Mechanical Performance of Reused Plastic Bottle as Structural Floor Panel

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Abstract. There have been many experiments regarding reusing plastic bottles, especially polyethylene (PET) as building materials. Some of them are experimenting with their compressive strength as exterior wall bricks (Mansour, et al., 2015); their energy consumption as roof insulations (Racolta, et al., 2016); their compressive and flexural strength as interior walls (Santana, 2016); and their compressive strength as walls and slabs (Oyinlola, et al., 2018). This paper discusses the compressive strength and the flexural strength of PET bottles as structural floor panels. This study explored the positions, binders, patterns, fillers, sizes, and supports of the PET bottles panel to reach the optimum combination of compressive and flexural strength. The experimental result shows that PET bottles panel with an upright position, sealant binder, and sand filler has better compressive strength and flexural strength. It also shows that the panels with more bottles face downwards have better compressive strength, while the ones with more bottles face upwards have better flexural strength. On the other hand, panel with smaller size and higher amount of support shows better flexural strength.

1. Introduction
Plastic waste is one of the most crucial environmental problems the world is facing now, including Indonesia. One of the reasons is because plastic waste is a non-biodegradable waste which can take up to 500 years or even forever to decompose in the natural environment [1]. Furthermore, Indonesia is one of the most polluting countries regarding plastic wastes, producing 3.2 tons/year, only second to China, which produces 8.8 tons/year [2]. Plastic waste in Indonesia contributes to 14% of Indonesia’s wastes, which equals to 8.96 tons/year; 60 – 70% of which is still in the landfill, 10 – 15% is recycled, and the rest 15 – 30% is not managed, so they end up in the aquatic environment, such as river, lake, beach and finally, ocean [3].

2. Literature Review
There has been a lot of study regarding how to reuse plastic waste, especially PET bottles, into building components. Taaffe et al. [4] reported that PET bottles filled with mixed plastic waste, which are called Eco-bricks, have better sound insulation properties than concrete brick and sand brick, which is 44 Db. Mansour et al. [5] reported that non-structural outer walls made of PET bottles filled with wet sand, dry sand, and compressed air have a compressive strength of 0.609 MPa, 0.623 MPa, and 0.670 MPa respectively. Furthermore, they have better thermal insulation properties than hollow concrete blocks. Racolta et al. [6] reported that roof insulation made of empty PET bottles could reduce heat energy
consumption up to 515 kWh/m² per year. Santana [7] reported that non-structural inner walls made of empty PET bottles which are arranged in diagonal patterns and tied with acrylic panels have better compressive and flexural strength than the ones arranged in hexagonal and horizontal patterns and tied with steel wires. Oyinlola et al. [8] reported that structures made of PET bottles filled with water and sand have a compressive strength of 0.0014 MPa and 0.025 MPa respectively. But on the other hand, PET bottles filled with water has better thermal insulation properties than the ones filled with sand.

The above literature shows that there is no study reported the mechanical performance of PET bottles as structural floor panels. This paper attempts to explore PET bottles arrangements with different positions, binders, patterns, fillers, sizes and supports; and then test their compressive and flexural strength as structural floor panels.

3. Method
There are many alternative sizes of PET bottles to choose from, including 330ml, 600 ml, and 1500 ml. The most appropriate size was found to be 600 ml because it is harder to pack a bottle of larger size manually. Also, this experiment required a high amount of bottles and it was found that there was a lot of 600 ml size bottles. The experiment was divided into six steps for each variable, starting with: 1) positions, 2) binders, 3) patterns, 4) fillers, 5) sizes, and 6) supports. The compressive strength test was done for step 1 – 4, while the flexural test strength was done for step 1 – 6.

