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Concrete bricks substituted with fly ash, PET (polyethylene terephthalate) plastic waste, and rice husk ash

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ABSTRACT

Polyethylene terephthalate (PET) plastic waste, fly ash, and rice husk ash are still underused. This study examined how combining the three substitute materials affects the compressive strength and water absorption of concrete bricks, and compared three ways of distributing PET in the mix. In a quantitative laboratory experiment, four mixes with a constant water-cement ratio of 0.25 were made: a control without waste (variation A), PET mixed evenly (variation B), PET placed in the center (variation C), and PET placed in the center under heavy compaction (variation D). Variations B, C, and D contain 200 g of PET, 100 g of fly ash, and 50 g of rice husk ash, with cement reduced by 20% and sand by 25%. Bricks measuring 20 × 10 × 6 cm^3 were cured for 28 days and tested following SNI 03-0691-1996. Variation B performed best, with a compressive strength of 33.80 MPa and water absorption of 5.78%, while the control reached only 11.96 MPa and 13.14%. Variation C gave 29.12 MPa and 5.70%. Variation D fell to 9.36 MPa and 8.00% because of the heavy compaction. Only variations B and C meet the quality requirements for concrete bricks. A preliminary cost estimate puts production about 11% below that of conventional bricks. Evenly distributed PET appears to be the key to turning these wastes into strong, sustainable concrete bricks.

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1. INTRODUCTION

Plastic waste keeps growing as populations grow. According to Indonesia's National Waste Management Information System, plastic made up 18.5% of all waste in 2023, the second-largest category. Only 15.24% of waste has been reduced, and 34.07% was still unmanaged [1]. Because plastic resists natural decomposition, plastic is buried in soil blocks, water infiltration and sunlight, lowers soil fertility, and adds to waterlogging and floods [2,3]. Large quantities also reach the oceans [4]. Common responses include cutting single-use plastics, sorting waste, and applying the 3R principles (reduce, reuse, recycle), sometimes extended to 5R [5]. Polyethylene terephthalate (PET), the plastic used for most drinking water bottles, is one of the most frequently found types. UIN Walisongo collects PET bottles every day, but processing remains limited because third parties handle them. A more direct use is needed, and construction is one possible outlet.

Concrete paving blocks are made from Portland cement or a similar hydraulic binder, water, and aggregate, with or without additives that do not reduce block quality [6]. Adding PET to paving blocks has been reported to increase strength, replace virgin materials, and cut plastic waste [7].

Sibuea and Tarigan, for example, added 0.25% – 1.0% plastic fiber to the mix and found that compressive strength rose by as much as 42.23% at 0.5% [8]. Other researchers have also tested PET bottles as an additive in paving blocks [9,10].

Fly ash and rice husk ash, meanwhile, are pozzolans. Their reactive silica and alumina combine with the calcium hydroxide released during cement hydration and form calcium silicate hydrate (C-SH), which adds strength [11,12]. Fly ash is the residue of coal combustion in power plants [13]; Rice husk ash comes from agricultural waste and is rich in silica [14]. Studies report that replacing part of the cement with rice husk ash lowers absorption and increases compressive strength [15-17].

Here, PET waste, fly ash, and rice husk ash are combined to replace part of the cement and sand in concrete bricks. Three ways of placing the PET are compared: mixed evenly, concentrated in the center, and concentrated in the center under heavy compaction. The study has three objectives: (1) to determine how the three wastes together affect compressive strength and water absorption; (2) to see whether the PET distribution strategy changes performance; and (3) to compare the modified bricks with a control containing no waste, as a measure of how well the waste is put to use. The work was done at laboratory scale, and only compressive strength and water absorption were measured.

2. RESEARCH METHODS

This was a laboratory experiment with a quantitative approach, designed to show how changes in material composition affect the physical and mechanical properties of concrete bricks.

2.1. Location and Materials

The specimens were prepared in the UIN Walisongo Semarang laboratory, and the compressive strength and water absorption tests took place at the Materials and Construction Laboratory of Diponegoro University. PET came from mineral water bottles collected at the Faculty of Science and Technology, UIN Walisongo. Fly ash came from the Jepara Power Plant, and rice husk ash was made by burning agricultural waste. The remaining materials were commercial cement, clean sand free of organic impurities, and water. Equipment consisted of scissors, a pot, a knife, brick molds, a plastic bucket, a scale, a mask, and a stopwatch.

