



## COMPRESSIVE STRENGTH MODEL FOR CONCRETE CONTAINING POLYETHYLENE TEREPHTHALATE (PET) BY USING ULTRASONIC PULSE VELOCITY

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**Abstract:** *This research proposed a model describing the relationship between ultrasonic pulse velocity (UPV) and the compressive strength test of concrete containing PET (Polyethylene terephthalate). This was achieved by measuring ultrasonic pulse velocity (UPV) on this type of concrete and comparing the result of compressive strength tests to clarify the accuracy of the ultrasonic test equation for this type of concrete. Waste bottles of water was used in this study by cutting them into laminar form of fibers with zigzag edges in different length (1,2,3) cm for each volume fraction of PET (1%,2% and 3%) by cement weight with fixed width (0.5) cm. Then, they were incorporated with the concrete. It was noticed from the laboratory tests results that the relationship UPV - strength are related together in the volume fraction of 1% for the length 3cm and the correlation factor (R) is equal to 0.94. This indicates a very good exponential relationship between UPV and compressive strength. Also, the results are compared and discussed with another proposed formula that found in literature.*

**Keywords:** Concrete contain PET, Non\_ Destructive tests, Compressive strength, Ultrasonic wave velocity (UPV).

### INTRODUCTION

Fibre-reinforced polymer (FRP) is the alternative techniques in modern life which in continuous progress by using it as a constituent of concrete in the construction industry. Significant research studied the destructive tests of concrete contains polyethylene terephthalate waste (PET) such as compressive strength, modules of elasticity, tensile strength and flexural strength. Moreover, these tests were examined in many of structural members like beams and columns. The ultrasonic techniques became popular within the civil engineering industry for a wide range of applications including the evaluation of concrete structures and pavements. It was used to evaluate the compressive strength of PET concrete.



Benosman et al. (2016) studied the properties of PET-mortar composites by destructive and non-destructive testing with different ratio of fibre (0%, 2.5%, 5% and 7.5%). They found The UPV values of the PET-Mortar composites and compressive strength decrease with an increase in the percentage of the PET waste particles content.

Lorenzi et al. (2007) created model between UPV and compressive strength test. They conducted an analysis for their results in order to understand how the results of UPV are affected by differences at concrete conditions. This can lead into a reduction of the mistakes considering the strength estimation. The results showed that there was a good correlation between compressive strength and UPV test.

Al-Nu'man et al. (2015) proposed the relationship formulas /curve between UPV and compressive strength for concrete having the collection from 18 to 55MPa of concrete strength. After analysing the data, they founded a good correlation between UPV and compressive strength of concrete.

Ammash et al. (2017) study the effect of using plastic waste on mechanical properties of concrete. noticed from laboratory tests that the addition of plastic fibres improves the compressive strength, tensile strength and modulus of rupture of concrete.

The aim of this research is to develop a model for the relationship between UPV and compressive strength for concrete containing Polyethylene terephthalate fibre, and calculate the correlation factor for all the results obtained. Different length of fibre was used (1,2,3) for each fibre content (ratio) (1,2,3) %. To determine which ratio gives the closest result between the compressive strength obtained from destructive and non-destructive tests in order to clarify the accuracy of the ultrasonic equation adopted in previous literature.

## 1. EXPERIMENTAL WORK

In the experimental work, 30 cubes were cast and tested in the laboratory to find the compressive strength for destructive and non-destructive tests of concrete, for different waste ratios. The dimensions of cubes were (150×150×150). The age of the test for all samples was 28 days. All the materials used in this study were tested and compared according to the Iraqi Standard Specification Requirements. The tested materials are:

### 1.1. CEMENT

Ordinary Portland cement was used in the experimental work. The chemical and physical tests were conducted in the construction laboratory of concrete /Engineering collage/ University of Al-Qadisiyah . The results satisfied to Iraqi Specification No.5/1984.The outcomes of the test are shown in **Table 1**.