The compressive strength test was done manually. The sample was placed on a flat surface (in this experiment: floor) to ensure an evenly distributed load flow. A masking tape and two perpendicular Hebel blocks were placed on the sides of the sample to mark its initial length and width. After the initial height and length had been measured, the loads were placed. The loads used for step 1 – 3 were AAC (Aerated Autoclaved Concrete) blocks, known as Hebel blocks, which weight around 8 kg each; while the loads used for step 4 were K-175 concrete cylinders which weight 10 – 13 kg each. For each load placed, the height decrease and the length increase of the sample were measured. The height decrease was measured using a ruler; while the length increase was measured using the masking tape and the perpendicular Hebel blocks that had been placed before.

Figure 1 (a) Compressive Strength Test; (b) Dimension Change of PET bottles during Compressive Strength Test

The flexural strength test was done manually. The sample was placed on a flat surface (in this experiment: floor) to ensure an evenly distributed load flow. A masking tape and two perpendicular Hebel blocks were placed on the sides of the sample to mark its initial length and width. After the initial height and length had been measured, the loads were placed. The loads used for step 1 – 3 were AAC (Aerated Autoclaved Concrete) blocks, known as Hebel blocks, which weight around 8 kg each; while the loads used for step 4 were K-175 concrete cylinders which weight 10 – 13 kg each. For each load placed, the height decrease and the length increase of the sample were measured. The height decrease was measured using a ruler; while the length increase was measured using the masking tape and the perpendicular Hebel blocks that had been placed before.

Figure 2 (a) Flexural Strength Test of Step 1 – 4; (b) Flexural Strength Test of Step 5 – 6; (c) Dimension Change of PET bottles during Flexural Strength Test
The flexural strength test was also done manually. First of all, the support of the sample was placed on a flat surface (in this experiment: floor). Then the sample was placed and measured its initial height. After that, the loads were placed. The loads used for step 1 – 3 were clay bricks which weight around 1 kg each; the loads used for step 4 were Hebel blocks which weight around 8 kg each; and the loads used for step 5 – 6 were K-175 concrete cylinders which weight 10 – 13 kg each. For each load placed, the height decrease of the sample was measured using a ruler.

The compressive strength and the flexural strength test were done manually to observe the process of the dimensional changes of the samples for each load placed. It was not done by test machine because the first weight loaded was 100 kg, which was not possible to observe the process of the dimensional change if the sample was already crushed during experiment.

4. Results and discussions

4.1. Step 1 - Positions

There were two position variants explored in step 1, which were resting and upright position. Figure 3 shows that PET bottles with upright position (A2) have higher compressive and flexural strength than PET bottles with a resting position (A1). Based on the compressive strength, A2 can endure 80 kg with 0.6 – 0.7 cm in height decrease and length increase; while A1 can only take up to 40 kg with 3.4 cm in height decrease and length increase. Based on the flexural strength, A2 can endure 20 kg with only 1.5 cm in height decrease; while A1 can only take up to 10 kg with 3.6 cm in height decrease.

This condition is affected by two factors. They are the height and the surface hardness of the sample which comes into contact with the floor. The height of both samples is 23 cm; which is not much of an influence. Meanwhile, the surfaces which come into contact with the floor for A1 are the bottles’ bodies; while for A2 are the bottles’ caps and bases. The bottles’ caps and bases are harder than their bodies, which explains why A2 has higher compressive and flexural strength than A1.
4.2. Step 2 - Binders

There were four binder variants explored in step 2, which were sealant, steel wire, fishing line, and elastic rubber binder. Figure 4b shows that PET bottles with sealant binder (B1) have higher compressive and flexural strength than PET bottles with steel binder (B2), fishing line binder (B3), and elastic rubber binder (B4). Based on the compressive strength, B1 can endure 80 kg with only 0.6 – 0.7 cm in height decrease and length increase; while B2, B3, and B4 can endure the same amount of loads, but with 1.5 – 1.6 cm in height decrease and length increase. Based on the flexural strength, B1 can endure 20 kg with 1.5 cm in height decrease; while B2, B3, and B4 are only able to take lighter loads (9 kg, 3 kg, and 2 kg respectively) with larger height decrease (3 cm, 2.8, and 3.3 cm respectively).
This condition is affected by two factors, which are the amount of the binder applied and the hardness of the binder. In B1, the binder is applied along the bottles’ bodies; while in B2, B3, and B4, the binder is only applied on the upper and lower part of the bottles’ bodies. This explains why B1 has higher compressive and flexural strength than B2, B3, and B4. And based on the binder hardness from high to low, it can be arranged into the following order: sealant (B1) – steel wire (B2) – fishing line (B3) – elastic rubber (B4); which results in the same order of flexural strength.

