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Study on Use of Recycled Plastic Bottle Chips as a Partial Replacement of Sand in Cement-Mortar Mix

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Abstract

Plastic is one of the most produced materials in 21st century. The amount of plastic wastes are increasing day by day. Dumped plastic in the environment causes pollution, so it is important to employ it as a substitute for engineering work. Despite the fact that plastic cannot be completely substituted for natural aggregate, the present work investigates partial replacement. This study employs Polyethylene Terephthalate (PET) plastic bottle wastes as partial replacement for coarse aggregate. The plastic chips are used as partial replacement for fine aggregate in seven mix proportions: 0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15%. To evaluate the behavior of concrete with this partial replacement some parameters such as- dry density, water absorption, and compressive strength of the mortar were determined. The experiment was performed on 1:3 mortar mix, and the tests were conducted according to the prescribed technique and ACI codes. The result found from the experiment showed that the variations of parameters were less than 80% of the concrete of 0% replacement, for 5% replacement of sand by plastic waste reduces the compressive strength to 80%. However, even with maximum (15%) replacement the compressive strength stays within minimum limit (7.5 MPa). The density of the concrete mix with 15% replacement of Sand by PET bottle was 9.40% less than that of pure concrete mix. Water absorption rate was around 12% for all percentage of replacement which was below standard 20%. PET bottles in concrete can carry low load as hollow block/ cement mortar brick and PET in concrete blocks may help reduce the quantity of plastic waste that is dumped into the environment, according to the trials conducted for the study.

Keywords: *PET Plastic Chips; Partial Replacement; Mortar; Strength parameters; Compressive Strength.*

1 Introduction

Plastic pollution harms marine life and ecosystems. Most water bottles end up in landfills, despite recycling efforts. Bottled water is costly and relies on millions of barrels of oil each year. Ocean pollution from billions of pounds of plastic is a major issue. Projects like the Panamanian Plastic Bottle Village and Nigeria's DARE NGO promote eco-friendly construction with plastic bottles.

The "Great Pacific Garbage Patch" contains 90% of ocean waste, causing harm to marine life. Floating plastic pieces reach an estimated 46,000 per square mile, leading to annual deaths of sea birds and marine mammals. Plastic bag bans are global to address landfill issues and soil and water contamination. Recycling is a solution, but incineration releases toxins. Recycled plastic in cement composites offers an eco-friendly and cost-effective alternative.

PET plastic bottles have been extensively studied (Asdrubali et al., 2015) for their potential use in construction. By adding PET plastic bottle flakes to concrete or bricks, a lighter and stronger material is created, ideal for building walls.

2 Literature review

(Rahmani et al., 2013) replaced sand with ground-filtered plastic in concrete blocks. A 5% sand replacement showed the highest increase in compression ratio at 8.86%, while higher replacements led to strength loss. (Albano et al., 2009) replaced aggregates with plastic flakes (11.4 mm and 2.6 mm) in a 50:50 ratio (0%, 10%, and 20%). Replacing 20% of small flakes increased strength to 21.5 MPa at water-cement ratios of 0.5 and 0.6. Replacing 10% showed similar results (23.2 MPa and 23.1 MPa). (Frigione, 2010) substituted ground PET bottles (0.1–5 mm) at a 5% ratio for sand grains. A cement aggregate ratio of 1:4.8 produced the best compressive strength (69.7 MPa). Greater strength was produced by a water-cement ratio of 0.45 than by 0.55. (Shalaby et al., 2013) Plastic chips (5.73 fineness modulus) substituted sand in varying ratios (0%, 10%, 20%, 30%, and 50%) in concrete blocks. Compressive strength dropped with certain ratios, but the maximum strength was achieved with a 10% sand substitution. (Akçaözoğlu et al., 2013) molded concrete blocks by using plastic chips (0.5 mm to 4 mm). When aggregates were replaced to varying degrees (0%, 30%, 40%, 50%, and 60%), the greatest compressive strength of 25.3 MPa was obtained. The compressive strength was useless at 60% replacement. (Mahzuz & Tahsin, 2019) studied the effects of partially substituting the coarse aggregate in concrete with plastic waste, particularly polyethylene. Four mix proportions were used: 1:1:1, 1:1.25:2.5, 1:1.5:3, and 1:2:4. The stone in the concrete mixture was substituted at 0%, 25%, and 50%.

