive strength was 54.85% higher [18]. Mixed plastic waste from polyethylene terephthalate (PET) and high-density polyethylene (HDPE), melted at a temperature of 257-315°C, is combined with sand in varying weight ratios, specifically 1:2, 1:3, 1:4, and 1:5, to create hollow blocks. The mean compressive strength of the ratios 1:2, 1:3, 1:4, and 1:5 is 3.87 MPa, 3.41 MPa, 3.29 MPa, and 3.09 MPa, respectively. The absorption ratios for the 1:2, 1:3, 1:4, and 1:5 mixtures were found to be 1.67%, 2.51%, 2.62%, and 2.81%, respectively [19]. Three types of waste are employed as substitutes for cement in mortar production: sawdust, shredded polyethylene terephthalate (PET) plastic bottles, and shredded used diapers. The proportion of cement substituted with waste material is 0%, 5%, 10%, 15%, and 20% by weight. The compressive strength of mortar with cement substitution using shredded PET plastic bottles is observed to be higher than that of the other materials [20]. In the manufacture of sand bricks, plastic waste, glass bottle waste, and paper waste are employed as alternative materials. The plastic waste employed is a combination of polyethylene terephthalate (PET), high-density polyethylene (HDPE), and low-density polyethylene (LDPE). The compressive strength obtained exceeds the requisite compressive strength for masonry. The absorption values are below the maximum absorption requirements for sand bricks [21].

In the province of D.I. Yogyakarta, Indonesia, plastic waste represents 26.37% of the province's total waste. This is the second most significant component of the waste stream after food waste [22]. Given this context, it is necessary to manage plastic waste for use in the production of sand bricks, a material with a clear and pressing need for such materials. This study aims to determine the effect of using melted PET waste as a binding material in sand bricks on compressive strength and water absorption.

2. Materials and Methods

The PET waste utilised in this process is derived from mineral water bottles sourced from the province of D.I. Yogyakarta in Indonesia with a specific gravity of 1.3. The sand utilized in this process is sourced from the riverbeds of the Indonesian province of D.I. Yogyakarta with a specific gravity of 2.6 and a size of 0.15 mm - 5 mm. The weight ratios of PET waste to sand employed are as follows: 1:2, 1:2.2, 1:2.5, 1:2.9, 1:3.3, 1:4, and 1:5. These ratios are based on trial results. The weight ratio of PET waste to sand exceeds 5; consequently, the melted PET plastic is insufficient to bind the sand. The test specimen is a cube with dimensions of 6 cm on each side, as shown in Figure 2. Each variant comprises five test specimens. The methodology employed for this research project is as follows:

a. Cleaning: The collected PET Plastic bottles were cleaned to remove adhering dirt.
b. Shredding: The collected PET Plastic bottles were shredded into small pieces to speed up the melting process.
c. Weighing: Weighing PET plastic bottles and sand according to the needs of each variation.
d. Melting: The shredded PET plastic bottle waste was melted.
e. Mixing: The sand and melted PET plastic bottle waste were mixed and stirred until a homogeneous mixture was achieved.
f. Molding: The mixtures were moulded on a wooden mould.
g. Curing: The test specimens were removed from the mould after 24 hours.

The methodology employed in the production of sand bricks is illustrated in Figure 1. The tests carried out were absorption testing and compressive strength testing. Compressive strength testing based on ASTM C109 using a digital compression test machine with a capacity of 2000 kN. The hardened sand bricks are weighed, then soaked in water for 24 hours. The sand bricks are removed from the soaking, the surface is dried, and then weighed. Absorption is calculated by subtracting the weight of the sand bricks after soaking from the weight of the sand bricks before soaking, then dividing by the weight of the sand bricks before soaking.

