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PERFORMANCE OF CONCRETE CONTAINING WASTE PLASTIC STRAW FIBERS

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Abstract

Using fibers in concrete applications has become a common practice. This is partly due to improvement in ductility and crack control of concrete. There will be an added advantage if these fibers come from a waste source as it would lead to reduction in environmental pollution and the need for landfill spaces. This paper forms the initial part of a wide range investigation on the use of waste plastic fibers in concrete applications. This study attempts to apply the concept of sustainability and reduces the environmental pollution by producing fibers from waste plastic straws and adding them to plain concrete to improve the tensile strength and ductility. The experimental work was carried to examine the effect of including waste plastic fibers on the properties of concrete. The fiber percentages used were 0%, 0.5%, 1.5% and 3%. Testing included workability, density, compressive and tensile strength, ultrasonic pulse velocity and length change. Generally, the addition of waste plastic fibers increased the tensile strength, whereas there was a slight reduction in compressive strength when more plastic fibers were added. The ultrasonic pulse velocity and density show a slight decrease in the presence of fibers.

Keywords

Fibers, Strength, Sustainability, Plastic straw, Waste

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1. INTRODUCTION

The global increase in population and human activities have led to drastic generation of waste including plastic wastes. The world's annual consumption of plastic materials has reached an alarming 200 million tons in 2017 compared with nearly 5 million tons in 1950 (Ritchie & Roser, 2019). The plastic wastes may be classified be considered as non-degradable if left untreated. Waste plastic is normally sent to landfill. Therefore utilizing plastic waste as well as other waste instead of its disposal is advantageous in terms of saving land space and reducing the impact on the environment (Ghanem *et al.* 2019, Machaka *et al.* 2019, Machaka *et al.* 2017).

Kandasamy and Murugesan (2011) used plastic cups as a fiber. Two mixes were considered; a normal mix without fiber, and a mix with 0.5% of added fibers by weight of cement. It was found that there is enhancement in both compressive strength and tensile strength in the presence of fibers.

Batayneh *et al.* (2006) evaluated the possibility of using waste plastic bottles and granulated plastic waste in concrete. The fiber addition ranged from 0% to 2% by volume of concrete. The results show that there a decrease in slump and compaction factor when fibers are present in the concrete. The higher the content the fiber the larger the reduction in slump and compaction factors.

Belarbi and Acun (2013) examined the effect of incorporating fibers on the compressive and tensile strength of concrete. The reading was noted at the time of first crack and at the time of failure. The required quantity of ingredients was weighed and were prepared cylinders with the help of molds and cured for 7 days and 28 days. It is found that the compressive strength is increased while placing only the fiber. The split tensile strength has been increased while using plastic fiber sheet at the outer side of the specimen.

Ahmed *et al.* (2016) studied the effect of different addition of waste plastic fibers addition on the strength properties of concrete. Generally, the compressive, tensile and flexural strength were found to increase as the percentage of fibers increased from 0% to 3%. The increase in compressive strength was about 13% whereas the increase in tensile strength and flexural strength was 38% and 68% respectively when adding more fibers to the concrete.

In another investigation, Jones (1974) compared the compressive and flexural strength of concrete with and without asbestos fibers at different curing periods. They found that increasing the amount of fibers up to a certain level leads to an increase in both compressive and flexural strength at all curing ages. However, beyond that level, no further increase in strength was noticed.

There is limited work done on the incorporation of fibers, made from waste plastic straw, on the properties of concrete. For this purpose, 4 different percentages 0%, 0.5%, 1.5%, 3% of plastic fibers were introduced to the concrete mix in the aim of studying their effect on concrete properties. Properties included; compressive strength, ultrasonic pulse velocity, drying shrinkage and autogenous shrinkage. Future investigation will examine the impact behavior of structural elements containing this type of fibers, waste material and other less energy intensive material (Khatib *et al.* 2018, Jahami *et al.* 2018, Jahami *et al.* 2019, Khatib *et al.* 2019[a], Khatib *et al.* 2019[b]).

