

MECHANICAL PROPERTIES OF CONCRETE REINFORCED WITH ALTERNATIVE FIBERS

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ABSTRACT

The aim of this study is to investigate the capability to use alternative fibers and their effectiveness in improving the mechanical properties of concrete. Alternative fibers made of cut stainless steel rebar tie wire (RTW) and shredded waste plastic bottles, polyethylene terephthalate (PET) has been used. The reason behind choosing these materials is the low cost and availability of them, as well as because nowadays the whole world is facing environment pollution problems, where many things which are invented for our life are responsible for polluting the environment due to improper waste management.

In total, 135 concrete specimens were produced in two stages and subsequently tested; in the first stage of specimen production, steel (RTW) fibers with volume fractions of 1% and 2% were added to M40 concrete mixture, and in the second stage, plastic (PET) fibers with volume fractions of 0.5% and 0.75% were added to M40 concrete mixture. The results indicate that both alternative fibers used have considerable effects on the mechanical properties of concrete, where the mechanical properties were improved at the different percentages used. In general, the use of alternative steel (RTW) fibers and plastic (PET) fibers show a significant enhancement of concrete mechanical properties.

KEYWORDS: Fiber reinforced concrete, rebar tie wire (RTW), Polyethylene terephthalate (PET), recycled fiber, Mechanical properties.

1. INTRODUCTION

Fiber is a small piece of reinforcing material possessing certain distinctive properties, and which can be circular or flat. Fiber is described by its aspect ratio and which is the ratio of fiber's length to its diameter, and fibers with a noncircular cross-section use an equivalent diameter for the calculation of aspect ratio.

Generally, there are different types of fibers and which can be categorized into, natural, synthetic, glass, and steel fibers; Steel and Synthetic Fibers are the most common fibers in the world. The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the concrete. Various studies have covered different mix designs, fiber types, fiber volumes, aspect ratios, and the other mentioned variables, but still, there is a gap in the knowledge of the possibility to use alternative fibers.

PFRC which is an FRC which contains cut recycled polyethylene plastics, as an alternative synthetic reinforcing fiber material has been confirmed to perform better than plain concrete [1,2, and 3]. Sampada Chavan et.al. found that

concrete reinforced with waste PET bottle fibers can be used not only as an effective plastic waste management practice but also as a strategy to produce more economic and sustainable building materials in the future [4].

T.Senthil Vadivel found that the addition of PET fiber in concrete enhanced the compressive strength of specimens and varied with the fiber geometry [5 and 6]. As well as, found that compressive strength of concrete is affected by the addition of plastic bottle fiber and it goes on increasing the percentage of plastic increases in concrete in strength after 28 days curing, [7, 8, and 9].

Also it was found that the addition of fibers in P-FRC attained maximum tensile [5]. They observed that tensile strength of waste plastic fiber reinforced concrete improved as compared to control concrete, and which is consistent with what was reported by [10], [11], and [12]. J.M. Irwan1 et al., proved that PET fiber can enhance the tensile splitting strength of concrete cylinder. The strength of concrete containing PF at 0.5% to 1.5% is increased compared to the normal concrete at all ages [13]. It has also been confirmed by another researcher where found that PF do increase the splitting tensile strength

and the split tensile strength was at 1% of fiber content was 11.21 % over control concrete (0% fibers content) [1]. In addition, [9], found that PF increased the strength about 3.66-25.04%. Also, Tensile strength test results demonstrated that the inclusion of 0.5% PF enhanced the tensile strength, [14]. [15], found that the tensile strength is decreasing when the amount of PET particles increases.

Different types of shredded recycled PET fibers, straight and deformed, together with different fibers lengths, 30 mm and 50 mm, have been assessed, for varying percentage addition in concrete has been shown to lead to interesting improvements in performance for various fiber concrete characteristics and offers a potential alternative for this material [16].

Results of the fiber-reinforced specimens [17] show that the use of fibers in any form and volume fraction resulted in an increase in the compressive strength compared to that of concrete without fibers, results also indicate that an increase in the fiber volume fraction led to an increase in the compressive strength. [18], in their investigations conducted uniaxial compression test on FRC specimens using steel fibers, that is consistent with what was reported by [19, 20].

