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Production of Sustainable Concrete Containing Recycled PET

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ABSTRACT

The attempt to reuse plastic waste in concrete is a significant issue because it helps in preserving natural resources and in decreasing environmental contamination. The main aim of this research is to investigate the impact of adding Polyethylene terephthalate (PET) particles on the characteristics of concrete. PET particles were utilized as a partial replacement of fine aggregate by 2.5%, 5%, 7.5%, and 10% of volume. Mechanical characteristics of concrete were evaluated by various tests such as compressive strength, flexural strength, and splitting tensile strength. Absorption rate test, dry unit weight test, and ultrasonic pulse velocity test were conducted to assess the performance of concrete. Fresh concrete properties were determined using a slump test. Different water-to-cement ratios of 0.4 and 0.55 and cement content of 400 kg/m3 and 300 kg/m3, respectively, were used to prepare samples. The compressive strength test was conducted on cubic concrete samples with dimensions of 15×15×15 cm. Beams with dimensions of 10×10×50 cm were utilized to measure the flexural strength of all mixtures. The findings were determined at 28 days of curing. It revealed that PET mixtures had lower workability compared to reference mixture. The mixture with 5% PET achieved maximum compressive strength increase by 7.1%, and 12.39% with respect to that of the reference mixture at w/c=0.4, and 0.55, respectively. Flexural strength takes the same direction as compressive strength. Indirect tensile strength decreased by increasing the ratio of PET. The elastic modulus of PET mixtures decreased with an increase in PET content.

Keywords: PET fibers, Dry unit weight, Ecosystem, Ultrasonic pulse velocity, Slump.

1. INTRODUCTION

Plastic waste harms the ecosystem. It represents a big problem for the environment because of low biodegradability. Almeshal et al. [1] produced concrete including PET particles as a partial replacement of sand with different ratios and assessed its performance. The findings indicated that the density of PET mixtures reduced. The replacement of sand with PET particles has a negative impact on the mechanical characteristics of concrete. Adnan and Dawood [2] studied the effect of PET fibers on the performance of reinforced concrete beams. Five mixtures of normal concrete with w/c=0.41 and four mixtures including different ratios of PET particles with various forms and lengths were prepared. Four beams with dimensions of 150×200×1400 mm were tested to determine the strength of simple support beams. It was noticed that there is a slight reduction in the maximum failure load of samples and their stiffness. Despite this, there was a significant enhancement in ductility property for all concrete beams, especially the hybrid beam and the initial stiffness has increased. Smaoui et al. [3] investigated the impact of PET fibers on the behavior of concrete up to 20 kg/m^3 of PET fractions. PET fibers were treated with heat. The splitting tensile strength increased up to 120% due to thermal treatment. The mechanical characteristics of concrete have significantly enhanced. Thermal conductivity decreased up to 30 % by using PET fibers. The findings indicated improved resistance to the explosives. Dawood et al. [4] showed that the density and ultrasonic velocity of PET concrete mixtures reduced while water absorption increased with an increase in PET ratios. The compressive strength, indirect tensile strength, and flexural strength increased at ratios of 5% -12.5% by 26.8 % – 43.64 %, 18.6 % – 26.9 %, and 18.1 % –30.2 % with respect to the control mix, respectively. Energy absorption and strain of the samples increased at ratios of replacement 5% - 20% of PET. The modulus of elasticity reduced as the ratios of PET particles increased. The substitution of sand with PET particles has a positive influence on the strength if the substitution ratio does not exceed 15%. PET fibers resulting from plastic bottles were utilized in reinforced concrete beams at two ratios of 0.5%, and 1% by volume. The flexural strength of reinforced beams with PET particles of layered distribution was assessed. The results indicated that the utilization of PET particles of layered distribution improved the maximum load. The curve of load deflection indicated that beams with layered PET fibers have additional deflections before rupture. The toughness of beams with PET particles of layered distribution multiplied at a ratio of 1% PET. This improvement in flexural toughness and ductility utilizing layered distribution is a significant discovery that can encourage this sort of sustainable concrete in a variety of construction applications [5]. Abdullah and Haido studied [6] the flexural strength of reinforced concrete beams produced with normal concrete and high-strength concrete as a repair material including PET fibers. A slant shear test was used to assess the effectiveness of high-strength concrete as a repair substance for normal concrete using four methods to rough the surface of normal concrete. The findings of flexural strength and slant shear revealed that using interfacial surfaces with sandblasted between normal concrete and high-strength concrete resulted in the best bond in members. The flexural strength of monolith and hybrid concrete beams containing PET fibers was investigated. For this purpose, six beams which measured 3300x150x250 mm in size were tested. Reference mixture and PET monolith samples were prepared. In addition, hybrid samples consisted of normal concrete in the upper part of the samples and PET concrete at the bottom of the samples. Various tests were conducted on the beams such as flexural strength, failure mode, and stiffness. Results indicated that the compressive strength and indirect tensile strength of PET mixtures decreased. Also, hybrid samples gave better behavior than PET monolith samples and there is no difference between failure mode in PET monolith and hybrid samples [7]. Mohammed and Karim [8] utilized PET fibers with various lengths and different ratios in concrete. Sixteen high-strength concrete mixtures were cast and subjected to various tests. Findings demonstrated a little variation in ultrasonic pulse velocity. The compressive strength of PET samples with lengths 10, 20, and 40 mm decreased by 15.74%, 14.37%, and 10.28%, respectively with respect to the reference mix. PET fibers improved indirect tensile and flexural strength by 63.3%, and 24.7%, respectively. Impact strength behavior enhanced in first crack impact and ultimate load impact which achieved 300%, and 833%، respectively based on the length and fraction volume of PET fibers. PET particles were utilized in concrete as a partial replacement for fine aggregate. Modulus of rupture and compressive strength tests were performed. The findings revealed that a mixture with 5%PET gave greater compressive strength than other samples. The modulus of rupture of PET mixtures was lower than that of the reference mix [9]. Panara et al. [10] evaluated the performance of concrete under cyclic loading. It was observed that PET strips could increase loading capacity, reduce variability, and delay the spread of collapse. A simple equation for calculating the confinement influence caused by the existence of PET strips in a concrete mixture was suggested. Most authors accepted that plastic waste reduces thermal conductivity. PET fibers used in concrete as a partial substitution of aggregate can decrease the density of concrete and increase the modulus of rupture and residual modulus of rupture [11]. Chong and Shi [12] used PET fibers as a partial substitution of fine aggregate and observed better results than the partial replacement of coarse aggregate. The compressive strength of PET concrete mixtures improved up to 30% a partial substitution of fine aggregate.