**Table 1:** Chemical Analysis and Physical Test Results of Cement

Chemical Test Results		
Oxide	Percent weight	Iraqi Specification
SiO <sub>2</sub>	21.3	-
CaO	64.64	-
MgO	2.62	≤5%
Fe <sub>2</sub> O <sub>3</sub>	2.58	-
Al <sub>2</sub> O <sub>3</sub>	6.16	-
Loss on ignition	3	≤4%
Irresolvable material	1.5	≤1.5%



Physical Test Results		
Property	Results	Iraqi Specification
Soundness (Autoclave)%	0.02	≤0.8
Initial setting time (min)	85	≥45
Final setting time (min)	260	≤600
Compressive strength (MPa)		
3 days	16.3	≥15
7 days	23.7	≥23

## 1.2. FINE AGGREGATE

This material was tested and used in the mixture of concrete according to the Iraqi Specification No.45/1984. The results of fine aggregate test were within zone 2 as shown in the **Table 2**.

**Table 2:** Grading of Fine Aggregate Test

Sieve size	% of pass	Iraqi specification
4.75 (mm)	100	90-100
2.36 (mm)	84	75-100
1.18 (mm)	68.7	55-90
600 micron	37.5	35-59
300 micron	9	8-30
150 micron	2.6	0-10
SO <sub>3</sub> salt	Result	Iraqi specification
SO <sub>3</sub> (%)	0.16	≤0.5%

## 1.3. Coarse Aggregate

According to Iraqi Specification No.45/1984, The Shattered Coarse Aggregate was used in the mixture and tested. The results of the test are shown in **Table 3** bellow.

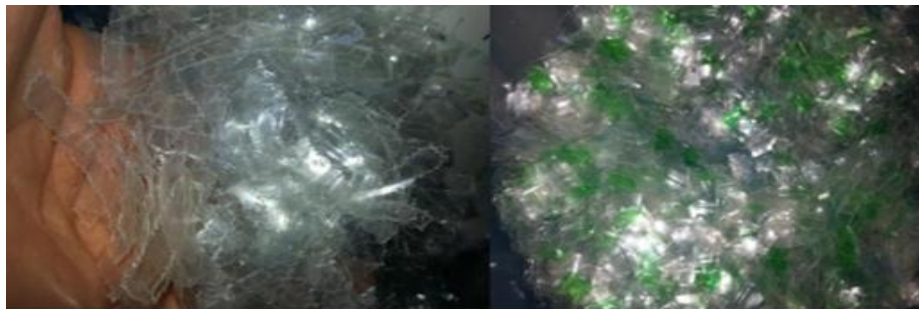
**Table 3:** Grading of Coarse Aggregate Test

Sieve size	% of pass	Iraqi specification
37.5 (mm)	100	100
20 (mm)	100	75-100
12.5 (mm)	88.50	-
9.5 (mm)	33.59	30-6

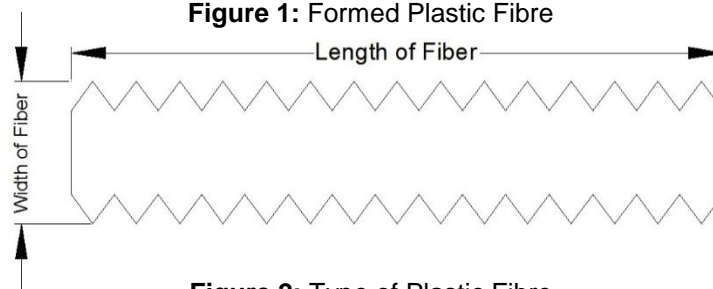
4.75 (mm)	0.5	0-10
2.36 (mm)	0.07	-
SO <sub>3</sub> salt	Result	Iraqi specification
SO <sub>3</sub> (%)	0.09	≤0.1%

#### 1.4. Plastic Fiber

Waste bottles of water were used by cutting them into small fibers with zigzag edges in different length (1,2,3) cm for each ratio of PET (1%,2% and 3%) by cement weight with fixed width (0.5) cm. Then, they were added to the concrete mixes. (**Figure 1 and 2**).