Other researchers reported that the addition of steel fibers in a concrete matrix improves all mechanical properties of concrete, especially tensile strength [21]. Sallal Al-Owaisy et al., observed that the presence of steel fibers enhances splitting tensile strength and flexural strength significantly [22]. Also, found that the addition of steel fibers always improved concrete flexural strength at the studied percentages [23]. Other results show that SFRC improves the flexural strength [17]. Where, Nataraj et al., stated that SFRC resulted in the increase from 25% to 55% in flexural strength [24]. While results obtained by Shah Surendra et al. showed the increase in strength from 22% to 63% in flexural strength [18].

2. EXPERIMENTAL PROGRAM

A total of 135 specimens were tested, made in three main groups: cubes, cylinders and beams specimens in order to test compressive strength, tensile strength and flexural strength. Each group consists of 45 specimens and two different material were added to the mix, steel rebar tie wire (RTW) and polyethylene terephthalate (PET) fibers. Therefore, the three

main groups classified into three categories (A, B and C). Group A is plain concrete, group B includes specimens with steel fiber by concrete volume ratio of (1% and 2%), whereas group C includes plastic fiber by concrete weight ratio of (0.5% and 0.75%).

For each variable studied in the present investigation, three identical specimens were tested using the same mixing, curing and testing conditions. The details of the parameters which were depended in the current experimental investigation are listed in Table (1).

Table (1): Parameters or variables which were studied in current experimental investigation

Group	Specimens	RTWF	PETF
A	Cube	0%	0%
B	Cube	1%	0%
	Cube	2%	0%
C	Cube	0%	0.50%
	Cube	0%	0.75%
A	Cylinder	0%	0%
B	Cylinder	1%	0%
	Cylinder	2%	0%
C	Cylinder	0%	0.50%
	Cylinder	0%	0.75%
A	Beam	0%	0%
B	Beam	1%	0%
	Beam	2%	0%
C	Beam	0%	0.50%
	Beam	0%	0.75%

3. MATERIALS AND METHOD

3.1 Main Materials

The main materials which were used in preparation of the concrete specimens for present investigation are as follow:

A. Cement: Ordinary Portland cement type I of specific gravity of 3.03 met the specification ASTM C150/C150M-18.

B. Sand: Iraqi local sand from Al-Khazer area of fineness modulus of 2.8 according to ASTM C33/C33M-18.

C. Gravel: Iraqi local rounded gravel from Al-Khazer area of maximum size of 19 mm according to ASTM C33/C33M-18.

D. Water: Potable drinking water is used for mixing and curing.

E. Admixture: High range water reducing admixture (HRWRA) was used which met the ASTM C494/C494M-17 specification.

F. RTW Fiber: Gage 19 low carbon steel rebar ties in coiled wire forms were used to obtain steel fiber with 1.07mm diameter. The stainless-steel wire coiled cutting with 60mm length to use as normal steel fiber replacement as shown

in figure (1-a). Aspect ratio of RTW fibers is 56, calculated by dividing the length on diameter.

G. PET Fiber: water bottle used to obtain the PET fiber, where the plastic bottle shredded longitudinally into small pieces each with 60mm in length and 3mm in width after cleaning and drying process as shown in figure (1-b). The PET fiber aspect ratio is 72, where it is calculated by dividing the length on equivalent diameter.



(a)



(b)

Fig. (1): RTW fibers and PET fibers

3.2 Mix Design Principle

According to the test results of the materials used in this research (cement, sand and gravel), concrete mix was designed by DoE method for a

minimum strength of 40 MPa at 28 days age. The concrete mix proportions were as follows:-
 $417\text{kg/m}^3:622\text{kg/m}^3:1059\text{kg/m}^3:207.6\text{kg/m}^3$
 (Cement, Sand, Gravel, Water), with 80-100mm slump and the High Rang Water Reducing Admixture content is 2% of the cement mass.

