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# The Effect of Recycled PET as a Partial Substitute for Fine Aggregates on the Properties of Concrete

Shiren Osman Ahmed
*Department of Civil Engineering, Delta Higher Institute for Engineering & Technology, Mansoura, Egypt*

***Abstract*****:** *The amount of waste plastics is increasing daily, and it takes a long time to decompose. Plastic waste recycling which is used in concrete is an important topic since it preserves nonrenewable natural resources and reduces pollution in the environment. The effects of replacing 2.5%, 5%, 7.5% and 10% of sand weight with PET processed particles have been studied. Cubic, cylindrical, and prismatic specimens with various water to cement ratios were made for this purpose, and the properties of fresh and hardened concrete were assessed. The results were recorded at the curing ages of 7 and 28 days to determine compressive strength, flexural strength, and splitting tensile strength of concrete prepared with PET. Various tests, such as the rate of water absorption and density, were performed on the samples. The workability of the fresh concrete was measured by a slump test. The results showed that concrete including PET particles had decreased workability and density. The substitution of 5% of sand with PET particles for w/c ratios of 0.4 and 0.55 resulted in compressive strength increases of 7.14 % and 12.4 % compared to the control mix after 28 days of curing, respectively. The flexural strength trend is like compressive strength. By replacing 10% of sand with PET particles for w/c 0.4 and 0.55, the reduction of splitting tensile strength was 14.55% and 16.67% compared to the control mix after 28 days of curing, respectively. The rate of water absorption increased with increasing of PET particles.*
***Key Word****: Recycled PET, Compressive Strength, Tensile Strength, Rate of Water Absorption, Density*