2.2. Mix Design Variations

Four mixes were prepared, all with a water-to-cement (w/c) ratio of 0.25, so that any difference in performance would come from the substitute materials and not from the water content (Table 1). Variation A was the control, with no waste. Variations B, C, and D share one base mix of 800 g cement, 1,500 g sand, and 200 ml water, plus 200 g PET, 100 g fly ash, and 50 g rice husk ash. They differed only in where the PET went: mixed evenly (B), placed in the center (C), or placed in the center and pressed hard (D).

Table 1. Concrete brick composition by variation.

Variations	Sand (g)	Cement (g)	Water (ml)	PET (g)	Fly ash (g)	Husk ash (g)	w/c	PET treatment
A	2,000	1,000	250	-	-	-	0.25	Control (no waste)
B	1,500	800	200	200	100	50	0.25	Mixed homogeneously
C	1,500	800	200	200	100	50	0.25	In the middle
D	1,500	800	200	200	100	50	0.25	In the middle, compact it hard

Cement and sand were reduced in variations B, C, and D so that the mix volume stayed close to that of the control. From the mass and density of each material [11,18], the control mix came to roughly 1.336 cm^3 and variations B, C, and D to roughly 1.363 cm^3. Fly ash and rice husk ash together (150 g) equal 18.75% of the cement mass (800 g), under the usual 30% ceiling for cement replacement [11,19].

2.3. Making Test Objects

The PET was cut into pieces of about 1 cm. Sand went into a bucket first, followed by cement added slowly and water added a little at a time while stirring. Fly ash, rice husk ash, and PET were added last, and mixing continued until the mixture was uniform. In variations C and D the PET was placed in the center of the specimen, and in D it was pressed hard to compact it. The mixture was cast in a 20 cm × 10 cm × 6 cm mold and compacted by hand pressure. After demolding, the bricks were cured for 28 days: they were sprinkled with water during the first week and then left to air-dry until day 28, since curing governs how completely the cement hydrates [20]. The specimens were kept outdoors, sheltered from rain and direct sun.

2.4. Testing

Compressive strength was tested at 28 days with a compression machine. Each specimen was loaded to failure at a rate adjusted so that failure occurred within 1 – 2 minutes. Strength was calculated with Equation (1).

$$f_c = \frac{k \times P}{A} \tag{1}$$

Here f_c is the compressive strength (MPa), P the maximum load (N; the load in tonnes multiplied by 9.81 m/s^2), A the loaded area (200 mm × 100 mm = 20,000 mm^2), and k a thickness correction factor of 1.06.

Water absorption was also tested at 28 days. Specimens were soaked for 24 hours until saturated and weighed to obtain the wet weight (A). They were then dried in an oven at 105°C for about 24 hours, until two consecutive weighings differed by no more than 0.2%, and weighed again for the dry weight (B). Water absorption was calculated with Equation (2):

$$Absorbency(\%) = \left(\frac{(A-B)}{B}\right) \times 100\% \tag{2}$$

Results were checked against the physical requirements for concrete bricks in SNI 03-0691-1996 [6] (Table 2). Abrasion resistance was not tested.

Table 2. Physical property requirements for concrete bricks according to SNI 03-0691-1996.

Grade	Average compressive strength (MPa)	Minimum compressive strength (MPa)	Max. average water absorption (%)	Usage
A	40	35	3	Road
B	20	17	6	Parking lot
C	15	12.5	8	Pedestrian
D	10	8.5	10	Parks and other uses

3. RESULTS AND DISCUSSIONS

3.1. Material Composition

By mass of solids, the control mix was 66.7% sand and 33.3% cement. Variations B, C, and D contain 56.6% sand, 30.2% cement, 7.5% PET, 3.8% fly ash, and 1.9% rice husk ash. Compared with the control, they therefore used 20% less cement, 25% less sand, and 20% less water. This matters because cement production consumes a large deal of energy and contributes to greenhouse gas emissions [21], and sand extraction can damage the environment. PET stands in for part of the sand as filler, while fly ash and rice husk ash take over part of the cement's binding role as pozzolans.

3.2. Water Absorption

Figure 1 shows the specimens after curing; the test results are in Table 3 and Figure 2.



Figure 1. PET waste-based concrete brick specimens (from left to right: variations D, C, B, and A).

Table 3. Results of water absorption and compressive strength tests on concrete bricks.