3.3 Preparation of Specimens

3.3.1 Mixing and Curing

Concrete ingredients were dried-mixed according to the designed mix proportions, water and HRWRA were added and mixed manually. Before casting the concrete in the cubical molds, the internal surfaces of these molds were oiled. Then concrete poured into the molds in three layers. 150x150x150mm Cubes (BS1881 part 108-02) and 560x150x150mm Beams (ASTM C31/C31M-08b) were compacted 35 and 60 times, respectively using standard square rod that is made of steel (16 mm diameter and 60 cm in length) and rounded or bullet shaped at one end. While, Cylinders (ASTM C31/C31M-08b) were compacted 25 times using a tamping rod that is small Round, straight steel (10 mm diameter × 300 mm long).

3.3.2 Curing Method:

After casting, the specimens were first covered with nylon sheets for about 24 hours to prevent loss of water due to evaporation. Then, the molds have been removed from the specimens and placed inside a curing tank (bath) for continuous moist curing or immersion curing.



Fig.(2): Casted Samples before Curing



Fig. (3): Cured Samples before Testing



Fig. (5): Sample after compression test

3.4 Concrete Testing

3.4.1 Compressive Strength Test

After taking out the concrete cubes from the curing tank, the cubes were allowed to be surface dried in room temperature before testing. Compressive Strength Test was conducted based on BS EN 12390-3:2002, see figures 4 and 5 . The following formula was used to find compressive strength of the samples:

$$\sigma = \frac{P}{A}$$

Where,

σ is compressive strength of a cube, *MPa*,

P is maximum applied load, *N*,

A is area of a cube loaded face, *mm²*



Fig. (4): Compression Testing Machine

3.4.2 Splitting Tensile Strength Test

This test was conducted as per ASTM C 496/C496M-17. The specimens used in this test were cylinders of standard size 150 mm diameter and 300 mm height, see figure 6. After the curing of the specimens, 3 specimens for each age were surface dried and placed horizontally on the compression machine plate. On the other hand, a plywood strips were placed at the top and bottom of the cylinder sample to avoid the crushing of concrete specimen at the points where the bearing surface of the compression testing machine and the cylinder specimen meets. The following formula was used to find the split tensile strength:

$$T = \frac{2P}{\pi DL}$$

Where,

T is splitting tensile strength, *MPa*,

P is maximum applied load indicated by the testing machine, *N*,

D is diameter of the specimen, *mm*,

L is length of the specimen, *mm*.



Fig.(6): Sample after splitting tensile test

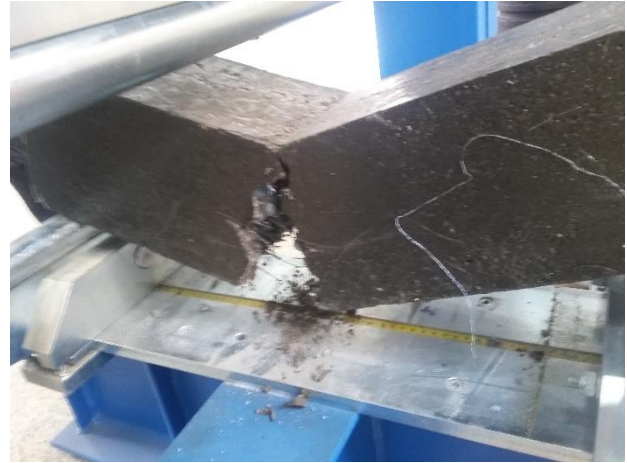


Figure (7): Sample under flexural test

3.4.3 Flexural Strength Test

This test was carried according to ASTM C 293/C293M-16, see figure 7. The specimens used in this test were beams of size 560mm length, 150mm width, and 150mm depth. Where, Center-Point Loading Method was used, in which the entire load is applied at the center of the span. A flexural testing machine was used in carrying conducting this test. After curing, the specimens were surface dried, then the loading and support locations were marked with a marker. The ultimate load was recorded and the following formula has been used to find the modulus of rupture:

$$R = \frac{3PL}{2bd^2}$$

Where,

R is modulus of rupture, *MPa*,

P is maximum applied load indicated by the testing machine, *N*,

L is span length, *mm*,

b is average width of the specimen, at the fracture, *mm*,

d is average depth of specimen, at the fracture, *mm*.