2. EXPERIMENTAL WORK

2.1 Mix Design

Four trial mixes were prepared in this experiment as an attempt to get on the perfect mixture with good workability and compressive strength equal to 25 MPa at 28 days. The proportions of the mixture were 1 (cement) : 1 (fine aggregate) : 2 (coarse aggregate) by weight and the water-cement ratio (W/C) was 0.4. The cement used in the concrete mix was of type 1. The coarse aggregates used consisted of a 10mm crushed limestone, having a density of 2550 kg /m^3. While the fine aggregate used consisted of a 5mm sand, having a density of 2650 kg /m^3. The waste plastic straws (WPS) were made from polypropylene and have a density of 975 Kg/m^3. They were obtained from a local restaurant and were shredded and cut to 2mm in width and 30mm in length (Figure 1).

The addition of WPS to the concrete mix affected the workability of the mixture and it was necessary to use a chemical whose properties are presented in Table 1. The dosage of admixture was increased as the percentage of WPS fibers increased; to attain adequate workability for all mixes. More details of the four mixes are shown in Table 2.

Table 1: Properties of the admixture used in the concrete mix

Color	Storage temperature	Chemical base	Density	PH value	Quantity	Mixing time
Yellowish liquid	$+5^{\circ}C$ to $+35^{\circ}C$	Synthetic Poly Carboxylates Ethers	1.05 Kg/L	~ 4.3 + 0.5	0.6 - 2% of the weight of cement	60s

Table 2: Details of concrete mixes

	Weight (Kg)					
Samples	Cement	Sand	Water	Gravel	WPS*	Admixture**
PS-0	670	670	270	1340	0	0
PS-0.5	670	670	270	1340	0.5	0.1
PS-1.5	670	670	270	1340	1.5	0.15
PS-3	670	670	270	1340	3	0.2

*% of waste plastic straws (WPS) by volume of concrete.
**By weight of cement (Kg).

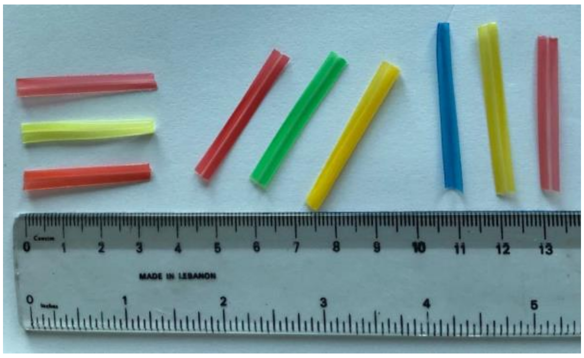

Fig.1: Shredded waste plastic straws (WPS).

2.2 Mixing Procedure and Casting

After preparing all the quantities needed, they were placed in a suitable mixer. The mixing procedure was carried out according to ASTM Standards 31/C 31M. A drum-type mixer was used as shown in Figure 2. First, the coarse and fine aggregates were placed in the mixer, followed by the cement and the WPS fibers. The dry materials were mixed for two minutes. Two third of the water was added gradually to the mix. Mixing continued for two minutes. Finally, the admixture and the remaining water were mixed and added to the mix until a homogeneous mix is achieved.

For each mix, six (10cm diameter and 20cm length) cylindrical specimens and three cubes of 10cm in size were cast. Specimens were compacted to guaranty that no air bubbles trapped inside the concrete (Figure 3). Then, the slump test was conducted for all mixes. The slump value was, 5.3, 4.7, 1.5 and 0.7cm for mixes with 0%, 0.5%, 1.5% and 3% respectively. The presence of fibers reduced the slump. After casting, the specimens were covered with plastic sheeting and left in the molds until demolding. This normally took 24 hours. The specimens were then placed in a water bath at 20C until the time of testing as shown in Figure 4.

Fig.2: Concrete mixer.

Fig.3: Compacting using a tamping rod.

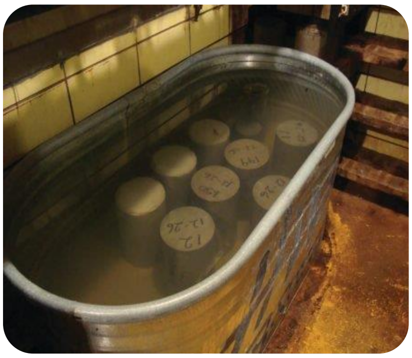

Fig.4: Curing of specimens.