Variation	Wet weight (g)	Dry weight (g)	Water absorption (%)	Max. load (ton)	Compressive strength (MPa)
A	2,419	2,138	13.14	23	11.96
B	2,453	2,319	5.78	65	33.80
C	2,521	2,385	5.70	56	29.12
D	2,416	2,237	8.00	18	9.36

The control (A) absorbs the most water, 13.14%, which points to a porous, loosely packed structure. Variations B and C absorbed only 5.78% and 5.70%, about 56% – 57% less than the control. Variation D absorbed 8.00%, more than B and C but still below the control (see Figure 2 (a)). PET does not take up water, and fly ash and rice husk ash act as micro-fillers that occupy the voids between particles, which is consistent with this drop [16,22]. Lower absorption means fewer connected open pores, so the bricks should cope better with moisture and weathering.

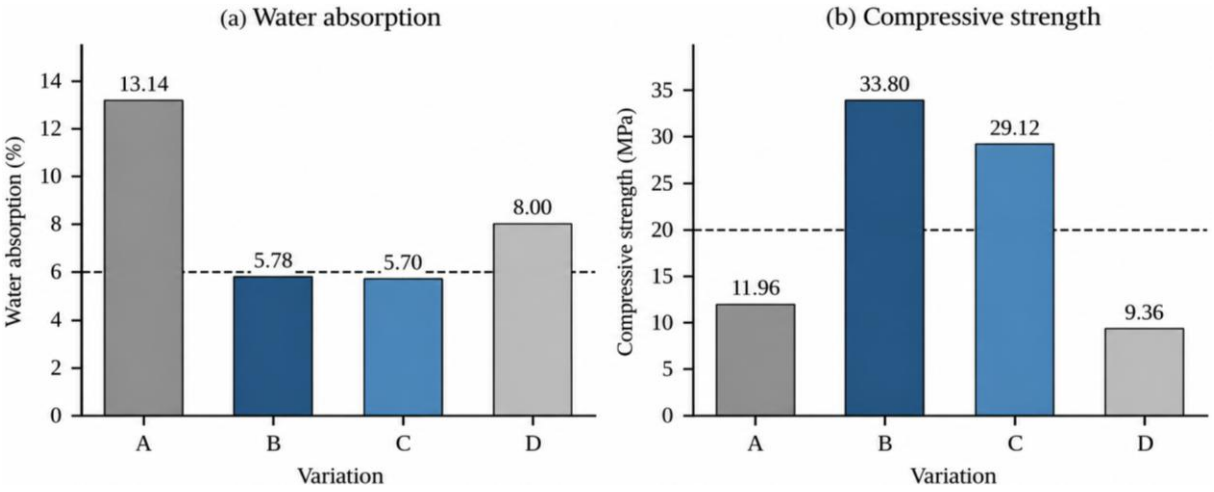


Figure 2. Water absorption (a) and compressive strength (b) of concrete bricks. The dashed line indicates the quality B limit according to SNI 03-0691-1996 (maximum water absorption of 6%; minimum average compressive strength of 20 MPa).

3.3. The Compressive Strength

The control reached only 11.96 MPa. The very low water-cement ratio (0.25) probably explains this: hydration and compaction were likely incomplete, leaving weak bonds between particles. Variation B reached 33.80 MPa, about 2.8 times the control, and variation C reached 29.12 MPa, about 2.4 times (see Figure 2 (b)). C was roughly 13.8% weaker than B. Placing PET only in the center apparently spreads load less effectively than PET spread throughout, so the specimen as a whole is less sound.

Variation D is the surprise. Although its composition matched B and C, its strength was 9.36 MPa, about 21.7% below the control. Pressing the PET hard probably caused micro-cracks or weak zones inside the specimen, so poor handling can undo the benefit of the materials. Among A, B, and C, absorption and strength move in opposite directions: the denser the brick, the lower the absorption and the higher the strength. D broke that pattern, since it absorbed less water than the control yet was weaker, which suggests strength depends on structural integrity and not on porosity alone.

3.4. The Role of Fly Ash, Rice Husk Ash, and PET

Fly ash is not cementitious on its own. It reacts with the calcium hydroxide produced by cement hydration and forms additional binders, mainly calcium silicate hydrate (C-S-H) and calcium aluminate silicate hydrate (C-A-S-H) [11,23], as shown in Equation (3).

$$\text{Fly ash } (SiO_2, Al_2O_3) + Ca(OH)_2 + H_2O \rightarrow \text{C-S-H} + \text{C-A-S-H} \quad (3)$$

Rice husk ash is rich in amorphous silica; burning at 600°C – 900°C is reported to give an amorphous silica content of 87% – 97% [24]. In the presence of OH^- ions this silica dissolves into $H_3SiO_4^-$ ions (Equation 4), which then react with Ca^{2+} to form C-S-H gel [25,26].

$$SiO_2 + H_2O + OH^- \rightarrow H_3SiO_4^- \quad (4)$$

The pozzolanic reactions add binding gel and densify the microstructure. This helps explain why cutting cement by 20% in variation B does not cost any strength; its compressive strength was in fact far above the control's. PET works as a filler that does not absorb water and, when spread evenly, helps carry load and lowers porosity. The three materials therefore work well together only if they are well distributed, which makes the PET mixing strategy a decisive factor.