**Figure 1: Formed Plastic Fibre**



**Figure 2: Type of Plastic Fibre**

By using theory of Archimedes, the density of fibre was equal to  $1.01 \text{ gm/cm}^3$ . As well as, many tests have been conducted by using tensile test machine such as yield stress, elongation and ultimate stress. The results of these tests were equal to 7.15 kN, 8 mm and 8.25 kN respectively.

#### 1.5. MIXING, CASTING AND CURING

The concrete reference mix consists of cement, sand and coarse aggregates with no fiber. The dry materials were mixed together then; the plastic fiber were gradually added to the mix to avoid blocking of concrete. Finally, the water was added to the dry materials and the mixing continued to produce homogeneous mix. The fresh concrete was cast into the moulds immediately after mixing, in three layers for cube specimens.

## 2. RESULT AND DISCUSSION

The following laboratory tests were implemented in the University of Al-Qadisiyah / College of Engineering.



## 2.1. COMPRESSIVE STRENGTHS TEST

the average of three specimens results from compressive strength test was recorded and listed in **Table 4**.

## 2.2. ULTRASONIC PULSE VELOCITY TEST

Ultrasonic pulse velocity (UPV) test mainly measures the speed of electronic wave through composite concrete. the ultrasonic pulse velocity tests are summarized by placing transducers in the same direction in opposite face of each face as shown in the **Figure (3)** . This method is called direct transmission. It gives a more accurate results than other method. During the test, the ultrasonic waves are passing from one transducer to the other. The time of the traveling the waves was recorded from one surface to the other and measured the distance between the two faces of the cubes. In this way, the velocity of the ultrasonic wave can be calculated. The results of ultrasonic pulse velocity are listed in **Table 5**.

**Table 4:** Compressive Strength( $F'_c$ ) for all Specimens (MPa)

Ref. Mix	Compressive Strength For 10 mm Fibre Length			Compressive Strength For 20 mm Fibre Length			Compressive Strength For 30 mm Fibre Length		
	1%	2%	3%	1%	2%	3%	1%	2%	3%
30.76	30.13	30.58	28.84	31.07	26.53	27.60	23.73	24.98	18.44
31.24	30.89	27.73	29.64	30.76	29.51	28.98	26.27	30.71	16.89
29.69	29.07	26.13	27.78	30.13	25.64	22.22	25.78	26.84	19.78

**Table 5:** Ultrasonic Pulse Velocity for all Specimens (m/s)

Age	Ref. Mix	UPV For 10 mm Fibre Length			UPV For 20 mm Fibre Length			UPV For 30 mm Fibre Length		
		1%	2%	3%	1%	2%	3%	1%	2%	3%
28 days	4.01	3.83	3.87	3.92	3.89	3.65	3.89	3.65	3.87	3.85
	3.88	3.73	3.95	3.88	3.78	3.85	3.84	3.88	3.85	3.88
	3.78	3.71	4.05	3.79	3.82	3.82	3.82	3.90	3.81	3.93

