Processing of recycled waste PET (polyethylene terephthalate) plastics bottle into for the lightweight and reinforcement bricks

D Alighiri1,*, M N Yasin1, B Rohmawati1 and A Drastisianti2

1 Chemistry Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia
2 Department of Chemistry Education, Faculty of Sciences and Technology, Universitas Islam Negeri Walisongo Semarang, Indonesia

*Corresponding author: dante_alighiri@mail.unnes.ac.id

Abstract. PET (polyethylene terephthalate) waste is a plastic bottle waste that difficult to recycle in large scale, so it was causing environmental pollution. In this research, PET waste used as a main material of bricks by using the mix design method. The mix design method used includes cutting of PET waste, melting of PET waste, mixing with other materials, and molding the materials. This research used four variations of PET waste added by cement and sand to find the ideal composition that mentioned by SNI (Indonesia National Standard). The ideal composition of brick is solid plastic: cement: sand volume ratio is 66:22:12. The result of this research showed that brick quality is ideal, which was characterized by FT-IR and SEM. This composition has 0% of water absorbency, the compressive strength is 75 Kg/cm², water absorbency of SNI brick is under 20%, and the compressive strength is between 60-100 Kg/cm².

1. Introduction

The plastic serves a significant use in daily life, but after being used their just to be thrown into the environment for an endless trip without aimless, leaving a traces of dangerous chemicals. Plastics find use in many products because they are robust, lightweight, easy to mold, and simple to produce. Accordingly, plastic consumption has grown steadily over the last 50 years [1-2]. The conveniences with which plastic can be used in increasingly distinct new applications will encourage increasing usage in the future. Recovery and recycling have not reflected the current consumption producing in massive accumulation over the years that aggravated the disposal problem and adding on to the environmental challenge. Growth in recycling plastic after end-of-life is slow, yielding in an increase in net disposal in the environment [2]. One type of plastic waste is PET plastic.

PET (Polyethylene terephthalate) is the source material for packaging, mainly for bottles with drinking consumables (water, milk, lemonades, and so on). From 2008 to 2013, there was an annual growth rate of plastic water bottle consumption of 6.2% [3]. A large proportion of PET plastic bottles is discarded after first use. Recycling PET plastic bottles still lags behind their production. In 2005 only 35% of all PET plastic bottles in Europe were recovered [4]. Waste from PET plastic bottles is hard to decompose, so that causes various problems. This waste is hard to be processed because of its massive amount, it's inefficient to be recycled, and its health effects [5-7].
A strong stream of growing literature suggest recycling plastic waste in construction materials [8]. Mixing plastic in construction materials is an environmentally friendly method of disposal, and it absorbs desirable properties in the finish products making favorable economic sense. For example, PET particles reduce the requirement of fine aggregate, increase resistance to corrosion, and make the concrete lighter [9-14]. This provides evidence that the addition of PET plastic into construction materials in the form of plastic flakes can produce fine aggregate [15].

One of the concern is the presence of plastic in construction material, especially bricks that may reduce the compressive strength (CS). However, empirical evidence eases such concern as CS of plastic-embedded-concrete and bricks are still quite high [16]. Siddique et al. (2008) was observed a 17% reduction in CS of concrete containing 10% plastic [17]. Among physical parameters, smaller the plastic granules, higher is the CS [18]. However, variation in CS all types of plastic is nominal. In short, adding of waste plastic does not reduce the CS, whereas, it increase energy efficiencies, and reduces the density of the construction materials [19].

Many studies have developed different methodologies for reusing waste plastics, especially in bricks mixtures, although it seems to still be in the field of research and development [20]. The use of massive recycled plastic in environmental friendly, such as bricks can lead to the management of sustainable waste plastic material [21]. Although results in several studies have shown hope, this technology has not found adoption in commercial-level applications [22]. Further research is thereby necessary for improving properties of the end products and increasing the percentage of plastic in bricks. In the other hand, the use of durable and cheap materials is also a problem, conventional brick generally uses high heat and produces a lot of CO₂ in the bolt [23].

One solution to process PET plastic bottles effectively and efficiently is by making plastic as an alternative brick [5,6,24-28] with the mix design method [29-32], before this, PET also has been used as an additive asphalt [30,33]. This paper introduces an experimental to the process of recycled waste PET plastic bottles into for the lightweight and reinforcement bricks. This novel bricks must have conventional brick standards according to Indonesia National Standard (Standar Nasional Indonesia or SNI), including compressive strength and water absorption [23,34-37]. This experiment is intended to find the ideal composition to obtain bricks according to SNI.

2. Methods
2.1. Material
The materials classified under the number symbol (1) PETE shown is a type of Polyethylene Terephthalate (PET) plastic. The mortars were made with: Portland cement (PCC/Portland Composite Cement) from Holcim and siliceous sand type from local construction material.