4.3. Step 3 - Patterns

There were nine pattern variants explored in step 3, as shown in Figure 5a. Figure 5b shows that PET bottles with more bottles facing downwards have higher compressive strength, while PET bottles with more bottles facing upwards have higher flexural strength. The compressive strength is affected by the surface hardness of the sample that comes into contact with the floor. There are two types of surfaces, which are the bottles’ caps and bases. The bottle’s cap has a higher hardness than its base. This explains why the more bottles facing downwards, the higher its compressive strength. On the contrary, the flexural strength is affected by the surface area of the sample that comes into contact with the floor. The bottle’s base (38.5 cm²) has a wider area than its cap (7.07 cm²). This explains why the more bottles facing upwards, the higher its flexural strength.
4.4. Step 4 - Fillers

There were three filler variants explored in step 4, which were sand, aluminum foil (alufoil) LDPE, and transparent LDPE. Alufoil LDPE is an opaque plastic and aluminum foil combination which mostly comes from instant drink packagings, such as juice and coffee packagings. Transparent LDPE is a transparent plastic which mostly comes from food packagings. Based on the fillers, that PET bottles filled with sand (D1-D4) have higher compressive and flexural strength than PET bottles filled with alufoil LDPE (D5-D8) and transparent LDPE (D9-D12), as shown in Figure 6b. Based on the patterns, Figure 6b shows that PET bottles with more bottles facing upwards have higher compressive and flexural strength than PET bottles with more bottles facing downwards.

The compressive strength is affected by two factors, which are the filler’s density and the surface hardness of the sample that comes into contact with the floor. There are two types of surfaces that come into contact with the floor, which are the bottles’ caps and bases. The bottle’s cap has a higher hardness than its base; but since the bottles are compactly filled, the base becomes harder than the cap. This explains why the more bottles facing upwards, the higher its compressive strength. The flexural strength is affected by two factors, which are the filler’s density and the surface area of the sample that comes into contact with the floor. The bottle’s base (38.5 cm²) has a wider area than its cap (7.07 cm²). This explains why the more bottles facing upwards, the higher its flexural strength.

Based on the filler’s density, the sand has 1.84 – 1.93 gr/cm³; alufoil LDPE has 0.54 – 0.59 gr/cm³; and transparent LDPE has 0.33 – 0.37 gr/cm³. Higher density results in higher strength. This explains why PET bottles filled with sand (D1-D4) have the highest compressive and flexural strength, followed by alufoil LDPE (D5-D8) and transparent LDPE (D9-D12).
4.5. **Step 5 - Sizes**

There were two size variants explored in step 5, which were 50 x 50 cm and 70 x 70 cm. Figure 7 shows that 50 x 50 cm module (E1) has a higher flexural strength than 70 x 70 cm module (E2). E1 can endure 240 kg with only 0.3 cm in height decrease; while E2 can endure the same amount of loads with 1 cm in height decrease. The flexural strength is influenced by the distance between supports; which is represented by the size of the module. E1’s support has the distance of 44 cm; while E2’s support has the distance of 64 cm. Shorter distance results in higher strength. This explains why E1 has higher flexural strength than E2.