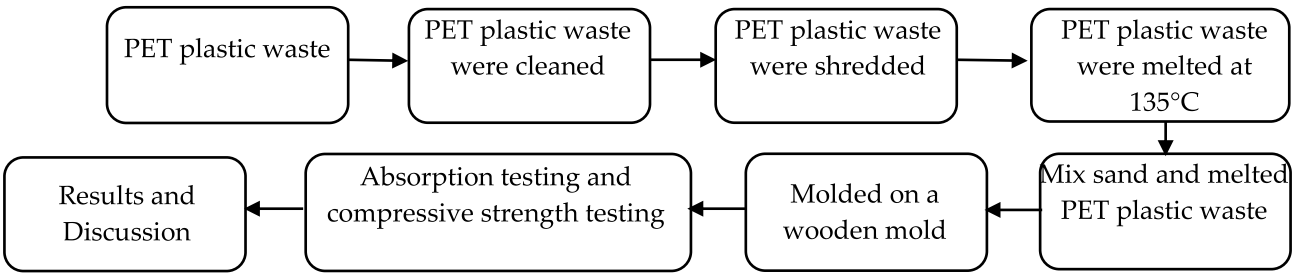

Figure 1. Process of making sand bricks

Figure 2. Sand bricks

3. Results and Discussion

3.1 Compressive strength of sand bricks

The average compressive strength of sand bricks with various weight ratios of PET plastic waste to sand is shown in Table 1 and Figure 3.

Table 1. Compressive strength of sand bricks

Weight ratio of PET plastic waste to sand	Average compressive strength (MPa)	P-Value
1:2	4.79	
1:2,2	4.05	
1:2,5	4.77	
1:2,9	4.29	0.0517
1:3,3	4.64	
1:4	4.00	
1:5	2.56	

Table 1 and Figure 3 illustrate that the highest compressive strength is observed at a weight ratio of PET plastic to sand of 1:2. In contrast, the lowest is observed at a weight ratio of 1:5. The compressive strength of the weight ratio of 1:2 to 1:4 exhibits fluctuations between 4.79 MPa and 4 MPa. This result is not much different from the report of Maunahan and Adeba [19]. This phenomenon can be attributed to the continued utilisation of a relatively rudimentary compaction technique, namely the use of a trowel. The compressive strength at a weight ratio of 1:5 is low due to the insufficient quantity of melted PET plastic to bind the sand.

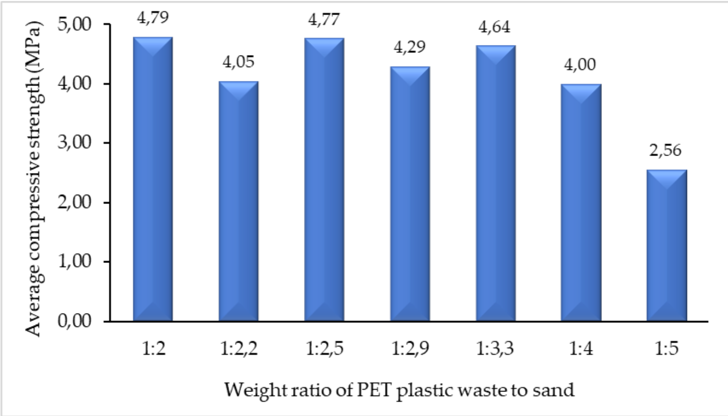

Figure 3. Compressive strength of sand bricks

Following the Indonesian National Standard SNI 03-0349-1989 [23] about concrete bricks for walls, the weight ratio of 1:2 to 1:4 is deemed to satisfy the criteria for quality level 3, with a minimum average compressive strength of 4 MPa. The weight ratio of 1:5 meets the requirements of quality level 4 with a minimum average compressive strength of 2.5 MPa. It can therefore be concluded that sand bricks with various weight ratios of PET plastic waste to sand meet the compressive strength requirements. From the ANOVA analysis, the P-value was obtained as $0.0517 > 0.05$, which shows that the weight ratio of PET plastic waste to sand used does not have a significant effect on compressive strength.

3.2 Absorption of sand bricks

The average absorption of sand bricks with various weight ratios of PET plastic waste to sand is shown in Table 2 and Figure 4.

Table 2. Absorption of sand bricks

Weight ratio of PET plastic waste to sand	Average absorption (%)	P-Value
1:2	8,69	
1:2,2	8,57	
1:2,5	8,79	
1:2,9	8,55	0.84016
1:3,3	7,62	
1:4	7,93	
1:5	9,18	