3 Material Properties

3.1 PET Bottle Chips

A popular plastic noted for its durability, clarity, and lightweight is PET, also known as polyethylene terephthalate. Food, drinks, including soft drinks, juices, and water, as well as many other things, including electronics and personal care items, are used in this method shown in figure 1 and figure 2.

Figure 1. Waste PET bottles

Figure 2. PET bottle chips

3.2 Cement

The main binding substance used in construction is cement, a fine powder. When combined with water, it hardens and reinforces construction materials like stones and bricks. Various chemical compositions of cement are shown in table 1 and table 2. Others materials are hollow brick, cement mortar, aggregate and sand.

Table 1. Typical composition of ordinary Portland cement

Chemical Name	Chemical formula	Weight (%)
Tri calcium silicate	$3CaO.SiO_2$	50
Di calcium silicate	$2CaO.SiO_2$	25
Tri calcium aluminate	$3CaO.Al_2O_3$	12
Tetra calcium aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	8
Calcium sulfate dehydrate (gypsum)	$CaSO_4.2H_2O$	3.5

Table 2. Specified quality of ordinary Portland cement

Test	Process	Value
Fineness by sieving	After sieving by weight on I.S. test sieve no. 9 not exceed	10%
Soundness by Le-chatelier's method	Expansion of any cement should not exceed	10 mm
Setting	Initial setting time not less than	30 minutes
	Final setting time not more than	10 hours
Tensile strength of cement mortar (1:3)	After 3 days not less than	20 kg/cm^2
	After 7 days not less than	25 kg/cm^2
compressive strength of cement mortar (1:3)	After 3 days not less than	115 kg/cm^2
	After 7 days not less than	175kg/cm^2

4 Methodology

The primary research of this project involves using recycled plastic bottles as a fine aggregate for the manufacture of hollow bricks. The mix design is created in accordance with the features discovered from the findings with the replacement of plastic aggregate with the following percentages: 0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15%.
A number of parameters, including cement content, mixing and compacting, curing time and temperature etc., contribute to the hardening characteristics of cement-treated sand mixtures. For different types of sand, the amount of cement affects various attributes to different extents, including plasticity, volume change, elastic properties, resistance to wet-dry alternations, and others properties. The degree of pulverization and moisture content of the material affect mixing efficiency. It also relies on the mixing duration, which may raise the ideal moisture content and lower the compressive strength. When the test temperature is around 25°C (77°F), as demonstrated by Clare and Pollard (1953), the seven-day compressive strength increases by 2 to 2.5% per degree temperature rises. In this research, bulk specific gravity and the fineness modulus of sand was taken 2.87 and 2.46 respectively according to the ASTM C128-15 and ASTM C136 code shown in figure 3. The unit weight of the loose and dense sand was found 42.09 kg/ft^3 and 47.53 kg/ft^3 respectively.