2.3 Testing

The concrete cylinders were used to determine the compressive strength according to ASTM standard (ASTM C39 / C39M – 18). An Amsler compression machine was used. The cylinders were placed vertically with their circular area perpendicular to the applied axial load. The load was increased until failure as shown in Figure 5.

The split tensile strength test is determined according to ASTM C496 / C496M – 17. The concrete cylinders were placed horizontally along its length. A vertical load (P) was applied gradually until failure. This is shown in Figure 6. Equation 1 was used to calculate the split tensile strength (T) in MPa as follows:

$$\text{Eq. (1)} \quad T= 2P/ \pi \times L \times D$$

Where D and L are the diameter and length of the cylinder in mm respectively and P is the maximum applied load in (N).

Fig.5: Specimen under compressive strength test

Fig.6: Specimen under splitting tensile test

The cylindrical specimens were also used to determine the ultrasonic pulse velocity (UPV) according to ASTM C597 – 16. The UPV in Km/s was calculated according to Equation 2 as follows:

$$\text{Eq. (2)} \quad UPV=L/T$$

Where L is the length of the cylinder (path length) in Km and T is the transit time in seconds. Figure 7 show the UPV testing setup.

Fig.7: Pulse velocity of the concrete specimens.

3. RESULTS AND DISCUSSION

3.1 Density

Mass density was measured for all mixes, and then the average density was presented in Figure 8. It can be noticed that control mix had slightly higher density (2501 Kg/m^3) than the other mixes containing fibers. The percentage decrease were 2.2%, 4.4% and 7.7% for concretes containing 0.5%, 1.5% and 3% WPS respectively.

3.2 Compressive Strength

Figure 9 shows the variation of compressive with curing time for concretes containing varying amounts of WPS. At 0.5% WPS, there is hardly any change in compressive strength compared to the control (PS-0). However, beyond 0.5%, there is reduction in compressive strength by around 24% and 37% for mixes containing 1.5% and 3% WPS respectively. This may be due to the voids created by the interfacial bond between the fibers and the concrete matrix or the lack of full compaction in the presence of fibers. Figure 10 shows the damaged cylinders for both PS-3 and PS-0 respectively. The mode of failure seems to be similar to both concretes with or without fibers.