Preparation of PET aggregates requires several steps. Firstly, we were collected waste from PET bottle from the municipal solid waste dump surrounding in Semarang City, Indonesia, for studies. PET bottles were collected and cut into flakes. These bottles then pre-washed before passing through a shredder and transformed into granular particles, also known as post-consumer PET flakes. To obtain only PET material, bottle caps and label papers were removed. PET bottles to sizes 1–4 mm by applying a thermal process to shredded PET bottle particles. The density, water absorption, and melting point of the waste PET were 1.34 g/cm³, 0.17%, and 250 °C, respectively.

2.2. Brick molding
The manufacture of plastic brick molder used material from stainless steel 304. This material has durability in the heating treatment of the dough so that it can accommodate the brick mixture when it is liquid. The size of the stainless steel 304 mold is made based on the SNI, with the provisions of the SNI brick size, as shown in Table 1.
Table 1. Standard size according to SNI 15-2094-1991

| Type | Thick (mm) | Wide (mm) | Long (mm) |
|------|------------|-----------|-----------|
| 1    | 52         | 115       | 240       |
| 2    | 50         | 110       | 230       |

2.3. Mix design

After curing under water for 24 hours, samples of PET plastic bottles were baked in an oven at a slightly higher temperature than the glass transition temperature of respective waste plastic. The samples were baked at 110 °C. The viability level was set in comparison with the performance of a control mortar, consisting of sand aggregates, water, and cement, at a volumetric ratio of 1:4 (cement/aggregate). Table 2 presents the composition of all the mixes produced.

Table 2. The composition of plastic brick mixes produced

| Type | Plastic (%) | Cement (%) | Sand (%) |
|------|-------------|------------|----------|
| A    | 50          | 50         | -        |
| B    | 75          | 25         | -        |
| C    | 69          | 23         | 8        |
| D    | 66          | 22         | 12       |

To prepare the specimen, the sand was first dried to constant weight in the oven at 110 °C. The temperature stability of the plastic mortar was evaluated under the testing temperatures of 30, 45, 60, 75 and 90 °C., and then mixed and heated with PET flakes at 280–290 °C until the PET flakes were melted. After that, it was manually mixed to obtain a uniform mixture. The mixture was then poured into the mold, which had been pre-heated to 180 °C, and compacted to produce plastic mortar. After cured under 180 °C for two hours, specimens were de-molded and cured in the room condition until the test.

The size of specimens for the compressive and flexural strength test was 50 x 110 x 230 and 52 x 115 x 240 mm. The compressive and flexural strengths of the plastic mortar specimens were measured. Since the strength development was very fast for the plastic mortar, only one-day compressive and flexural strengths were tested. All strengths were obtained from three replicates, and the average of three samples was presented and discussed in the study. To test the water absorption, specimens were first dried in the oven. The dry mass of specimens in the air was then weighed. After that, the specimens were immersed in the water. At testing time, specimens were taken out of the water with its surface water wiped with a wet towel, and its saturated surface-dry mass was weighed.

2.4. Testing methods

Slump tests were also conducted for each category of the samples to measure the workability of bricks. Molds were removed after 24 h and then cured in water at room temperature of 25 ± 2 °C for 30 days.  

2.4.1. Water absorption and thickness swelling

Water absorption (WA) was calculated by the following equations:

\[ WA = \frac{m_t - m_0}{m_0} \times 100\% \]  

where m0 and mt are the mass of the sample before and after immersion, g.
2.4.2. Compressive strength test
The compressive strength of the brick was tested by the Universal Testing Machine (UTM). Samples of bricks that have beam shape are cut first to form cubes to have an identical surface area. Then the sample is entered into UTM to be tested. The SNI standard for brick, as shown in Table 3.

Table 3. Standard of compressive strength test (SNI 15-2094-1991)

| Quality | Compressive Strength Average |
|---------|-----------------------------|
|         | Kg/cm² | N/mm² |
| I       | >100    | >10   |
| II      | 100-80  | 10-8  |
| III     | 80-60   | 8-6   |

2.4.3. Outer brick test view
The outer brick view must meet the national brick requirements in SNI-10-1978 and SII-0021-72 regarding the outward brick view. The brick must have sharp ribs, and the sides must be flat, not show hair cracks, the shape changes are insignificant and not easily destroyed [37].

2.4.4. FT-IR analysis
Infrared Spectrum test was performed to determine the main functional groups. The FTIR spectrometers (PerkinElmer Spectrum Version 10.4.00) with scanned absorption bands from 400 to 4000 cm⁻¹ was employed.

2.4.5. Structural analysis
The specimens studied were tested of the morphology with a scan electron microscope with energy dispersive X-ray spectroscopy (SEM-EDX, Phenom Pro X, manufactured by the Netherlands). The SEM-EDX analysis was used to review the extent of brick homogeneity on a microscopic scale and to review the constituent elements of plastic brick. This analysis is done to facilitate the improvement of the composition of the brick compiler when its physical properties are engineered to obtain a better quality of plastic bricks.