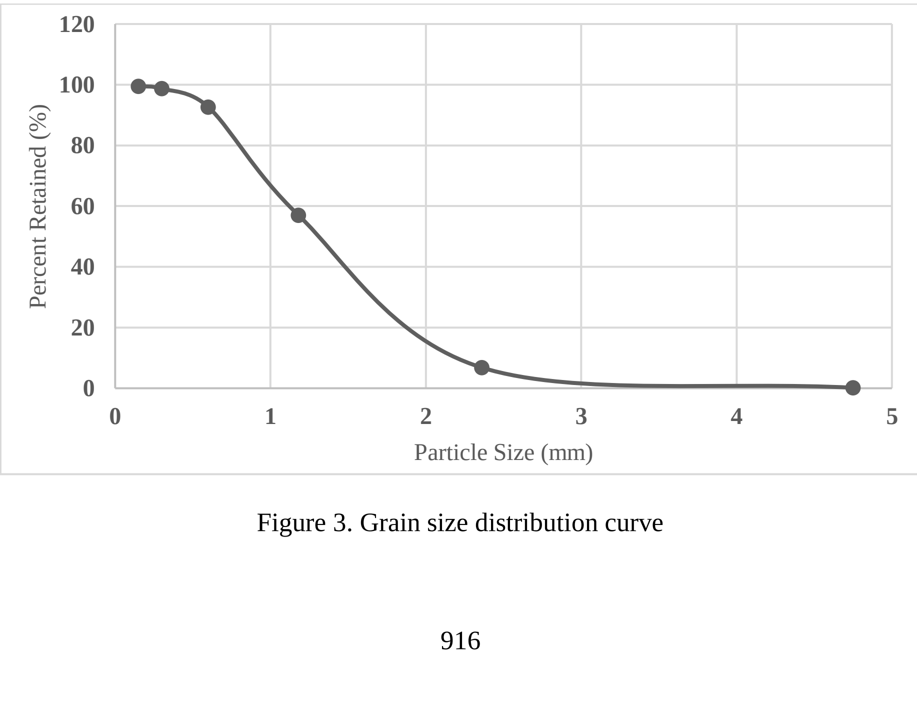

Figure 3. Grain size distribution curve

Figure 4. Wooden mold

Figure 5. Casting of the mortar

Wooden mold of size 24.13 cm x 11.43 cm x 6.35 cm was taken (Figure 4 & 5). To make the holes on the bricks, plastic pipes of 1 inch diameter was taken. Cement and sand were used in 1:3 composition. Plastic bags were placed inside the mold, covered with a layer of grease and mortar was casted inside. After unmolding the bricks, they were kept under water inside a curing tank for 7, 14 and 28 days respectively. After that, water absorption test (ASTM C1403-15) and compressive strength test was performed.

For compressive test, a computerized compressive test machine named MATEST Servo Plus Evolution was used where the calibration equation 1 was:

$$P_A = 1.0111 \times P_M + 0.0785 \qquad \text{(i)}$$

Here, P_A = Actual Load
P_M = Machine Load

5 Results and Discussion

5.1 Density of Specimens

With an increase in the percentage of plastic, which replaces the amount of sand, the density drops. While the minimum weight is 1902.28 kg/m3 when 15% of the sand is replaced by plastic chips, the maximum density is 2091.24 kg/m3 when there are no plastic chips which is due to the lower unit weight of it.

5.2 Water Absorption of Specimens

With an increase in the amount of plastic that substitutes the sand in terms of volume, the water absorption drops. The highest rate of water absorption is 12.75% for 0% plastic chips, while the minimum rate is 12.10% for 15% (figure 6)

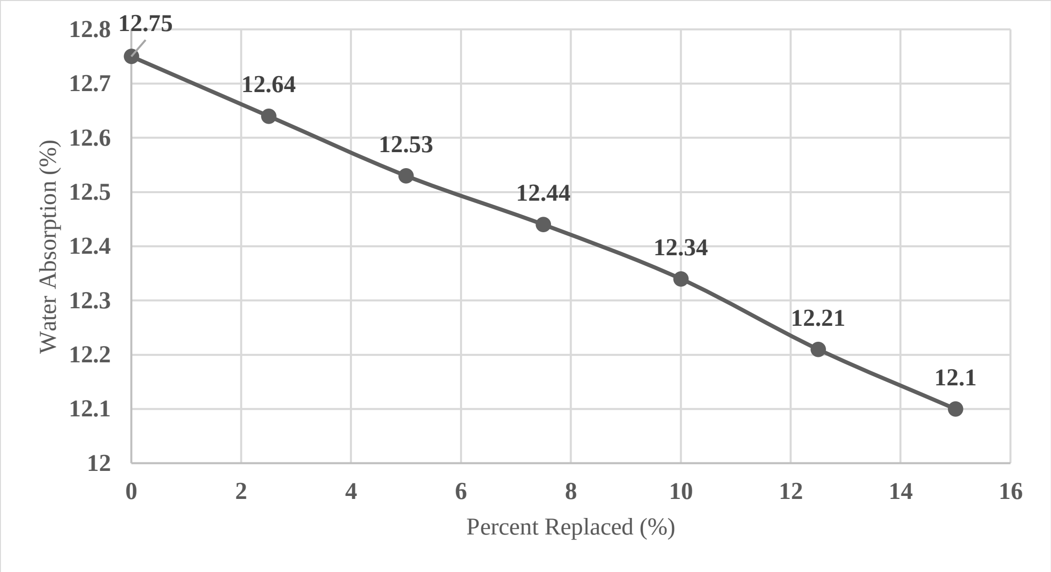

Figure 6. Variation of Water Absorption

5.3 Compressive Strength

The outcomes of the compressive strength tests conducted on all three samples of cement-mortar at cure times of 7 days, 14 days and 28 days reveal that the strength decreases with the increase of plastic chips as shown in figure 7. The compressive strength is roughly 65% for a 15% substitution of plastic chips for sand. However, the compressive strength of that is still greater than the minimum strength of cement mortar for a 1:3 mix. Furthermore, a 15% replacement reduces density by around 10%.