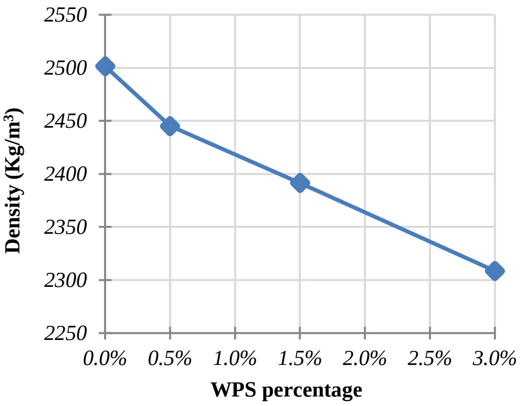

Fig.8: Density for concrete mixes

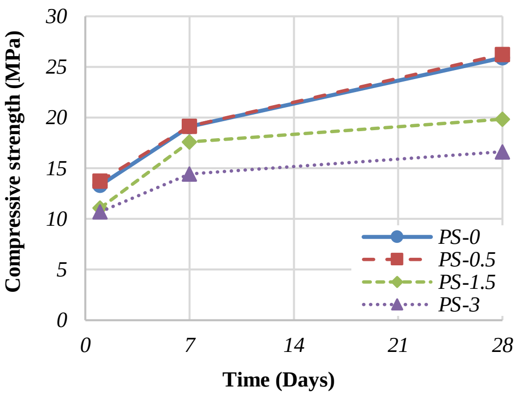

Fig.9: Compressive strength for all mixes

a) PS-0

b) PS-3

Fig.10: Compression damage for specimen a) PS-0 and b) PS-3

3.3 Tensile Strength

Figure 11 shows the splitting tensile development with age. There is a systematic increase in tensile strength with the increase in fiber addition. This may be due to the relatively higher tensile strength of the fibers compared with that of concrete. Using 3% of PS fibers resulted in a 10% increase in tensile strength at 28 days of curing. Table 3 presents the ratio between tensile and compressive strength for all concrete mixes. This ratio increases as the percentage of PS fibers increases. Concrete with 0% PS fibers (PS-0) has a percentage ratio of 0.15 compared with 0.25 for concrete with 3% PS fibers. Figure 12 shows the good distribution of fibers in concrete samples after the failure of specimens.

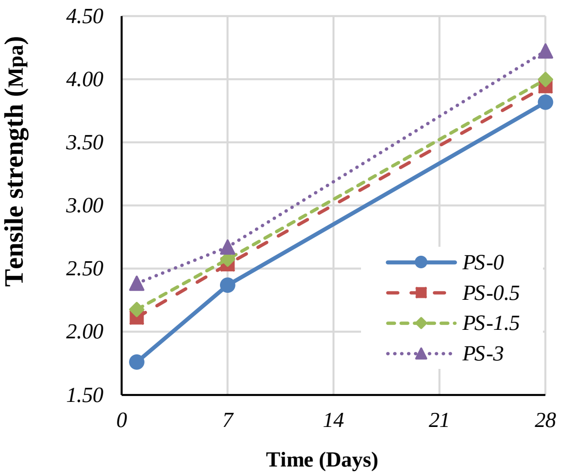

Fig.11: Tensile strength for concrete mixes

Fig.12: Fiber distribution after testing for PS-0.5 sample

Table 3: Ratio between tensile and compressive strength

Test day	PS-0	PS-0.5	PS-1.5	PS-3
Day 1	0.13	0.15	0.20	0.22
Day 7	0.12	0.13	0.15	0.19
Day 28	0.15	0.15	0.20	0.25

3.4 Ultrasonic Pulse Velocity (UPV)

The UPV test results are represented in Figure 13. Concretes with 0.5% PS fibers recorded the highest UPV values, and that this trend is similar to the compressive strength results. In other words, a slightly higher strength for the mix containing 0.5% WPS led to a higher UPV value.

Generally, there is a correlation between compressive strength and UPV and this has been examined by various researchers (Khatib 2008[a], Khatib 2008[b]). One of them is the research done by (Shakir Al-Aasm 2018) that suggested a relation to link the UPV in km/s with the cube compressive strength (f'_c) in MPa as shown in Eq. (3):

$$\text{Eq. (3)} \quad f'c = Me^{1.3(UPV)}$$

Where M=0.11-0.019(AC/C/ρ), AC/C is the Aggregate Content to Cement Ratio and ρ is the density of concrete in g/cm3.