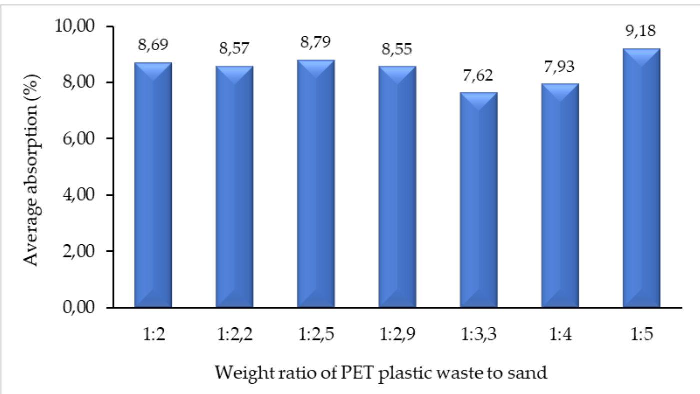

Figure 4. Absorption of sand bricks

Table 2 and Figure 4 indicate that the highest absorption is 9.18%, while the lowest is 7.62%. Following the Indonesian National Standard SNI 03-0349-1989 [23] about concrete bricks for walls, the weight ratio of 1:2 to 1:5 is deemed to satisfy the requisite quality level 1 standards, with a maximum average absorption of 25%. Following the Indonesian National Standard SNI 15-2094-2000 [24] about clay bricks, the maximum permissible absorption is 20%. In light of the findings above, it can be posited that sand bricks comprising varying proportions of PET plastic waste satisfy the requisite absorption standards. From the ANOVA analysis, the P-value was obtained as 0.84016 > 0.05, which shows that the weight ratio of PET plastic waste to sand used does not have a significant effect on absorption.

3.3 Density of sand bricks

The average density of sand bricks with various weight ratios of PET plastic waste to sand is shown in Table 3 and Figure 5.

Table 3. Density of sand bricks

Weight ratio of PET plastic waste to sand	Average density (kg/m^3)	P-Value
1:2	1140	
1:2,2	1102	
1:2,5	1076	
1:2,9	958	0.00003
1:3,3	958	
1:4	885	
1:5	994	

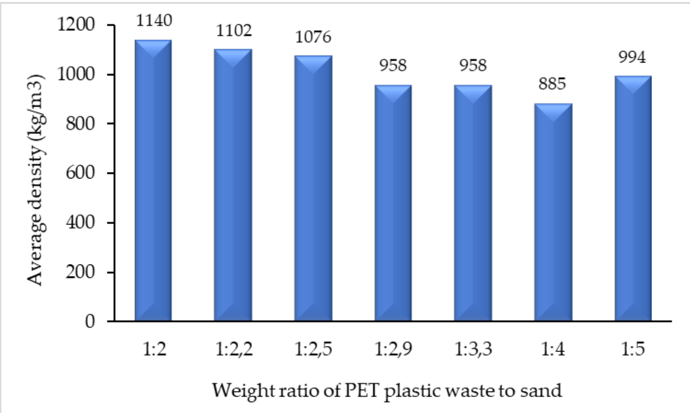

Figure 5. Density of sand bricks

As illustrated in Table 3 and Figure 5, the highest density is observed at weight ratios of PET plastic waste to sand of 1:2. In contrast, the lowest density is observed at weight ratios of 1:4. This phenomenon can be attributed to the fact that the melted PET plastic content at weight ratios of 1:2 is the highest, while at weight ratios of 1:4, it is the lowest. The density of the sand bricks produced in the course of the experiment ranged from 885 to 1140 kg/m^3. The density of sand bricks with various weight ratios of PET plastic waste to sand is less than that of clay brick masonry, which has a density of 1700 kg/m^3. From the ANOVA analysis, the P-value was obtained as 0.00003 < 0.05, which shows that the weight ratio of PET plastic waste to sand used has a significant effect on density.

4. Conclusions

The incorporation of melted PET plastic waste as a binder in the production of sand bricks effectively enhances the material's properties, ensuring it meets necessary construction standards, including compressive strength and water absorption requirements. The addition of PET plastic, which acts as a bonding agent, significantly contributes to achieving the required compressive strength, thereby making these bricks structurally sound and suitable for various building applications. Moreover, the integration of this plastic waste results in sand bricks with improved absorption characteristics, aligning with established building material standards. Another advantageous property of utilizing PET plastic as a binder is the resultant decrease in the bricks' overall weight compared to traditional clay-based bricks, which can facilitate easier handling and reduce transportation costs. This approach not only provides an innovative solution to plastic waste management but also offers a sustainable and potentially cost-effective alternative to conventional building materials.

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