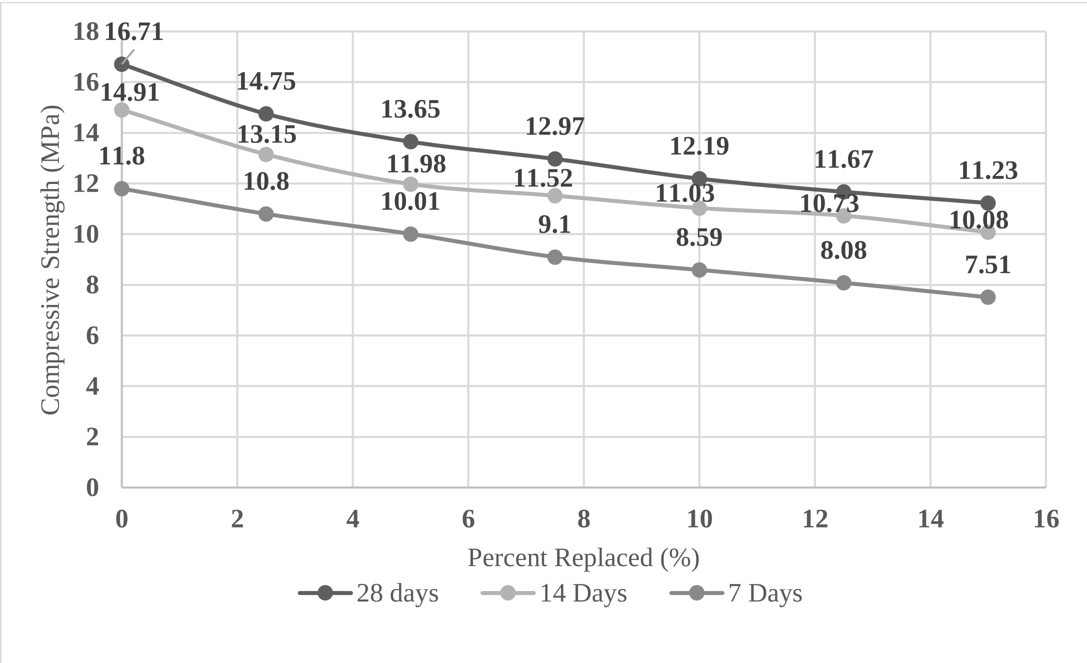

Figure 7. Variation of Compressive Strength (After 7,14 &28 days curing)

6 Conclusion and Recommendation

6.1 Conclusion

- The density of the cement mortar blocks was found 1902.48 for 15% replacement of sand by plastic flakes. This is slightly lower than the actual density of the pure cement mortar mix (2100 Kg/m^3). This result is somewhat satisfactory.
- The water absorption test of the hollow bricks shows that for 0% to 15% replacement of sand by plastic waste the water absorption percentage is around 12% which is below the standard water absorption rate (20%).
- The compressive strength results for 7 days, 14 days, and 28 days show that the compressive strength decrease with the increase of plastic chips. However, even with maximum (15%) replacement the compressive strength stays within minimum limit (7.5 MPa).
- The overall results show that the sand can be replaced by plastic waste up to 5%, within which the specimens show better result. Only 20% strength reduction occurs in this case and it is within the prescribed limit. Also, the density is decreased by 5.5% which is not significant. Further investigation should be carried out for better guideline.

6.2 Recommendation

According to the trials carried out for the study, using PET in concrete blocks may help decrease the amount of plastic waste that is discharged into the environment. High-quality PET used now degrades relatively slowly and has a considerable negative impact on the environment. The building industry might reduce this environmental impact by using the smaller-sized PET aggregate more frequently. Additional investigation is thus needed to lower the cost of manufacturing concrete blocks using PET.

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