3. Result and Discussion
Mechanical properties such as outer brick views, compressive strength, and water absorption of bricks with a waste of PET plastics bottle is presented in Table 4, 5, and 6. The functional group of bricks with a waste of PET plastics bottle is presented in Figure 1. The images and morphology of brick from PET plastics bottle are presented in Figure 2, which demonstrate the porosity and the homogeneity of the mix.

3.1. Analysis of outer brick views
From the outside of brick, the view is used to review how well the quality of the physical outside of the brick and outside physical characteristics of brick are shown in Table 4.

| Variation | Elbow | Side field | Observation |
|-----------|-------|------------|-------------|
| A         | No    | Clumps     | There is clumping on the dough, and the mixture cannot be molded |
| B         | Yes   | Flat       | Can be molded, there are cracks because the side of the surface dries faster |
| C         | Yes   | Flat       | No hair cracks |
| D         | Yes   | Flat       | No hair cracks |
3.2. Brick compressive strength analysis
Brick compressive strength is the most critical parameter in brick production. This test is done by the Universal Testing Machine (UTM) tool, which the obtained results, as shown in Table 5.

| Variation | Large (cm²) | F (Kg) | P (Kgf/cm²) |
|-----------|-------------|--------|-------------|
| B         | 9           | 238    | 26          |
| C         | 9           | 486    | 54          |
| D         | 9           | 671    | 75          |

3.3. Water absorption test analysis
Water absorption test is done to determine the ability of the brick to absorb water in the brick. The less water absorption shows the good quality of the brick. All variations of brick have a low absorption value, and this has happened because the basic material of PET plastic is not porous. The results of water absorption, as shown in Table 6.

| Variation | Initial mass (g) | Final mass (g) | Percent absorption (%) |
|-----------|------------------|----------------|------------------------|
| B         | 77               | 78             | 0.008                  |
| C         | 175              | 176            | 0.006                  |
| D         | 75               | 75             | 0.003                  |

3.4. FT-IR Analysis
In the FTIR test, there is evidence of a wave component that proves the presence of PET and other minerals from cement and sand. The spectrum illustrates that the material contained carbonyl C=O (1719.53 cm⁻¹) stretching. This spectrum is like the presence of groups C=O at wavelengths 1780-1650 cm⁻¹ with vigorous intensity. The functional group of an aromatic skeletal stretching show at 1410.60 cm⁻¹. This spectrum is characteristic of aromatic groups were found at wavelengths between 1600-1430 cm⁻¹ with vigorous weakening intensity. The functional groups of C(O)–O stretching of the ester group show in the intensity at 1345.26 cm⁻¹. The wavelengths of 871.17 and 724.38 cm⁻¹ are assigned to the coupled vibrations of the aromatic out-of-plane C-H bending mode and the out-of-plane O=C–O bending mode, respectively. The result clearly demonstrates that the waste material is PET.

Figure 1. FTIR result in D variation brick
3.5. SEM-EDX Analysis
In the SEM-EDX analysis, it was enlarged to see the microscopic surface of plastic bricks, the used magnification was 1000 times and 2000 times, as in Figure 2.

![Figure 2. The result of SEM in brick D variation](image)

In the analysis of elements in plastic brick compared to concrete as in Figure 3 and 4, there is a significant difference because of carbon elements addition from PET plastic, it makes the physical character of the brick softer than conventional brick but still has a compressive strength value which is included in the SNI standard, higher than 60 Kg/cm². Another consequence of the high plastic composition is the ability of bricks not to absorb water better than conventional bricks. Constituents of bricks from PET plastics bottle used in the experiment as determined in EDX are as follows: C (35.1%), C (31.2%), Ca (24.4%), Si (8.9%), S (0.2%), and Fe (0.1%).

![Figure 3. The result of EDX in brick D variation, Result of EDX in concrete](image)

| Element | Weight percentage | Certainty |
|---------|------------------|-----------|
| O       | 35.1 %           | 0.98      |
| C       | 31.2 %           | 0.98      |
| Ca      | 24.4 %           | 0.99      |
| Si      | 8.9 %            | 0.99      |
| S       | 0.2 %            | 0.84      |
| Fe      | 0.1 %            | 0.29      |

![Figure 4. The percentage of EDX results in variation D the brick sample](image)
Conclusion
The results of the present study reveal a clear possibility of adding of waste from PET plastics bottle in bricks with a limited compromise on mechanical properties. These bricks possess favorable properties of construction materials as they are lightweight, porous, and reinforcement from compressive strength value. Based on the results of the study, it can be concluded that the D variation of plastic brick with a ratio of solid PET : cement : sand is 66 : 22 : 12 with the mix design method can be an alternative brick that complies with SNI standards. Thus, while the process provides a convenient way of disposing of waste plastic, particularly from PET plastic bottle, it also creates economic value in terms of energy efficiency in buildings.

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