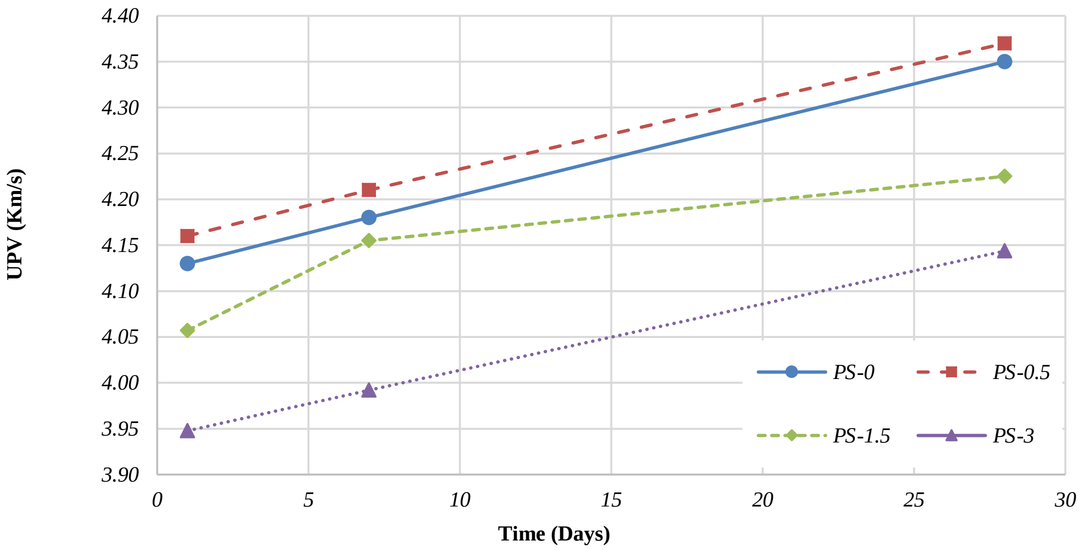

Fig.13: UPV test results

Table 4 shows the predicted compressive strength by (Shakir Al-Aasm 2018) compared to the experimental strength. It can be realized that the error between the correlated value (f'cc) to the experimental value (f'ce) for reference sample PS-0 was 3.9% only. As for samples containing WPS the error percentage was 3.1%, 6.1%, and 11.5% for concrete with 0.5% WPS (PS-0.5), concrete with 1.5% WPS (PS-1.5), and concrete with 3% WPS (PS-3) respectively. These percentages prove the suitability of Shakir's formula.

Table 4: Application of correlation equation (Shakir Al-Aasm 2018)

	PS-0	PS-0.5	PS-1.5	PS-3
AC/C	3.000	3.000	3.000	3.000
ρ (g/cm^3)	2.500	2.450	2.390	2.310
M	0.087	0.087	0.086	0.085
B	1.300	1.300	1.300	1.300
V (Km/s)	4.350	4.370	4.230	4.140
f'cc (MPa)	24.914	25.434	21.059	18.554
f'_{cc}/f'_{ce}	0.961	0.969	1.061	1.115

3.5 Correlation Between Compressive Strength and Other Properties

Figure 14 plots the compressive strength versus density for all mixes at 28 days of curing. An increase in density seems to be associated with an increase in compressive strength. A linear correlation seems to be adequate as the correlation coefficient is 0.88.

The correlation between compressive strength and tensile strength is shown in Figure 15. An increase in compressive strength is associated with an increase in tensile strength.

If a linear relationship (y=ax+b) is fitted to the various mixes, a high correlation coefficient is obtained (>0.9) for the control mix and the mix containing 0.5% fiber. However, for mixes containing high volume of fiber the correlation coefficient is reduced. More details are shown in Table 5.

Figure 16 shows the correlation between compressive strength and the ultrasonic pulse velocity (UPV) for concretes with and without WPS fibers at all curing ages. An increase in UPV leads to an increase in compressive strength. The theoretical values obtained from Equation 3 and Table 4 are plotted against the experimental values in Figure 17. A strong linear relationship is obtained as indicated in the correlation coefficient value (R2=0.98).