3.5. Quality based on SNI 03-0691-1996

The results were compared with the requirements in Table 2 and summarized in Table 4. Only variations B and C qualify as concrete bricks. B suits areas with moderate traffic (grade B), and C suits lighter loads. A and D are not recommended because they fall short of the minimum strength.

Table 4. Quality classification of concrete bricks based on SNI 03-0691-1996.

Variation	Water absoption (%)	Compressive strength (MPa)	Compressive strength classification	Water absorption vs. SNI	Suitability
A	13.14	11.96	Below grade C	Does not meet (more than 10%)	Not suitable
B	5.78	33.80	Quality B	Fulfil	Suitable
C	5.70	29.12	Approaching B quality	Fulfil	Suitable
D	8.00	9.36	Below grade C	Fulfil	Not suitable

Two caveats apply. Each variation is represented by a single test result, and the composition changes (cement, sand, water, PET, fly ash, and rice husk ash) were made together, so the contribution of each material cannot yet be separated. The quality assessment is therefore indicative and should be confirmed by testing replicate specimens as SNI requires.

3.6. Cost Estimation and Potential Waste Utilization

Table 5 gives the estimated production cost per square meter. Composite bricks are estimated at Rp. 80,000 per m^2, roughly 11% less than conventional bricks (Rp. 90,000). The savings come from cement (Rp. 6,000), sand (Rp. 10,000), and production energy (Rp. 2,000), which more than offsets

the Rp. 8,000 added for PET, fly ash, and rice husk ash. The estimate is illustrative and excludes the cost of a plastic shredder.

Table 5. Estimated production cost per 1 m^2 of concrete brick.

Component	Conventional concrete brick (Rp)	Composite concrete brick (Rp)
Cement	30,000	24,000
Sand	40,000	30,000
PET plastic waste	-	5,000
Fly ash	-	2,000
Rice husk ash	-	1,000
Production energy	20,000	18,000
Total cost	90,000	80,000

On waste utilization, the Semarang City waste data used in this study puts plastic at about 13% of 1,229 tons of daily waste, or roughly 160 tons (160,000 kg) per day. One 20 cm × 10 cm × 6 cm brick contains 200 g of PET and covers 0.02 m^2, so 1 m^2 takes 50 bricks, or 10 kg of PET. If all of that plastic were used, about 800,000 bricks could theoretically be made each day, covering roughly 16,000 m^2. This is a theoretical ceiling, since not all plastic is PET or can be recovered, but it shows how much plastic could be converted into construction products.

4. CONCLUSION

Combining PET waste, fly ash, and rice husk ash to replace cement and sand raised the compressive strength and lowered the water absorption of concrete bricks relative to the waste-free control. Variation B (PET mixed evenly) performed best, at 33.80 MPa and 5.78% absorption, against 11.96 MPa and 13.14% for the control. Even distribution of PET worked better than central placement (variation C: 29.12 MPa; 5.70%), and heavy compaction of the PET (variation D: 9.36 MPa; 8.00%) lowered performance. By SNI 03-0691-1996, only B and C are suitable as concrete bricks, with B appropriate for moderate-traffic areas. A preliminary estimate puts production cost about 11% below that of conventional bricks.

Future work should cover (1) replicate specimens, durability tests (weathering and wet-dry cycles), abrasion resistance, tensile strength, and TCLP testing for outdoor use; (2) other proportions of PET, fly ash, and rice husk ash to find the optimum mix, together with material characterization; and (3) a life cycle assessment and cost-benefit analysis to confirm long-term technical, economic, and environmental feasibility.

AUTHOR CONTRIBUTIONS

Nana Misrochah: Conceptualization, methodology, investigation, material preparation, specimen fabrication, laboratory testing, data curation, formal analysis, preliminary cost estimation, visualization, writing—original draft, and writing—review and editing. The author approved the final manuscript and accepts responsibility for the accuracy and integrity of the work.

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The authors declare that no AI tools were used in preparing this manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data supporting this study are included in the article. No separate datasets are available.

ETHICAL APPROVAL

Ethical approval was unnecessary, as no humans or animals were involved.

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