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## I. Introduction

PET is a type of polymer that is utilized in the production of polyester fibers, bottle resin, and engineering polyester in most countries throughout the world. Many researchers around the world were inspired to investigate innovative ways to recycle and reuse this polymer due to the widespread use in the food packaging industry and the long-term degradation of this type of waste material in nature. The effects of replacing 5%, 10%, and 15% of the sand with PET processed particles have been explored. Fresh concretes containing PET particles had decreased workability and density, according to the findings. In comparison to conventional concrete, PET particles showed a lower modulus of elasticity and splitting tensile strength. At first, the compressive and flexural strengths appear to be increasing; nevertheless, this tendency soon reverses [1]. All other proportions are maintained while sand is partially replaced by equivalent weight percentages of PET waste particles. The results of the experiments revealed that the inclusion of PET particles affected the physical and mechanical properties of the concretes that were produced. As PET ratios increased, physical properties (density and ultrasonic velocity) steadily reduced, whereas absorption rate increased .When it came to strength-related properties, the results showed that partial substitution ratios ranging from 5% to 12.5% increased compressive, tensile, and flexural strengths by 26.8% to 43.64 %, 18.6% to 26.9%, and 18.1% to 30.2 %, respectively, when compared to the reference specimens [2]. In concrete, pulverized PET was utilized in percentages of 5%, 10%, and 15% by weight of conventional fine aggregate. There were four different types of concrete specimens made, including a control. After 3 days, 7 days, 14 days, and 28 days of curing, the flexural and compressive strength of the concrete specimens were evaluated. The concrete specimen containing 5% PET by weight had higher compressive strength than the other specimens. Concrete specimens containing PET aggregate had a lower flexural strength than control concrete [3]. For grade M25, the mix design includes a 1:2:4 concrete mix ratio, 0.55 water/cement ratio, ordinary Portland cement (OPC) as the binder, variable quantities of heat-processed waste PET, and river sand as fine particles, and granite as coarse aggregate. Results indicate that workability increased with increasing percentages of waste PET plastics until the 40%PET level, beyond which workability reduces. The compressive and splitting tensile strength of waste PET plastics decreased as the percentage of waste PET plastics increased. During heat flow, 100 % PET goes through three stages of change. A glass transition, an exothermic peak below decomposition temperature after cooling from PET crystallization at 199.88 °C, and a baseline shift after the endothermic peak at 243.22 °C were observed. Thermogravimetry found that 100 % PET decomposes in two stages, with the first stage accounting for an 87.41 % reduction in sample mass and the second stage accounting for a 12.79 percent mass loss [4]. The fibers were made by shredding old PET bottles into 50 mm long and 5 mm wide microfibers, which were then added to the concrete mix in fractions of 0.5 %, 1.0 %, 1.5 %, and 2.0 %. To evaluate the concrete workability, the properties of the fresh concrete mix were tested using a slump test. A compressive strength test was used to measure the concrete strength at 7 and 28 days to determine the hardened concrete properties. The addition of PET fibers in concrete mixtures reduced the concrete workability slightly, according to slump test results. When PET fibers were added to concrete, the compressive strength of the concrete increases at lower fiber volume content and decreases at larger fiber volume content [5]. A series of tests were carried out on concrete reinforced with circular Fibers and long strips. Concrete has become more ductile, and there is a high level of concrete-PET adhesion. PET fibers and strips provide the following significant advantages: Plastic waste reduction, production cost reduction, and reduction of structural degradation due to steel corrosion [6]. Five normal concrete mixtures with a 0.41 w/c ratio were evaluated to see how waste affects the performance of reinforced concrete beams. Four normal concrete combinations with varying concentrations of polyethylene terephthalate waste fibers in diverse shapes and lengths make up the mixtures. The behavior of four 150 mm x 200 mm x 1400 mm simply supported concrete beams with various percentages of wastes in the concrete mixture was then tested, as well as the impact of wastes on the strength and serviceability of concrete beams. The mechanical properties of mixtures containing plastic wastes were evaluated and compared to those of a control mixture using appropriate techniques. Load-deflection behavior, cracking research, ductility indices, and stiffness were among the test variables for reinforced concrete beams. The ultimate failure load of the specimens and secant stiffness both decreased slightly during the testing of reinforced concrete beams. Despite this, all beams showed a significant improvement in ductility behavior, particularly the hybrid beam, as well as an increase in initial stiffness [7]. The combined effects of PET and rubber crumb (RC) as fine aggregate replacement in concrete are studied. The concrete's mechanical (compressive and flexural strength) and durability characteristics (electrical resistivity and water absorption) were examined in this study. The fine aggregate was substituted with 10%, 20%, and 30% binder by weight, and the curing times were 7, 28, 60, and 90 days. The results revealed that increasing the replacement of PET in a higher proportion (up to 20%) and RC in a lower proportion (up to 10%) decreased the compressive strength of concretes. The same trend was seen in flexural strength, with strength decreasing as the ratio of replacements increased. With the increased substitution of PET and RC in concrete, the electrical resistance increased [8]. The compressive strength improvement of concrete containing all types of PET-aggregate is like that of conventional concrete, although the addition of any type of PET-aggregate reduces the compressive strength of the resultant concrete significantly. The incorporation of PET aggregate improves the toughness of the produced concrete. This behavior is influenced by the shape of PET-aggregate and is best observed in concrete containing coarse, flaky PET-aggregate. The reduction in compressive strength of concrete containing plastic particles is proportional to the splitting tensile and flexural strength properties [9]. The researchers created concretes from portland cement (OPC), silica sand, gravel, water, and recycled PET particles. For comparison, specimens were made without PET particles. The results suggest that using smaller PET particle sizes in lower concentrations improves compressive strength and strain while increasing the size of PET particles utilized decreases Young's modulus [10]. In varying percentages, polyethylene terephthalate (PET) aggregates made from waste unwashed PET bottles in shredded form were utilized to partially substitute fine and coarse aggregate in concrete (0%, 5%, 10%, 15%, and 20%). An optical microscope was used to perform microstructural analysis on the specimens. It was observed that as the amount of PET waste in concrete increased workability, compressive strength, flexural strength, and dynamic and static modulus of elasticity decreased. With increasing amounts of PET waste, the water permeability of concrete was found to improve [11].

**Work Objective**

The purpose of the research is to assess the mechanical and physical properties of concrete produced from PET waste as a partial substitute for fine aggregates.

## II. Experimental Work

**Materials**

The different materials used in this investigation are: -

Cement: Ordinary Portland Cement (CEM-I) with grade 42.5 N.

Fine Aggregate: Sand with 4.75 mm maximum size was used, its fineness modulus was 2.7.

Coarse aggregate: Crushed stone aggregate dolomite with 20 mm maximum nominal size.