2. RESEARCH SIGNIFICANCE

Most researchers investigated the utilization of plastic waste in concrete, but their studies gave weak compressive strength results. The main objective of this research is to enhance the performance of concrete. The recycled PET was used as a partial replacement of fine aggregate with different ratios of PET, water-to-cement ratios of 0.4 and 0.55, and cement content of 400 kg/m^3 and 300 kg/m^3. Locally available materials were used. The tests results of PET mixtures have been compared with that of the control mix at 28 days of curing. The effect of PET fibers on the consistency of concrete, mechanical, and physical properties was assessed. This research considers an approach toward improving sustainable concrete.

3. EXPERIMENTAL PROGRAM

3.1. Materials

Ordinary Portland cement CEM I 42.5N was utilized. The fineness modulus of used sand was 2.65, the bulk density was 1728.9 kg/ m^3, and the maximum nominal size of dolomite was 19 mm. Used bottles have been washed to clean them from any impurities, then have been grinded to have PET with sizes from 1-5 mm. The bulk density of PET particles was 464.265

kg/m^3. Figure 1 presents PET fibers used in preparing concrete mixtures.

Figure 1: PET fibers used in preparing concrete mixtures

3.2. Mixture Proportions

Four mixtures were performed with four replacement ratios of fine aggregate 2.5%, 5%, 7.5%, and 10% by volume to study the effect of PET fibers on the characteristics of concrete along with the control mix. Various tests were conducted on the samples such as compressive strength, indirect tensile strength, flexural strength, density, water absorption, modulus of elasticity, and ultrasonic pulse velocity for hardened concrete. The slump test was performed on fresh concrete. Mix proportions were designed based on the British method. Different water-to-cement ratios of 0.4 and 0.55 and cement content of 400 kg/m^3 and 300 kg/m^3, respectively, were used to prepare samples. The results of PET concrete mixtures were compared to the reference mix. Tables 1 and 2 present mix proportions for 1m^3 of concrete.