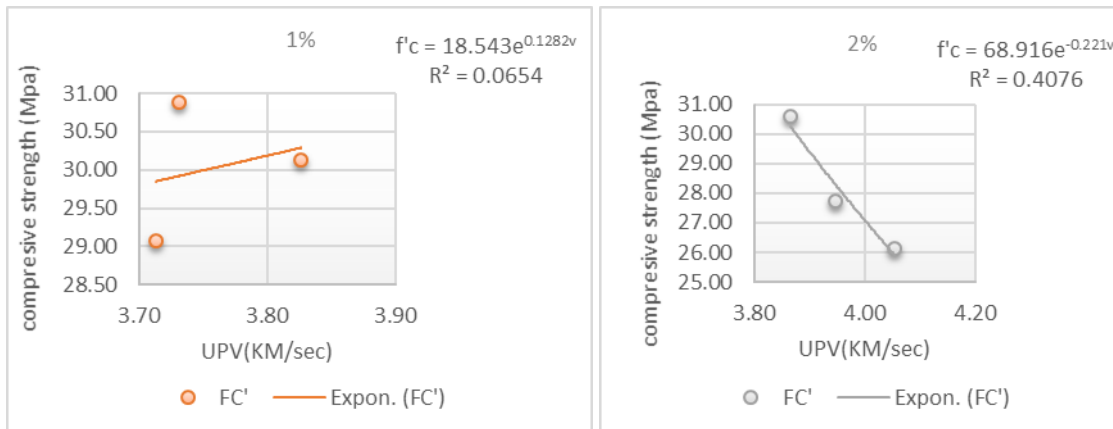


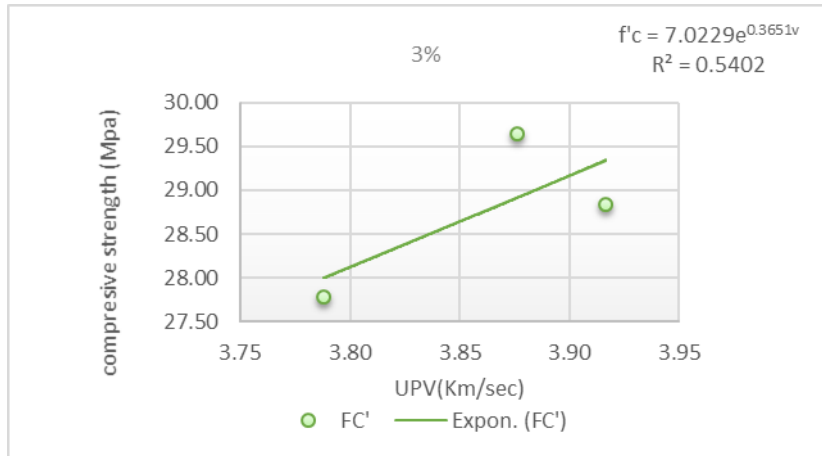
Figure 3: Ultrasonic Pulse Velocity Device

### 3. THE RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND UPV

The ultrasonic pulse velocity (UPV) can be related to compressive strength of concrete. Based on the value of the correlation coefficient (R), the strength of the relationship varies. Thus, this relationship is used to classify the sample of the concrete containing PET.

For the length 1cm with ratio (1%,2%) there is positive relationship, however this relationship is weak. While the ratio 3% for the same length showed a close relationship as shown in **Figure 4**.





**Figure 4:** Relationship Between UPV and Compressive Strength for Length 1cm

Remark: X axis present pulse velocity and Y axis present compressive strength.

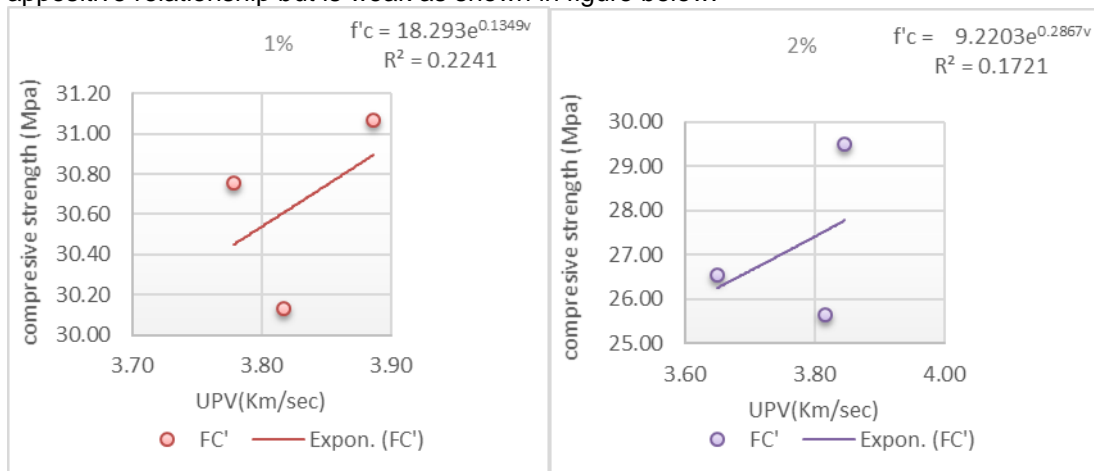
The value of compressive strength is accounted by exponential relationship curve with UPV (see **Figure 5**). The following model (proposed formal) is founded between compressive strength (Mpa) and UPV (m/s).