Water: drinkable water

PET: PET is a byproduct of the shredding of bottles. The PET bottles were chopped into pieces that were 5mm in size as shown in Figure.1

Figure 1: PET particles

## III. Concrete Mixes

The purpose of this experiment was to see how PET as a partial replacement for sand affected the characteristics of concrete. The concrete mixture was mixed for 2 minutes in a mechanical mixer. For several testing, the concrete mixture was cast in steel moulds. After 24 hours, test specimens were demolded, and they were cured after 7 and 28 days. two classes of control samples with the w/c ratios of 0.40 and 0.55 and the cement content of 400kg/m3 and 300 kg/m3 were implemented. The sand was replaced with PET at the ratios of (2.5%, 5%, 7.5%, and 10%) by weight. These mixes were compared to the control mix. Table no 1 shows the materials required per cubic meter of concrete mix.

**Table no 1**: Mix design (Kg/m$^3$)

| Mix | w/c=40% | | | | PET |
|---|---|---|---|---|---|
| | Water | Cement | Coarse aggregate | Fine aggregate | |
| Control | | | | 741.5 | - |
| M1 2.5%MW | 160 | 400 | 1112.3 | 722.69 | 4.98 |
| M2 5%MW | | | | 704.43 | 9.95 |
| M3 7.5%MW | | | | 685.88 | 14.9 |
| M4 10%MW | | | | 667.35 | 19.9 |
| | w/c=55% | | | | PET |
| | Water | Cement | Coarse aggregate | Fine aggregate | |
| Control | | | | 769.35 | - |
| M1 2.5%MW | | | | 750.12 | 5.16 |
| M2 5%MW | 165 | 300 | 1154 | 730.88 | 10.3 |
| M3 7.5%MW | | | | 711.65 | 15.5 |
| M4 10%MW | | | | 692.42 | 20.7 |

## IV. Testing

### Fresh Concrete

### Slump Test

The purpose of the slump test is to measure the consistency of concrete mix prepared in the laboratory or on the site. The slump test is the most basic concrete workability test. The slump is performed according to ASTM C143 procedures.

### Hardened Concrete

### Compressive Strength Test

Compressive strength tests were carried out after 7 and 28 days of curing. The cubic specimens, which measure 15*15*15 cm in size, were cast. The concrete specimens were put in the compression testing machine. and the load was applied to the samples until failure happened. The result of the crushing value for each sample was determined using the failure loads that were recorded. From each mixture, three specimens were made. The cubes were tested on a hydraulic machine capable of 1500 kN of force [12]

**Flexural Strength Test**

Prisms with dimensions of 10*10*50 cm were tested for flexural strength under four points loading. Three specimens were made and cured in water for each age. For 7, and 28 days, the flexural strength was calculated for all concrete mixes [13, 14].

**Splitting Tensile Strength Test**

Splitting tensile strength was performed on all mixes after 7 and 28 days of curing. The tests were carried out on concrete cylindrical samples with dimensions of 30 cm and 15 cm, using a compression testing machine. Three specimens were made and cured in water for each age. For 7, and 28 days, the tensile strength was calculated for all concrete mixes [15].

**The Rate of Water Absorption Test**

The 10*10*10 cm cubic specimens were cured at 7, and 28 days, and then the concrete samples were dried in an oven at 100 to 110 °C for at least 24 hours. The mass of each specimen was determined after it was removed from the oven and cooled in dry air. The samples were then submerged in water at a temperature of around 21°C for at least 48 hours. After removing the samples from the water, the excess water was toweled off and the samples were weighed. The rate of absorption of water was calculated for all concrete mixes [16].

**Density Test**

The cubic specimens with dimensions of 15*15*15 cm were made and cured at the age of 28 days. For all concrete mixes, the density was calculated [17].

## V. Results & Discussion

**Fresh Concrete**

**Slump Test**

Slump testing was used to assess the workability of concrete when PET is added in different amounts and w/c ratios were 0.4 and 0.55. The results are shown in Figure 2. It can be found that when the PET amount increases, the slump reduces for a constant w/c ratio. Because of their irregular shape and PET particles have a higher specific surface area than sand. As a result, there would be increased friction between the particles, reducing the mixture's workability. When the w/c ratio rises, the effect of PET becomes more obvious.