Table 1. Mixture proportions for m^3 of concrete

(w/c=.4, cement=400 kg/m^3)

Mix Materials (kg)	PET0	PET 2.5%	PET 5%	PET 7.5%	PET 10%
Cement	400	400	400	400	400
Sand	741.5	722.7	704.5	686	667.4
Dolomite	1112	1112	1112	1112	1112
PET	0	5	10	15	20
Water	160	160	160	160	160

Table 2. Mixture proportions for m3 of concrete

(w/c=0.55, cement=300 kg/m^3)

Mix Materials (kg)	PET0	PET 2.5%	PET 5%	PET 7.5%	PET 10%
Cement	300	300	300	300	300
Sand	769.4	750	730.9	711.7	692.5
Dolomite	1155	1155	1155	1155	1155
PET	0	5.2	10.4	15.5	20.7
Water	165	165	165	165	165

4. RESULTS & DISCUSSION

4.1. Results of Fresh Concrete

A slump test for PET mixes was conducted to evaluate the effect of PET fibers on the workability of fresh concrete according to ASTM C143. It was observed that slump values of PET fibers mixtures decreased with respect to that of the reference mix at w/c=0.4, and 0.55 as shown in Figure 2. The higher the PET percentage, the lower the slump values. This is consistent with other research [1, 2, 13, 14]. For substitution ratios 2.5%, and 10% of PET, The slump values decreased by 12.5%, and 37.5% at w/c=0.4, and it diminished by 5.5% and 33.3% at w/c=0.55. The reduction of slump values can be explained that PET fibers have a sharp and irregular shape. This increases the surface area of fibers leading to increased mixing water consumption. Several authors have confirmed these observations [1,15].

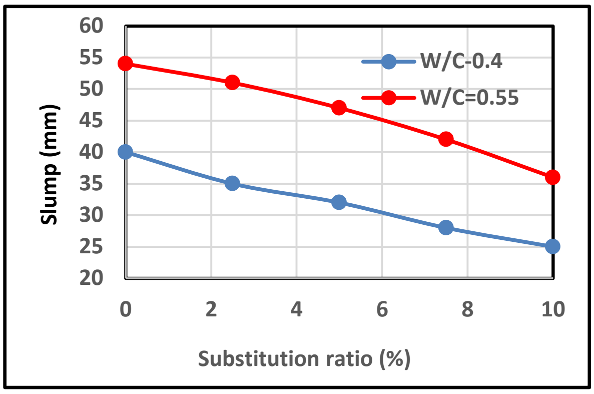

Figure 2: Effect of PET fibers on the slump of fresh concrete at various ratios of water to cement

4.2. Results of Hardened Concrete

4.2.1. Compressive Strength

The compressive strength of PET mixtures was measured at 28 days of curing on cubic samples with dimensions of 15×15×15 cm and compared with that of the reference mix [16]. Figure 3 shows that the compressive strength of PET mixtures increased at the substitution ratio of PET2.5%, and PET5% by 4.5%, and 7.1% while decreased by 1.31%, and 3.7% at the substitution ratio of PET7.5%, and PET10%, respectively at w/c=0.4. The compressive strength of PET mixtures at w/c ratios of 0.55 was lower than that of PET mixtures with w/c ratios of 0.4. It was observed the same trend of compressive strength at w/c=0.55. It increased by 5.95%, and 12.39% at substitution ratio of PET2.5%, and PET5% while reduced by 2.85%, and 5.95% at substitution ratio of PET7.5%, and PET10%, respectively. This can be explained that with the increasing ratio of PET more than 5%, the voids ratio of PET mixtures increased and the compaction of concrete decreased. Therefore, the adhesive force between the PET particle's surface and the cement paste reduced. This agrees with other studies [1,18]. The mixture with 5% PET achieved a maximum increment in compressive strength compared to other PET mixtures.

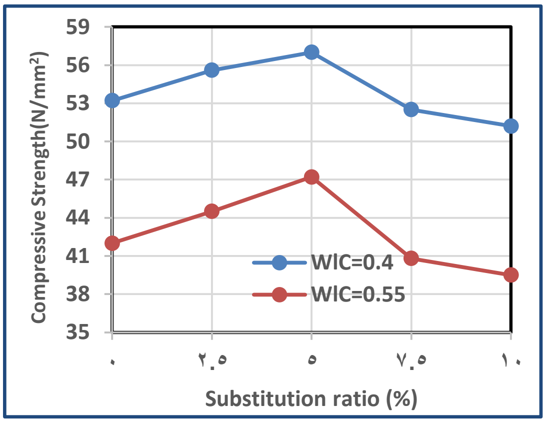

Figure 3: Influence of PET fibers on the compressive strength at various ratios of water to cement at 28 days of curing