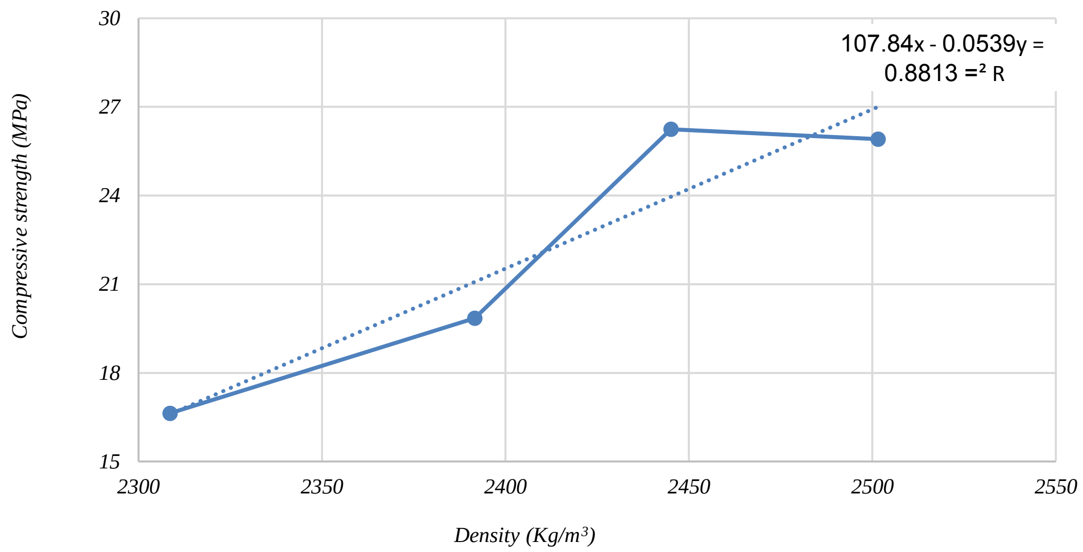

Fig.14: Compressive strength versus density at 28 days for all mixes

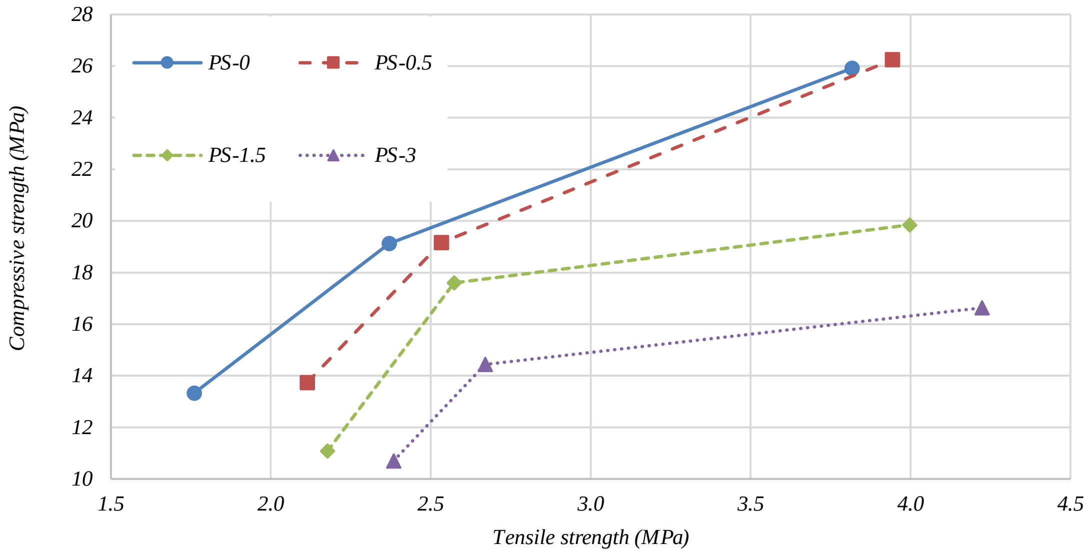

Fig. 15: Compressive vs tensile strength for all mixes

Table 5: Linear relation parameters for the correlation between compressive and tensile strength

Specimen	a	b	R^2
PS-0	5.86	3.92	0.97
PS-0.5	6.38	1.45	0.95
PS-1.5	3.96	4.64	0.69
PS-3	2.62	5.82	0.75