1% adding the model is  $f'c = 18.543e^{0.1282v}$   $R = 0.0654$  .....(1)

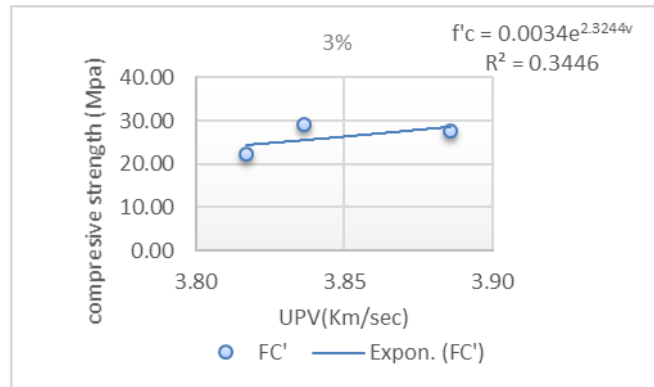
2% adding the model is  $f'c = 68.916e^{-0.221v}$   $R = 0.4076$ .....(2)

3% adding the model is  $f'c = 7.0229e^{0.3651v}$   $R = 0.5402$ ..... (3)

Heterogeneous nature of this composite concrete. For the length 2 cm with ratio (1%,2%,3%) there is appositive relationship but is weak as shown in figure below.







**Figure 5:** Relationship Curve Between UPV and Compressive Strength

for length 2cm

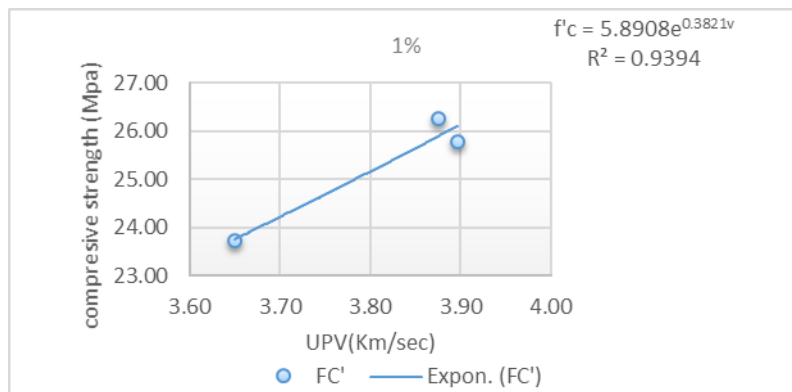
The following model (proposed formals) is founded between compressive strength (Mpa) and UPV (m/s)

1% adding the model is  $f'c = 18.293e^{0.1349v}$   $R = 0.2241$ ..... (4)

2% adding the model is  $f'c = 9.2203e^{0.2867v}$   $R=0.1721$  .....(5)

3% adding the model is  $f'c = 0.0034e^{2.3244v}$   $R = 0.3446$  .....(6)