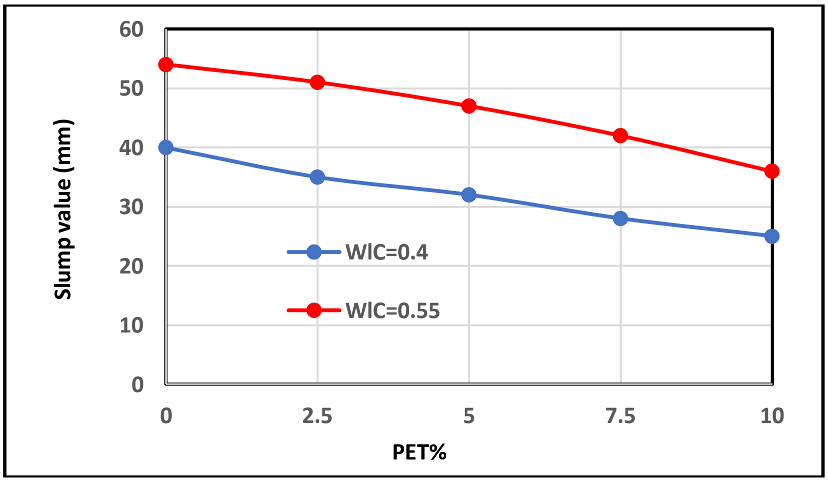


Figure 2: Slump values for different mixes

**Hardened Concrete**

**Compressive Strength Test**

The effect of PET particles as a partial replacement of sand on the compressive strength of concrete after 28 days of curing is demonstrated in Figure 3. It was observed that the compressive strength increased initially when the rate of sand replacement with PET particles increased at 2.5% and 5%, but then decreased at 7.5% and 10%. The substitution of 5% of sand with PET particles for w/c ratios of 0.4 and 0.55 resulted in compressive strength increases of 7.14 % and 12.4 % compared to the control mix after 28 days of curing, respectively, because of interlocking between PET particles due to their shape. Also, replacing 10% of the sand with PET particles for w/c ratios of 0.4 and 0.55 resulted in compressive strength decreases of 3.76 % and 5.95 % compared to the control mix after 28 days of curing, respectively, because of increase in PET particles prevent the cement paste from bonding to aggregates. When the w/c ratio reduces, compressive strength improves, which is consistent with normal concrete mixes.

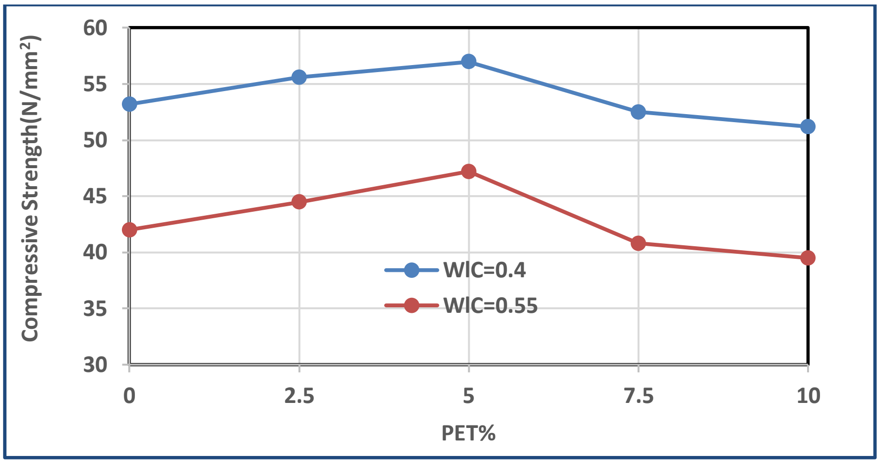


Figure 3: Compressive strength for different mixes

**Flexural Strength Test**

A flexural strength test was carried out. The results of the flexural strength were indicated in Figure 4. The flexural strength trend is like compressive strength. When the quantity of PET particles was increased, the flexural strength first increased, but after that decreased. The partial replacement of 5% of sand with PET particles for w/c ratios of 0.4 and 0.55 resulted in strength increases of 7.54 % and 9.28 % compared to the control mix after 28 days of curing, respectively. replacing of 10% of the sand with PET particles for w/c ratios of 0.4 and 0.55 resulted in flexural strength decreases of 4.46 % and 10.11 % compared to the control mix after 28 days of curing, respectively. A comparison of the flexural strength of mixtures for w/c ratios of 0.4 and 0.55 and the same ratio of replacement of sand revealed that the w/c ratio of 0.4 resulted in increased flexural strength.