3.4.4 Ultrasonic Pulse Velocity (UPV) Test

This test was conducted as per ASTM C 597/C597-09 using MATEST Ultrasonic Pulse Velocity Tester C372N, as shown in figure 8. The specimens used in this test were cubes of standard size 150 mm length, 150 mm width, and 150 mm depth. Where the outcome of this test is the time sound waves take to move from transducer to receiver through concrete in, to find the velocity the following formula is used:

$$v = \frac{d}{t}$$

Where,

v is the velocity in *m/s*,

d is the path length in the concrete, e.g. distance between the transducers, *m*,

t is the time taken from the UPV tester, *s*.

In addition, in carrying out this test, direct method was used and the samples as mentioned was left to dry before conducting this test. As well as, a greasy substance was applied on the transducers and on the specimen testing surface area, as to minimize the effect of surface voids and the testing surface area was about the centroid of each surface, see figure 9.



Fig. (8): Ultrasonic Pulse Velocity Test



Fig. (9): Sample under ultrasonic testing

4. RESULTS AND DISCUSSION

4.1 Compressive Strength

The results of concrete compressive strength are listed in table 2 and plotted in figure 10 and 11, shows that adding 1% steel RTW fiber to concrete increases its strength about 8% and 16% at 3 days and 28 days respectively, as listed in table 3. Where, it increases the strength to about 23% and 22% at 3 days and 28 days when 2% steel RTW fiber was added. Plastic PET fiber has less effect on concrete compressive strength as it increases the strength to about 6% at 28 days when 0.5% was added. While 0.75% added of PET fiber increases the strength about 9%. The results clearly show that the steel RTW fiber have higher improvement on the compressive strength comparing with plastic PET fiber. This increase in the compressive strength can be explained by the ability of fibers to restrain the extension of cracks, reduce the extent of stress concentration at the tip of cracks, change the direction of cracks, and delay the growth rate of cracks.

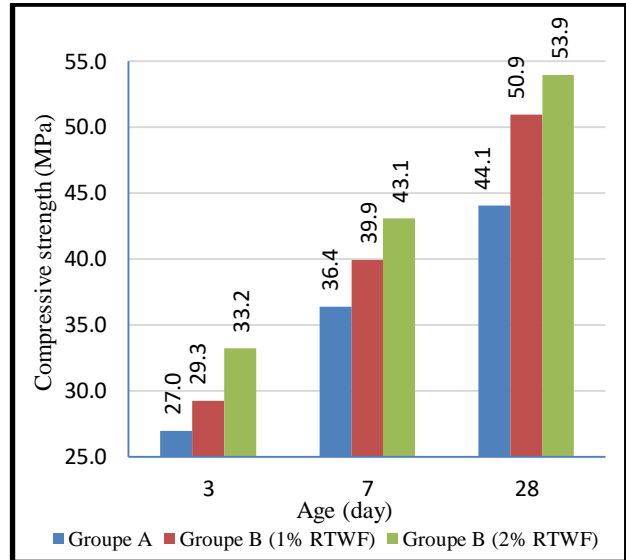


Fig. 10: Relation between the compression strength and the age (RTWF)

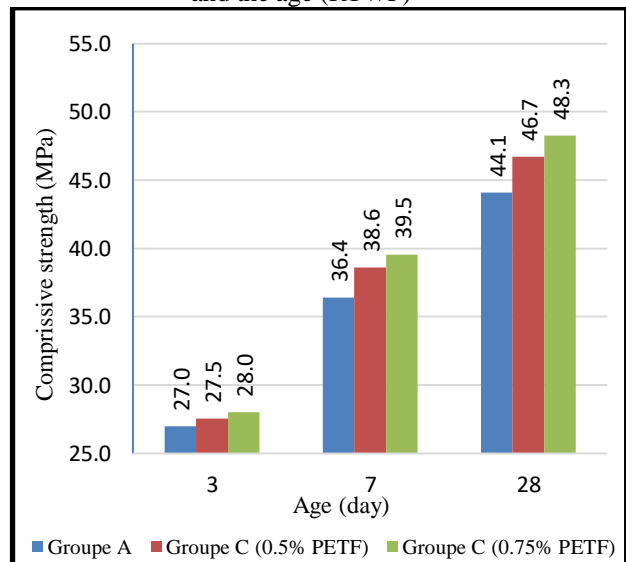


Fig. 11: Relation between the compression strength and the age (PETF)

In term of density, control specimen density was 2362 kg/m^3 and it increases to 2422 kg/m^3 when 1% of steel added and when 2% added the density was 2462 kg/m^3 . On the other hand, the density reduced when plastic added to concrete mixture to 2342 kg/m^3 when 0.5% added and reduced to 2338 kg/m^3 when the ratio was 0.75%.