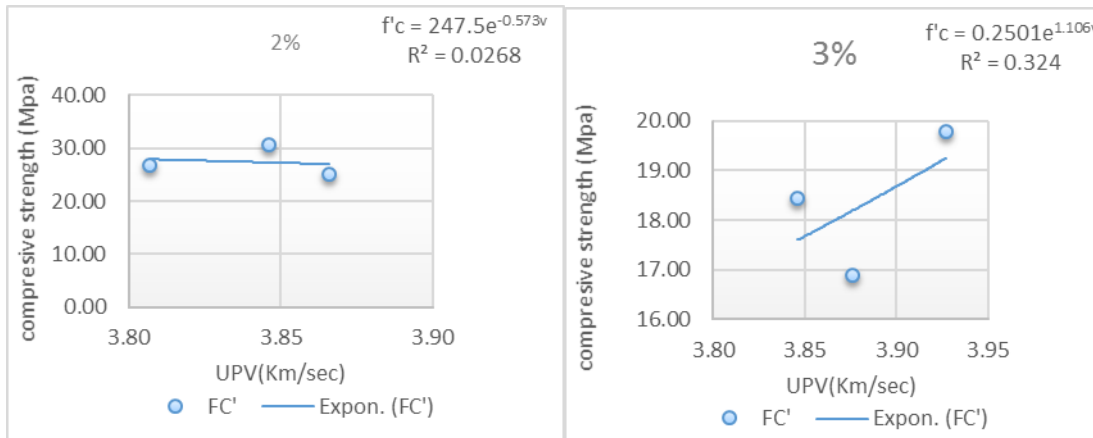
For the length 3 cm with ratio (1%) there is a strong related to each other. The correlation factor (R) is equal 0.94 as shown in **Figure 6** below:



**Figure 6:** Relationship Curve Between UPV and Compressive Strength for Length 3cm and ratio 1%

While the ratio (2%,3%) of adding PET for the same length (3 cm) is weak. As shown in **Figure** below.





**Figure 7:** relationship Curve between UPV and compressive strength for length 3cm and ratio 2%,3%

The following model (proposed formal) is founded between compressive strength (Mpa) and UPV (m/s)

1% adding the model is  $f'c = 5.8908e^{0.3821v}$   $R=0.94$  .....(7)

2% adding the model is  $f'c = 247.5e^{-0.573v}$   $R = 0.0268$  .....(8)

3% adding the model is  $f'c = 0.2501e^{1.106v}$   $R = 0.324$  ..... (9)



#### 4. COMPRASSION WITH OTHER MODLES

Al-Nu'man et al.(2015), equations proposed depended on density of course aggregate factor as shown below:

$$F'c= 8.88 e 0.42 v \quad R= 0.83 \quad \text{for CA} =1000 \text{ Kg/m}^3 \dots\dots\dots (10)$$

$$F'c=0.06 e1.6v \quad R=0.87 \quad \text{for CA}= 1200\text{Kg/m}^3 \dots\dots\dots (11)$$

$$F'c=1.03 e0.87v \quad R=0.88 \quad \text{for CA}= 1300\text{Kg/m}^3 \dots\dots\dots (12)$$

$$F'c=1.39 e0.78v \quad R=0.84 \quad \text{for CA}= 1400\text{Kg/m}^3 \dots\dots\dots (13)$$

They considered course aggregate content as a key factor that capable to determining the better relationship between UPV and compressive strength of concrete. In comparison with data of this research, it could be seen the main factor were fibers plastic content. For lengths (1 and 2) cm increase the ratio of fibers lead to more correlated between UPV and compressive strength. In a more suitable way, the previous equations for both lengths can be rewritten as follows:

For length 1cm:

$$1\% \text{ fibres plastic} \quad f'c = 18.5 e0.13v \quad R = 0.07 \dots\dots\dots (14)$$

$$2\% \text{ fibres plastic} \quad f'c = 68.9 e-0.22v \quad R = 0.4\dots\dots\dots (15)$$

$$3\% \text{ fibres plastic} \quad f'c= 7 e0.4v \quad R = 0.5\dots\dots\dots (16)$$

For length 2cm:

$$1\% \text{ fibres plastic} \quad f'c = 18 e0.13v \quad R = 0.2\dots\dots\dots (17)$$

$$2\% \text{ fibres plastic} \quad f'c = 9 e0.3v \quad R=0.2\dots\dots\dots(16)$$

$$3\% \text{ fibres plastic} \quad f'c = 0.003 e2.3v \quad R = 0.35 \dots\dots\dots(19)$$