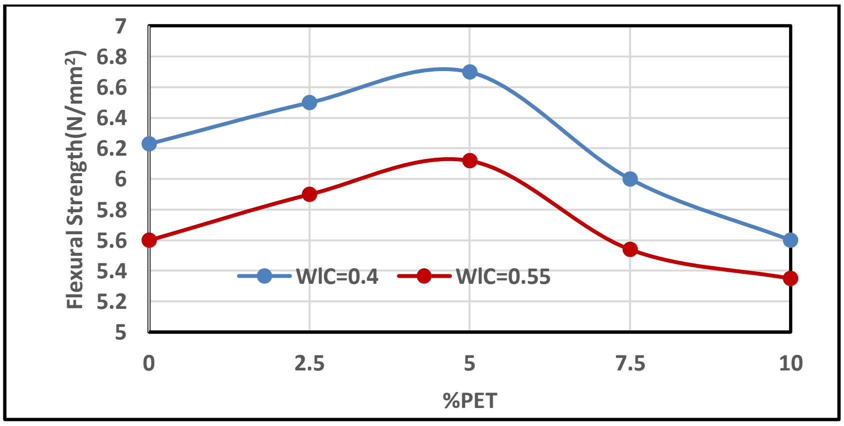


Figure 4: Flexural strength for different mixes

**Splitting Tensile Strength Test**

Splitting tensile strength was recorded and presented in Figure 5. It was noticed that splitting tensile strength decreased with the increase of PET particles as a partial replacement of sand. By replacing 10% of sand with PET for w/c 0.4 and 0.55, the reduction of splitting tensile strength was 14.55% and 16.67% compared to the control mix after 28 days of curing, respectively. This may be due to that PET particles have a smooth surface, which reduces the bond strength. The reduction in splitting tensile strength becomes more noticeable as the w/c ratio decreases.

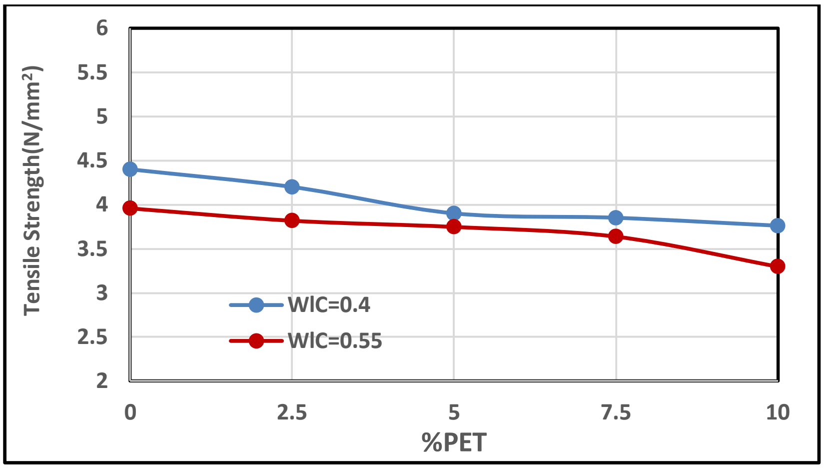


Figure 5: Splitting tensile strength for different mixes

**The Rate of Water Absorption Test**

Rates of water absorption results for concrete mixes after 28 days of curing are shown in Figure 6. The rate of water absorption increased with increasing of PET particles as a partial replacement for sand. This is due to the irregular shape of PET particles that forms more pores and voids. Also, PET particles behave as a barrier between the cement paste and the aggregates, preventing the cement paste from adhering to aggregates. The substitution of 10% of sand with PET particles as a partial replacement for w/c 0.4 and 0.55 achieved the highest rate of water absorption compared with the control mix. It was noticed that the rate of water absorption increases as the w/c ratio increases because excessive water in concrete specimens that do not participate in hydration creates pores and gaps after drying.