4.2 Tensile Strength

The result of tensile strength are shown in table 2, figure 12 and 13, show that adding 1% RTW fiber increases tensile strength about 22% at 28 days and up to, 45% when 2% was added, as shown in table 3. Tensile strength affected by adding plastic PET fiber to the mixture but not as much as affected by the steel fiber. The tensile, as a result of bonding enhancement,

increases to about 13% when 0.5% of plastic PET fiber were added and 19% was the increment when the ratio was 0.75%.

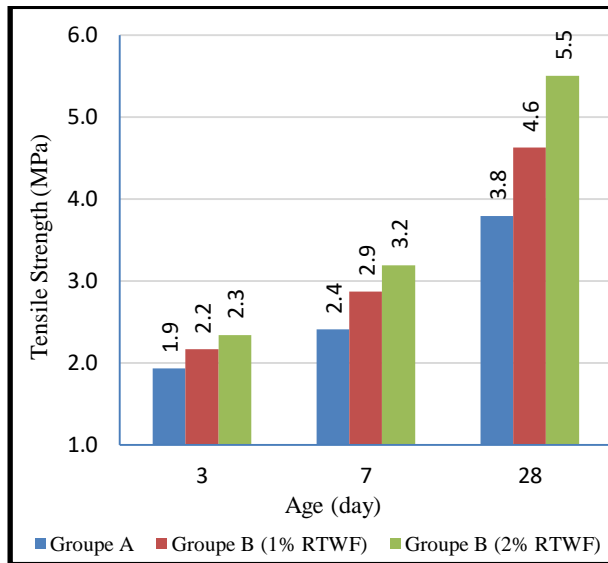


Fig. 12: Relation between the tensile strength and the age (RTWF)

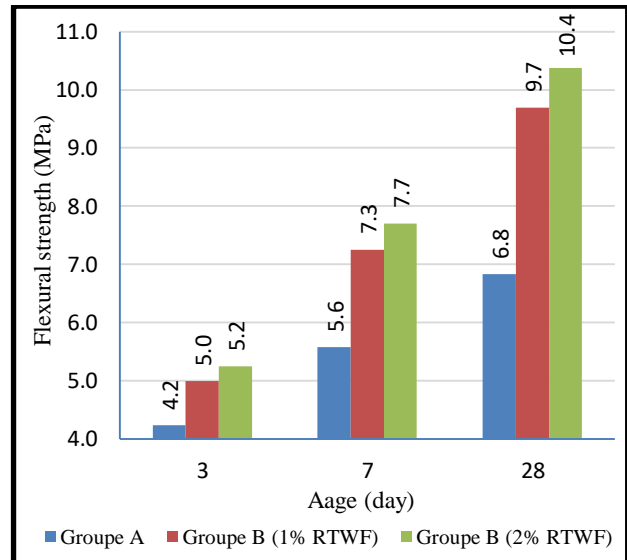


Fig.14: Relation between the flexural strength and the age (RTWF)

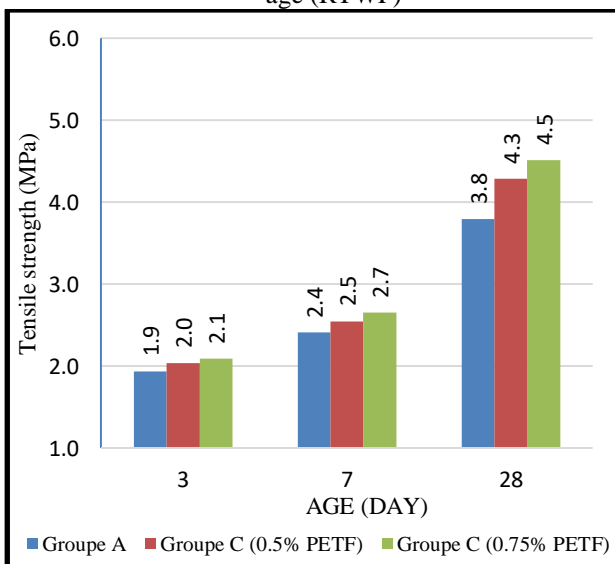


Fig. 13: Relation between the tensile strength and the age (PETF)