4.2.2. Flexural Strength

The influence of PET fibers on flexural strength was determined on concrete beams with dimensions of 10×10×50 cm at 28 days of curing [19,20]. Figure 4 illustrates that flexural strength takes the same direction as compressive strength. Flexural strength of PET mixtures increased at replacement ratios of PET2.5%, and PET5% while decreasing at PET7.5%, and PET10% for w/c=0.4, and 0.55 [17].It increased by 4.3%, 7.5% at PET2.5% and PET5% while reduced by 3.7%, and 10.1% at PET7.5%, and PET10% for w/c=0.4.It also increased by 5.4%, 9.3% at PET2.5% and PET5% while decreased by 1.1%, and 4.46% at PET7.5%, and 10% for w/c=0.55. When PET ratios increase more than 5%, the flexural strength decreases due to the low bond between the surface of PET particles and cement past resulting from the hydrophobic behavior of PET fibers as was observed in various research [1,21].

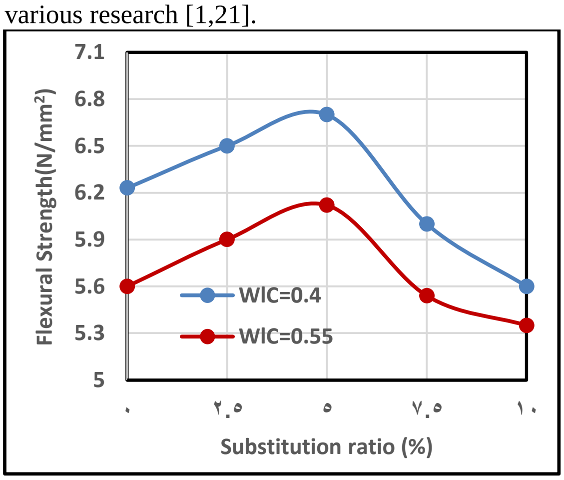

Figure 4: Influence of PET fibers on the flexural strength at various ratios of water to cement at 28 days of curing

4.2.3. Splitting Tensile Strength

A splitting tensile strength test was conducted on cylindrical samples with dimensions of 15×30 cm at 28 days of curing [22]. The results indicated that splitting tensile strength reduced as the content of PET increased at w/c=0.4, and 0.55 with respect to the reference mix as illustrated in Figure 5. The splitting tensile strength of PET mixtures reduced by 4.5%, 6.8%, 9.1%, and 14.5% at replacement ratios of PET2.5%, PET5%, PET7.5%, and PET10%, respectively compared with reference mix for w/c=0.4. It takes the same trend at w/c=0.55.The maximum decline of splitting tensile strength was at 10% PET. The reduction of splitting tensile strength was due to low stiffness, angular shape, and smooth surface of PET fibers compared with fine aggregate. This is in line with many researchers [1,23]. The failure mode of PET mixtures resulting from the splitting tensile strength test is shown in Figure 6. It was observed that the distinguished shape and flexibility of PET particles hinder the complete collapse of the cylinder, where PET particles can interlock between the two cracked surfaces[17].

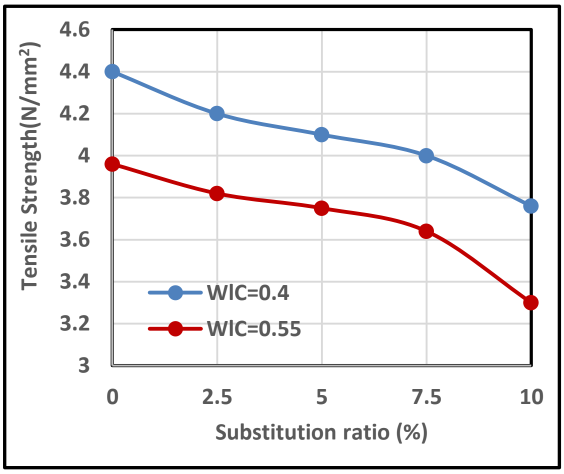

Figure 5: Influence of PET fibers on splitting tensile strength at various ratios of water to cement at 28 days of curing

Figure 6: The failure mode of the concrete cylinder including PET particles in splitting tensile strength test

4.2.4. Absorption Rate

The absorption rate was performed on cubic samples with dimensions of 10×10×10 cm at 28 days of curing [24]. The results demonstrated that the absorption rate increased with increased ratios of PET fibers [25]. The reference mix achieved absorption rates of 1.1%, and 1.5% with ratios of w/c=0.4, and 0.55, respectively.