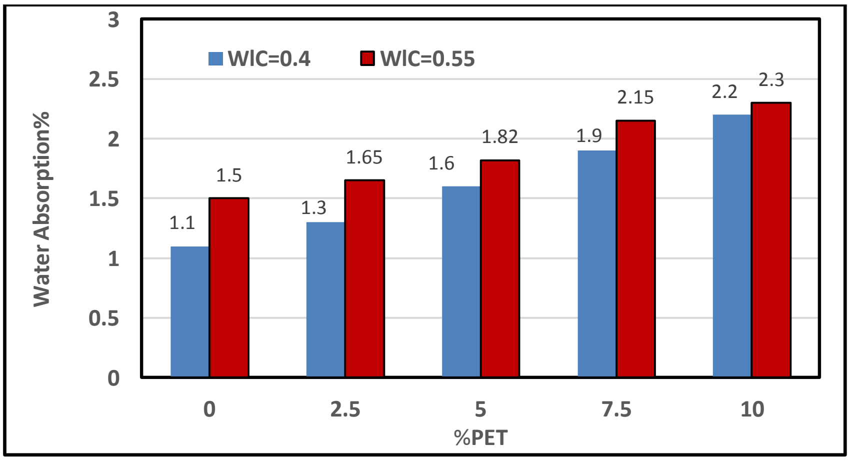


Figure 6: The rate of water absorption for different mixes

**Density Test**

After 28 days of curing, the density of the concrete mixes was calculated and presented in Figure 7. The density of mixes reduced with an increase in the amount of PET as a partial replacement of sand. Because PET particles have a lower unit weight than sand and the shape of PET particles forms more pores. It was observed that density decreases as the w/c ratio increases because excess water in concrete specimens that are not involved in the hydration forms pores after drying.

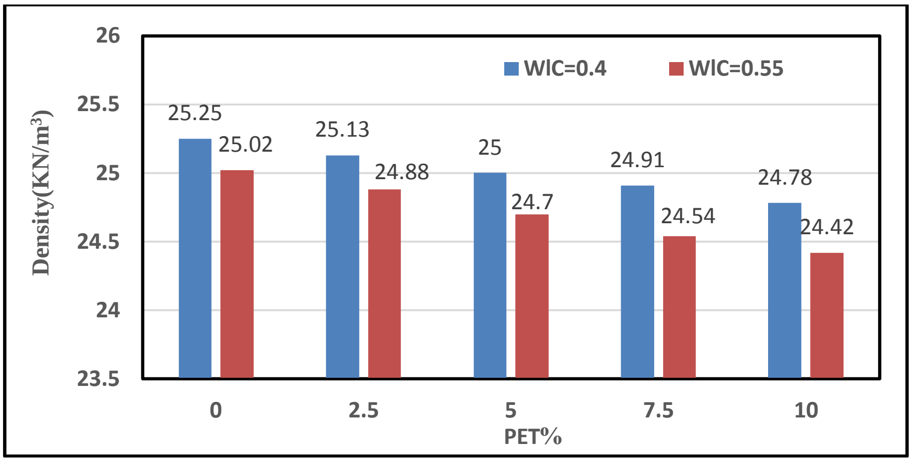


Figure 7: The density for different mixes

## VI. Conclusions

The properties of concrete including PET particles were investigated, as a result, the following findings were achieved:

1. Slump values reduced for a constant w/c ratio as the PET particles increased, because of their irregular shape, and PET particles have a higher specific surface area than sand.
2. The compressive strength increased initially when the rate of sand replacement with PET particles increased at 2.5% and 5% but then decreased at 7.5% and 10%. The substitution of 5% of sand with PET particles for w/c ratios of 0.4 and 0.55 resulted in compressive strength increases of 7.14 % and 12.4 % compared to the control mix after 28 days of curing, respectively.
3. The flexural strength trend is like compressive strength. When the quantity of PET particles was increased, the flexural strength first increased, but after that decreased.
4. The splitting tensile strength decreased with increasing of PET. By replacing 10% of sand with PET for w/c 0.4 and 0.55, the reduction of splitting tensile strength was 14.55% and 16.67% compared to the control mix after 28 days of curing, respectively.
5. Rate of water absorption increased with increasing of PET particles. The substitution of 10% of sand with PET particles as a partial replacement for w/c 0.4 and 0.55 achieved the highest rate of water absorption compared with the control mix.
6. The density of mixes reduced with an increase in the amount of PET particles. The density decreased as the w/c ratio increased.

**Data Availability**

All data can be made available from the authors upon request.

**Conflicts of Interest**

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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