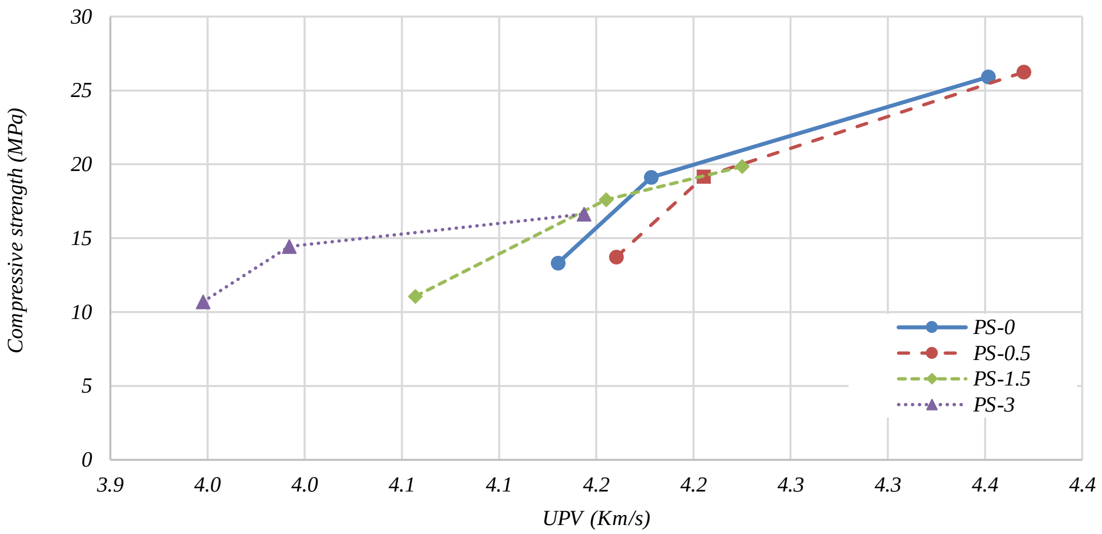

Fig.16: Correlation between compressive strength vs UPV

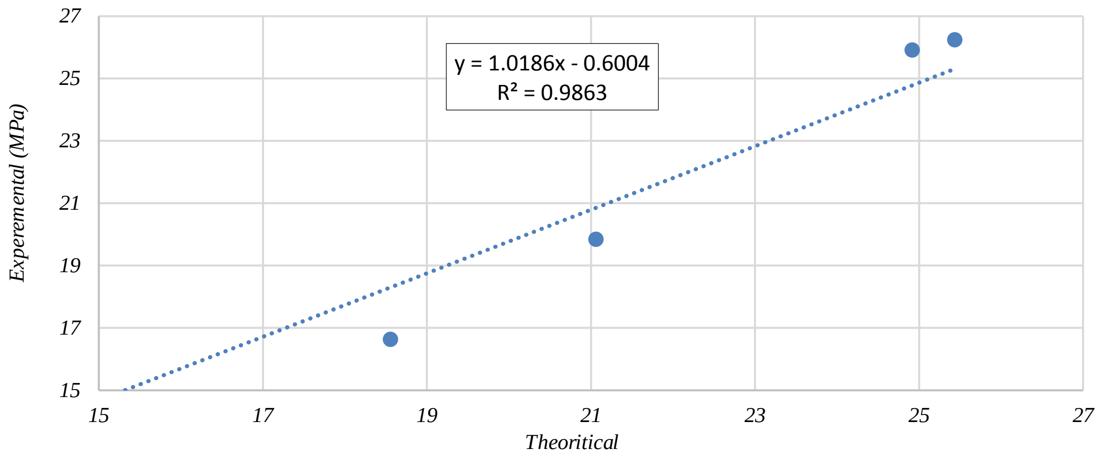

Fig.17: Experimental vs Theoretical values of compressive strength using Equation 3

4. CONCLUSIONS

The following conclusions can be made:

1- Adding WPS fibers to concrete mix causes a reduction in density from 2500 Kg/m^3 for PS-0 (control) to 2308 Kg/m^3 for PS-3. This may be due to the light density of the added fibers and the degree of compaction.

2- Adding 0.5% WPS fibers increases the compressive strength. Beyond 0.5%, there is a decrease in compressive strength by about 24% and 37% for concretes with 1% and 3% PS fibers respectively at 28 days. The UPV data show similar trend to the of compressive strength in the presence of fibers.

3- Using WPS fibers in concrete causes an increase in tensile strength. Tensile strength was increased from 3.82 MPa for the control mix (PS-0) to 4.22 MPa for concrete containing 3% PS fibers. This may lead to a better ductility in the concrete. In addition, the tension to compression strength ratio was increased as the percentage of PS fiber increased.

4- Future investigations should explore the effect of adding plastic fibers on concrete containing different sizes and types of aggregate (fine and coarse). Also, using fibers in mortar should be examined as this may reduce the crack width and shrinkage if used for plastering or for bonds between building blocks.

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