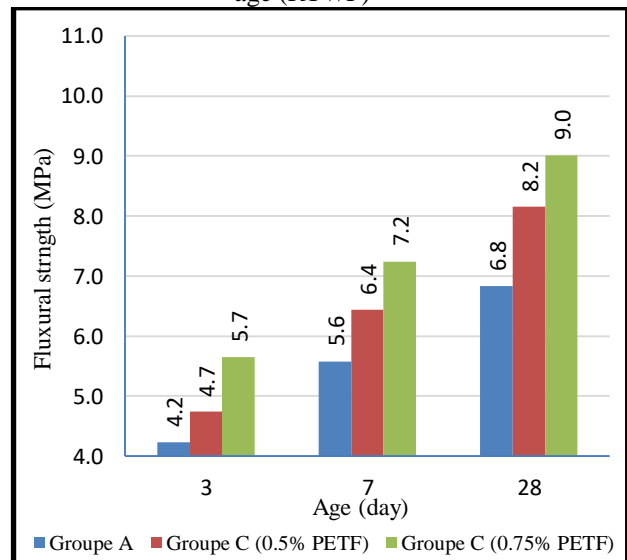


Fig. 15: Relation between the flexural strength and the age (PETF)

4.3 Flexural Strength

Beam specimens show significant influence on results of flexural strength when steel RTW fiber were added, strength increases to 42% when only 1% steel is added and reach 52% when 2% added. Not only steel has significant effect on flexural strength but plastic PET fiber also has increases flexural strength to about 19% when 0.5% plastic is added and to 32% when 0.75 ratio is added as shown in figure 14 and 15.

Table 2: Data result

	Concrete Type	Fiber Content	Age (Day)		
			3	7	28
			Compressive Strength (MPa)	RC	0%
RTWF	1%	29.3		40.0	51.0
	2%	33.3		43.1	54.0
PETF	0.50%	27.5		38.6	46.7
	0.75%	28.0		39.5	48.3
Tensile Strength (MPa)	RC	1%	2.2	2.9	4.6
	RTWF	2%	2.3	3.2	5.5
		0.50%	2.0	2.5	4.3
	PETF	0.75%	2.1	2.7	4.5
		0%	1.9	2.4	3.8
Flexural Strength (MPa)	RC	0%	4.2	5.6	6.8
	RTWF	1%	5.0	7.3	9.7
		2%	5.3	7.7	10.4
	PETF	0.50%	4.7	6.4	8.2
		0.75%	5.7	7.2	9.0

Table 3: Increases in strength with respect to control specimens

	Concrete Type	Fiber Content	3 Days	7 Days	28 Days
Compressive Strength (MPa)	RTWF	1%	8%	10%	16%
		2%	23%	18%	22%
	PETF	0.50%	2%	6%	6%
		0.75%	4%	9%	9%
Tensile Strength (MPa)	RTWF	1%	12%	19%	22%
		2%	21%	33%	45%
	PETF	0.50%	5%	6%	13%
		0.75%	8%	10%	19%
Flexural Strength (MPa)	RTWF	1%	18%	30%	42%
		2%	24%	38%	52%
	PETF	0.50%	12%	15%	19%
		0.75%	34%	30%	32%

4.4 Ultrasonic Pulse Velocity

The results of the UPV test are tabulated in Table 4 and shown in figures 16 and 17. As can be noted that, the UPV has been higher in RTW fiber and the reason related to the fact of the waves where the velocity of pulse gets faster by increasing the density of concrete. On the other hand, the density of Plastic PET fiber is lower than that of plain concrete, this led to a decrease in the plus velocity with the increase of PET fiber percentage, as shown in table 4 and figure 17. In addition, it can be noticed in Figure (16) that the UPV increases when the volume fractions of steel RTW fiber increases.