The mixture with PET10% showed the maximum absorption rate compared with other PET mixtures, it increased to 2.2%, and 2.3% at ratios of w/c=0.4, and 0.55 as illustrated in Figure 7. The irregular shape of PET fibers is a reason for this increment. There is agreement on this explanation from researchers [17].

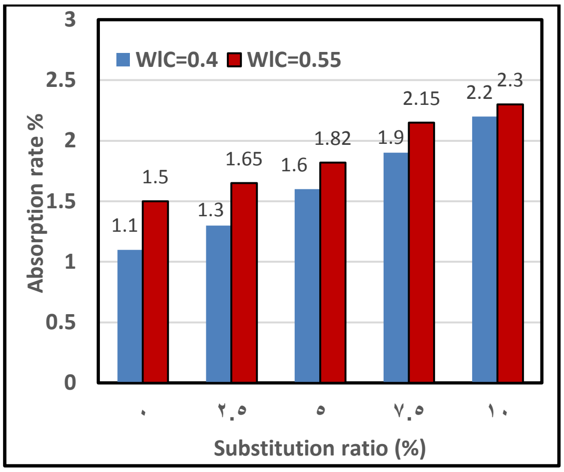

Figure 7: Influence of PET fibers on absorption rate at various ratios of water to cement at 28 days of curing

4.2.5. Dry Unit Weight

The dry unit weight of cubic samples containing PET fibers with dimensions of 15×15×15 cm was determined after 28 days of curing and compared with the reference mix at w/c=0.4, and 0.55 [26]. The dry unit weight of PET mixes decreased with respect to that of the reference mix as presented in Figure 8. The dry unit weight of the control mix was 25.25, and 25.02 KN/m^3 at w/c=0.4, and 0.55, respectively. Dry unit weight reduced at PET2.5%, 5%, 7.5%, and 10% to 25.13, 25, 24.91, and 24.78 KN/m^3 at w/c=0.4 and it decreased to 24.88, 24.7, 24.54, and 24.42 KN/m^3 at w/c=0.55. This is due to the low unit weight of PET particles compared to that of fine aggregate. Other studies had the same results [5,27,28]. The 10%PET mix achieved the minimum dry unit weight compared to that of the control mix at w/c=0.4, and 0.55.

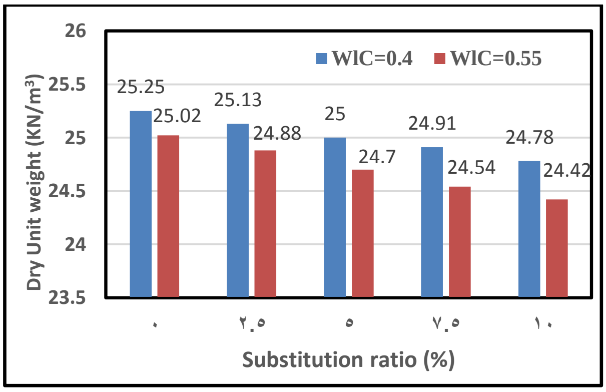

Figure 8: The dry unit weight of PET mixes at various ratios of water to cement at 28 days of curing

4.2.6. Ultrasonic Pulse Velocity

The effect of PET fibers on the ultrasonic pulse velocity was studied. The findings indicated that the higher the PET fibers ratios the lower the ultrasonic pulse velocity as illustrated in Figure 9, where the nature of PET fibers causes many voids in concrete mixtures. Also, Ultrasonic pulse velocity reduced with increment water to cement ratio because extra water evaporates, leaving voids in its place [1,17].