But, the length (3) cm with ratio (1%) achieve the better relationship between point data and slop curve. The correlation factor was equal 0.94. It can be say, this length was as a bridge connecting the components of mixture concrete. In addition, it was filling the gaps inside of the mixture. These gave more continuity to the transmission of waves without interruption. Also, in a more suitable way, the previous equations for length (3) cm can be rewritten as follows:

$$1\% \text{ fibres plastic} \quad f'c = 6 e0.4v \quad R=0.94\dots\dots\dots (20)$$

$$2\% \text{ fibres plastic} \quad f'c = 248 e-0.6v \quad R = 0.03 \dots\dots\dots (21)$$

$$3\% \text{ fibres plastic} \quad f'c = 0.3 e1.12v \quad R = 0.32 \dots\dots\dots (22)$$

For the reference mixture (0% plastic), the proposal formula was

$$f'c=18e0.14v \quad R^2 = 0.4$$



## 5. COMPARISON BETWEEN COMPRESSIVE STRENGTH RESULTS FOR DESTRUCTIVE AND NON-DESTRUCTIVE TEST

Table below shows the result of destructive and non-destructive test.

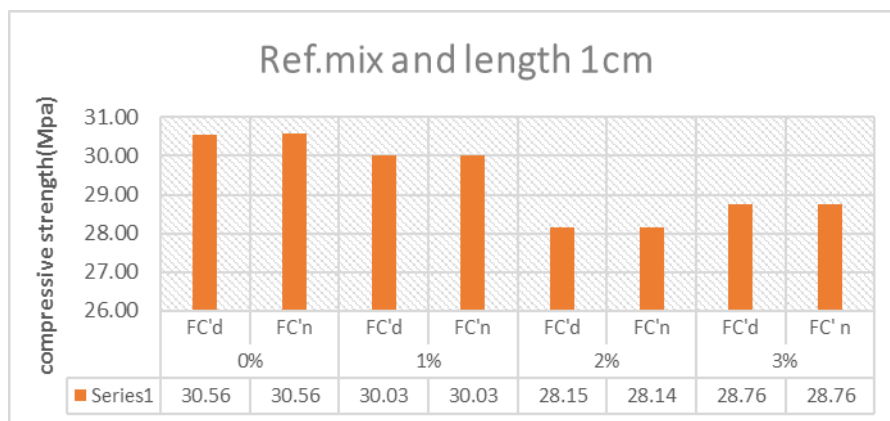
**Table 6:** Result of Destructive and Non-Destructive Test for all Specimens (MPa)

0%( Ref. Mix)		1cm length						2cm length						3cm length					
		1%		2%		3%		1%		2%		3%		1%		2%		3%	
F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>	F' <sub>Cd</sub>	F' <sub>Cn</sub>
31.1	30.8	30.3	30.1	30.2	30.6	29.3	28.8	30.9	31.1	26.3	26.5	28.5	27.6	23.8	23.7	27.2	25.0	17.6	18.4
30.5	31.2	29.9	30.9	28.3	27.7	28.9	29.6	30.4	30.8	27.8	29.5	25.7	29.0	25.9	26.3	27.4	30.7	18.2	16.9
30.1	29.7	29.9	29.1	25.9	26.1	28.0	27.8	30.6	30.1	27.5	25.6	24.6	22.2	26.1	25.8	28.0	26.8	19.3	19.8

Remark: F'<sub>Cd</sub>= compressive strength from destructive test.

F'<sub>Cn</sub>= compressive strength from non-destructive test.

The data was presented in the graphical shape as shown in the **Figures** below:



**Figure 8:** Comparison between Destructive and Non-Destructive Test for Reference mix and Length 1cm

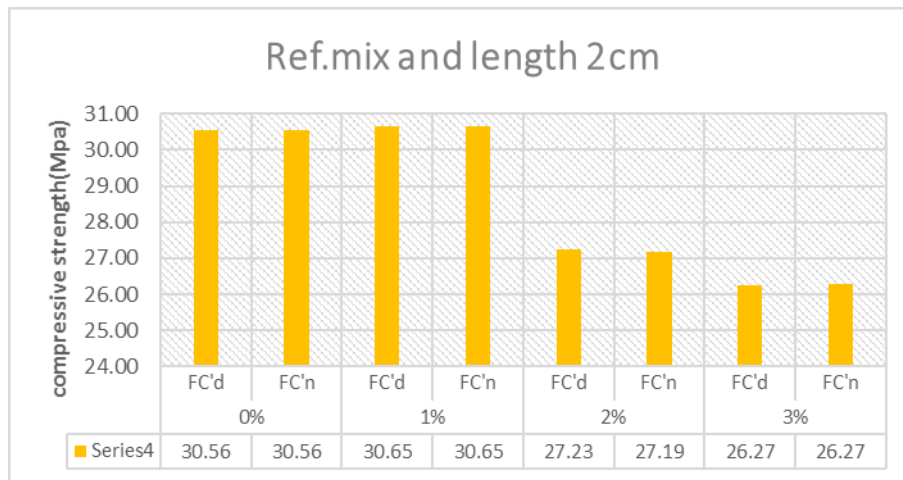


Figure 9: Comparison between Destructive and Non- Destructive Test for the Length 2cm

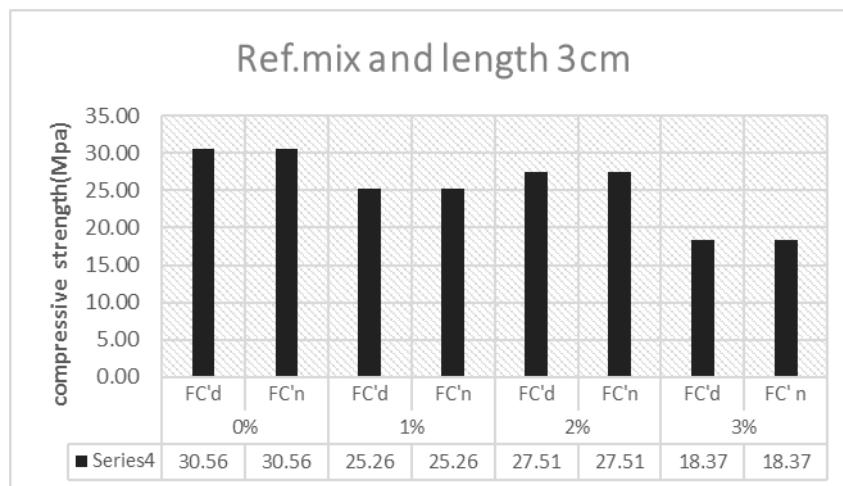


Figure 10: Comparison between Destructive and Non- Destructive Test for the Length 3cm

It can be seen that, there were a big proximity in results between strength obtained from destructive and non-destructive test. The results show, it can have used UPV to estimate the compressive strength of concrete contain PET by modified the proposal formulas according to mention above. This is a very good indicator to use waste bottle water in concrete.

## 6. CONCLUSION AND RECOMMENDATIO

To evaluate the concrete strength by using UPV test, it must follow the following rule:

UPV should be greater than 3.5km/sec otherwise the concrete considered unsuitable and weak.

The proposal equation to calculate strength of hardened concrete by using UPV was according to the ratio of adding as mentioned above. Therefore, there is no exceptional relationship can be recognized to cover all concrete specimens.



Also, the results of this study show that the ratio (1%) for length (3 cm) gives the closest result between the compression strength calculated from destructive and non-destructive test to clarify the accuracy of the ultrasonic equation test because the correlation factor (R) is equal 0.94. This beyond to the following:

- This ratio in this length gives homogeneity components of the mixture. This helps to fill the voids without discontinues waves.
- The edge of the fibre in form of zigzag give strong bond between the fiber and the mixture without segregation in components of it. This also gives the waves that are transferred continuously without interruptions.

For future study, the following point are recommended:

- Develop this study, by increased the number of samples to achieve the accuracy of the ultrasonic equation test for this type of concrete.
- Used indirect test method instead of method used in this study to understand their effect on the results.
- Chang the water cement ratio and increased the ratio of adding plastic as a ratio of the cement weight

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