Table 4: UPV test result

Mix no.	Mixture ID	Fiber volume fraction	UPV (m/s)		
			Age (day)		
			3	7	28
1	plain	0%	4230	4279	4344
2	RTWF	1%	4265	4307	4376
3	RTWF	2%	4303	4342	4407
4	PETF	0.5%	4000	4098	4225
5	PETF	0.75	3977	4087	4198

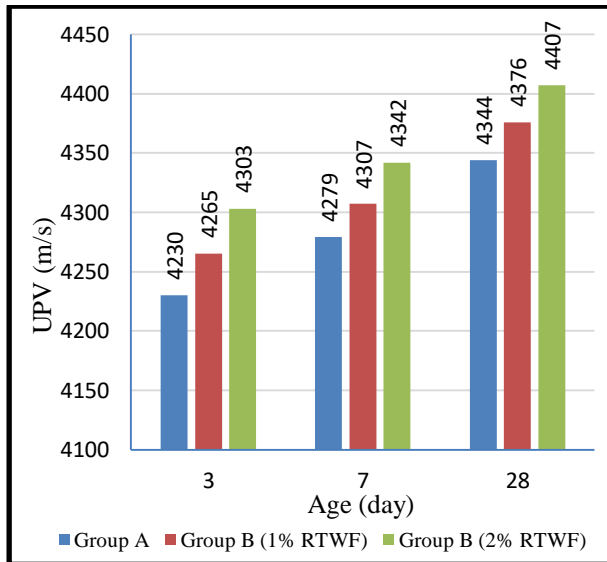


Fig. 16: Relation between UPV test and the age (RTWF)

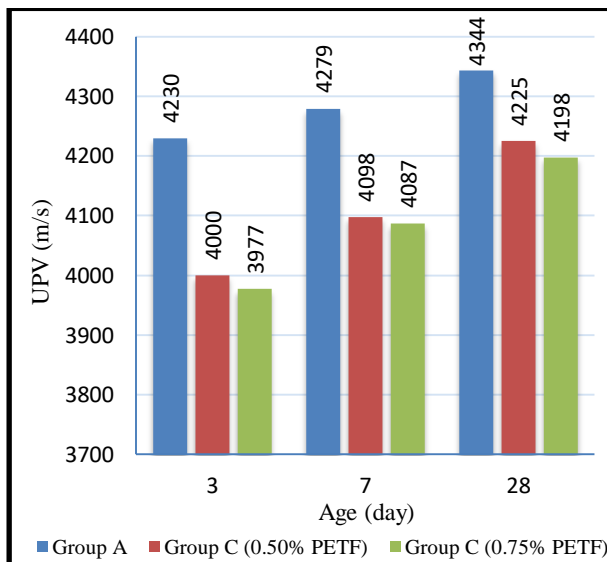


Fig. 17: Relation between UPV test and the age (PETF)

5 CONCLUSION

1. The result show that compressive strength of concrete of RTW fibers is more effected compare to PET fibers. When 2% steel RTW fiber added to the mix the strength increases to 22% and 16% when only 1% added. Plastic PET fiber also contributes to the strength to about 9% when 0.75% added and this result is a consequence of better bonding after adding recycled fibers.

2. Tensile strength of concrete also increases when fiber added. Plastic PET fiber has fewer effects on tensile strength compared with steel fiber. The highest tensile strength increases when 0.75% of plastic PET fiber added is 19%

at 28 days. While tensile strength increases reached to 45% when 2% of steel RTW fiber added. It is clear that steel fiber has a higher effect on the tensile strength of concrete.

3. Beam specimens also show the relative advantage of using additive fiber material in which flexural strength increases to 32% at 28 days when 0.75% of plastic PET fiber used and to 52% when 2% steel RTW fiber used.

4. It's clear that the density of the specimens will effect on the UPV results. Where the velocity pulse decreased with increasing of the plastic fiber ration due to decreasing of the density, while the velocity pulse increased with increasing of steel fiber ratio and that is due to the increase in the density of the specimens.

5. In conclusion steel fiber has high effect on mechanical properties of concrete as shown above. On the other hand, plastic fiber has less effect, but still significant, on the mechanical properties of concrete compared with steel fiber. However, plastic PET and steel RTW fibers have low cost which can be considered as a cheap alternative additive fiber materials.

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