4.6. **Step 6 - Supports**

There were four support variants explored in step 6, which were: 1) edge support; 2) east-west support, 3) north-south support, and 4) all side support. Figure 8 shows that module with all side support (F4) has higher flexural strength than module with edge support (F1), east-west support (F2), and north-south support (F3). F1 can endure loads 240 kg with only 0.3 cm in height decrease; while F2, F3 and F4 can endure the same amount of loads with larger height decrease (0.45 cm, 0.5 cm and 0.4 cm respectively).

The flexural strength is affected by two factors, which are the area and the number of bottles supported. F1, F2, F3 and F4 support the total area of 369.6 cm², 215.6 cm², 269.5 cm² and 431.8 cm² respectively. From low to high, it can be arranged into the following order: F2 – F3 – F1 – F4. However,
the result shows different order, which is: F2 – F1 – F3 – F4. It is because the flexural strength is apparently more affected by the number of bottles supported. F1, F2, F3 and F4 support bottles with the total number of 12, 8, 14 and 18 consecutively. From low to high, it can be arranged into the following order: F2 – F1 – F3 – F4; which is the same order as the flexural strength of the samples.

5. Conclusions

Based on the results of the experiment from each step, it can be concluded that:

1) Upright position results in better compressive and flexural strength than resting position. This is because the surfaces which come into contact with the floor in upright position are the bottles’ caps and bases; while in resting position, they are the bottles’ bodies; in which the former have a higher hardness than the latter.

2) Sealant binder results in better compressive and flexural strength than steel wire, fishing line, and elastic rubber binder. This is because sealant has wider application area and higher hardness (when it dries) than other binders.

3) More bottles facing upwards results in lower compressive strength, but higher flexural strength than more bottles facing downwards. This is because the bottle’s base has lower hardness, but wider surface area than its cap.

4) Sand filler results in better compressive and flexural strength than alufoil LDPE and transparent LDPE filler; since sand has higher density than alufoil LDPE and transparent LDPE.

5) 50 x 50 cm module results in better flexural strength than 70 x 70 cm module; since a floor panel with smaller modules has more supports than the one with larger modules.

6) All-side support results in better flexural strength than edge support, east-west support, and north-south support; since more support results in higher strength.

Overall, the best combination is 50 x 50 cm sand-filled PET bottles module, binded with sealant, with all of the bottles facing upwards and placed in a upright position on all side support. The PET bottles module resulted from this experiment can be used for structural floor panel, which is placed between floor beams and floor tiles.

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References

[1] Wilf Malcolm Institute of Educational Research, The University of Waikato. (2008). *Measuring Biodegradability*. Hamilton, New Zealand: Science Learning Hub.

[2] Jambeck, Jenna R., et.al. (2015). “Plastic Waste Inputs from Land into the Ocean”, in *Science* 347(6223). Washington, DC: Science/AAAS. pp.768-771.

[3] Directorate General of Waste Management. (2018). *Declaration of Reducing Plastic Waste*. Jakarta: Ministry of Environment and Forestry.

[4] Taaffe, Jonathan., et.al. (2014). “Experimental Characterisation of Polyethylene Terephthalate (PET) Bottle Eco-bricks”, in *Materials and Design* 60. Amsterdam: Elsevier. pp.50-56.

[5] Mansour, Ashraf., et.al. (2015). “Reusing Waste Plastic Bottles as an Alternative Sustainable Building Material”, in *Energy for Sustainable Development* 24. Amsterdam: Elsevier. pp.79-85.

[6] Racolta, Andrei., et.al. (2016). “The Analysis of PET Bottle Reuse as A Roof Thermal Insulation Component”, in *16th International Multidisciplinary Scientific GeoConference SGEM*. Albena: Curran Associates, Inc. pp.731-738.

[7] Santana, Ignatius A. (2016). *Used PET Bottle Exploration as Non-structural Wall with Reused Approach*. Depok: Universitas Indonesia.

[8] Oyinlola, Muyiwa., et.al. (2018). “Bottle House: A Case Study of Transdisciplinary Research for Tackling Global Challenges”, in *Habitat International* 79. Amsterdam: Elsevier. pp.18-29.