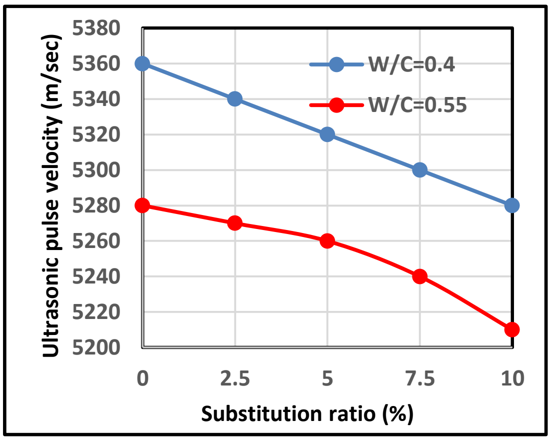

Figure 9: Ultrasonic pulse velocity of PET mixes at various ratios of water to cement at 28 days of curing

4.2.7. Elastic Modulus

The stress-strain curves of the PET and control mixtures were used to determine the modulus of elasticity conforming to ASTM C-469 [29]. Elastic modulus was conducted on PET mixtures and the results compared with that of the reference mix as presented in Figure 10. It was noted that the elastic modulus of PET mixtures decreased with an increase in PET content at w/c=0.4, and 0.55. The relationship between elastic modulus and PET ratios is linear. The main reason for this reduction in elastic modulus is due to the weak adhesion of PET fibers with cement paste [17].

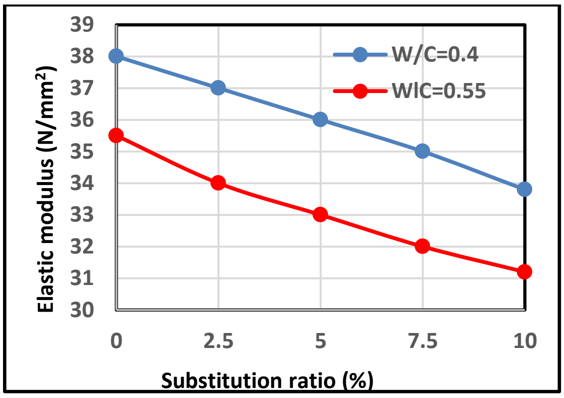

Figure 10: Elastic modulus of PET mixes at various ratios of water to cement

5. CONCLUSIONS

The previous tests led to the following conclusions:

1- The workability of PET fibers mixtures decreased with respect to that of reference mix at w/c=0.4, and 0.55. The higher the PET percentage, the lower the slump values.
2- Absorption rate increased with increasing ratios of PET fibers. The mixture with PET10% showed the maximum absorption rate compared with other PET mixtures, it increased to 2.2%, and 2.3% at ratios of w/c=0.4, and 0.55.
3- The compressive strength of PET mixtures increased at the substitution ratio of PET2.5%, and PET5% by 4.5%, and 7.14% while decreasing by 1.31%, and 3.7% at the substitution ratio of PET7.5%, and PET10%, respectively with w/c=0.4. The compressive strength of PET mixtures at w/c ratios of 0.55 was lower than that of PET mixtures with w/c ratios of 0.4. It was observed the same trend of compressive strength with w/c=0.55. It increased by 5.95%, and 12.39% at substitution ratio of PET2.5%, and PET5% while reduced by 2.85%, and 5.95% at substitution ratio of PET7.5%, and PET10%, respectively. The mixture with 5% PET achieved a maximum increment in compressive strength compared to other PET mixtures.
4- Flexural strength takes the same direction as compressive strength. The flexural strength of PET mixtures increased at replacement ratios of PET2.5%, and PET5% while decreasing at PET7.5%, and PET10% for w/c=0.4 and 0.55.It increased by 4.3%, 7.5% at PET2.5% and PET5% while reduced by 3.7%, and 10.1% at PET7.5%, and PET10% for w/c=0.4. It also increased by 5.4%, 9.3% at PET2.5% and PET5% while decreased by 1.1%, and 4.46% at PET7.5%, and 10% for w/c=0.55.
5- The splitting tensile strength reduced as the content of PET increased at w/c=0.4, and 0.55 with respect to the reference mix. The splitting tensile strength of PET mixtures reduced by 4.5%, 11.36%, 12.5%, and 14.5% at replacement ratios of PET2.5%, PET5%, PET7.5%, and PET10%, respectively, compared with reference mix for w/c=0.4. It takes the same trend at w/c=0.55.The maximum decline of splitting tensile strength was at 10% PET.
5- The dry unit weight of PET mixtures reduced with respect to that of the reference mix. The mixture with 10%PET achieved the minimum dry unit weight compared to that of the control mix at w/c=0.4, and 0.55.
6- The higher the PET fibers ratios in the mixtures the lower the ultrasonic pulse velocity where the nature of PET fibers causes many voids in concrete mixtures.
7- The elastic modulus of PET mixtures decreased with an increase in PET content at w/c=0.4, and 0.55. The relationship between elastic modulus and PET ratios is linear.

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Declaration of competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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