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Investigate the Fresh and Hardened Properties of Shotcrete Concrete Contains Different Types of Plastic Fibers

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ABSTRACT

Adding fibers to the shotcrete concrete mixes is very important to increase the load carrying capacity, toughness, and reducing crack propagations by bridging the cracks. On the other hand, this fiber has an effect on the fresh and hardened properties of shotcrete. In this study, fresh properties evaluated by using slump flow, T_{50}, and segregation resistance tests. Hardened properties included testing of air voids, dry density, water absorption, ultrasonic pulse velocity (UPV), compressive strength, and flexural strength. This works including two types of fibers in three forms (waste plastic (PET)fibers only, polypropylene fibers (PP) only, and hybrid fiber (PET and PP)), each form added by three percentages (0.35%, 0.7%, and 1%) by volume. The results showed that the addition of 1% of all types of fiber has a negative impact on fresh properties. Especially in shotcrete containing waste plastic fiber. Also, all specimens containing fibers showed a decrease in the ultrasonic pulse velocity (UPV) and an increase in air voids and water absorption compared to the reference specimens. Also, the results clarify that the addition of waste plastic fiber to shotcrete led to a slight decrease in dry density. The highest increasing in compressive strength of shotcrete recorded by about 8.2% with using 0.35% PP fiber and highest decreasing was 20.9% with using 1% waste plastic fiber. the highest increasing in flexural strength was 62 with using 1% PP fibers.

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1. Introduction

The quality of Shotcrete can be assessed by evaluating the properties of Shotcrete in two states: the fresh (plastic) state and the hardened state. While the properties of Shotcrete in hardened state have essentially the same performance requirements as cast-in-place concrete, the fresh properties of Shotcrete have a number of distinct performance characteristics that do not apply to cast-in-place concrete(Morgan & Jolin, 2022). In this regard, (Guler, Öker, & Akbulut, 2021) studied the effects of fibers such as polyamide, macro steel, and forta-ferro fiber on the slump of wet-mix Shotcrete. The authors found that the slump value decreased greatly for all fiber-reinforced Shotcrete mixes when the ratio of fiber increased from 0.25 percent to 1 percent. The highest decrease in slump value was observed with polyamide fiber reinforced Shotcrete mixes. (Cui, Liu, Wang, & Qi,

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2019) studied the effect of length, width, and content of PET fiber on the properties of wet-mixed Shotcrete like pumpability, shoot ability, and mechanical properties. The result indicated that the performance of Shotcrete changes with the increase in the parameter properties of PET fiber. This change includes increased slump and decreased compressive strength with the increase of fiber width. On the other hand, increasing fiber length led to increased build-up thickness and decreased pressure drop and slump. Furthermore, increasing fiber content caused a reduction in slump and an increase in build-up thickness, and splitting strength. Also, (Enad, Al-Hadithi, & Mansoor, 2022) discovered that the increasing the waste plastic fiber percentage to 0.5 and 0.75 increased the density and slump flow but caused decreasing in the compressive strength of Shotcrete. (Jawheer, Mansoor, Al-Hadithi, & Hamad, 2021) studied the effect of waste plastic as fiber and coarse aggregate on Shotcrete. The results of compressive and flexural tests confirmed that when 0.5% of plastic fiber is used, the strength performance of Shotcrete concrete increases. (Al-Hadithi & Hilal, 2016) investigated the impact of adding PET fiber on the fresh properties of self-compacting concrete, in addition to the mechanical properties, including compressive and flexural strength at 7, 14, and 28 days. The content of PET fiber ranged from 0–2% by volume. The author found that the waste plastic fibers have a negative impact on the fresh properties and a positive impact on the mechanical properties. The following two suggestions were made by (Mazaheripour, Ghanbarpour, Mirmoradi, & Hosseinpour, 2011) to improve the workability of fiber-reinforced concrete: a) limit the volumetric proportion of macro plastic fibers from 0.1 to 1%, and b) add more water. However, this addition of water causes a reduction in the strength of concrete, thus water-reducing admixtures or plasticizers are often used to improve workability in fiber reinforced concrete without the need to add water. This study aimed to investigate the effect of waste plastic fiber and polypropylene fiber on the fresh and hardened properties of shotcrete in order to obtain flowability and shoot ability shotcrete with good compressive and flexural strength.

2. Experimental work

2.1. Materials Used

The cement used through this work was Ordinary Portland Cement (Al-Mass), which conformed to the Iraqi specifications (IQS No.5/ 2019) (see Table-1) [8]. In addition to use fine aggregate and coarse aggregate (with particle size up to 10 mm), which met the requirement of the Iraqi standard specification (I.Q.S.) No.45/84(see Table-2) [9]. Tap water has been utilized for mixing and curing. The additives that were utilized in this study including: Master Glenium® 51 superplasticizer which confirms to ASTM C 494 Type F: High Range Water Reducing/Super plasticizer Concrete Admixture Standards [10], Sika® Rapid-1 was utilized in this study as an accelerator in accordance with ASTM C 494 [10] to make the mixture more hardened after been threw out from the machine then increase the build-up thickness, waste plastic fiber (WPF) with dimension 4mm width x 27mm length that produced by paper shredded machine, and Polypropylene fiber (PPF) with dimension 0.84mm diameter x 30mm length (See Table-3 and Fig. 1). Table 1 shows the mix proportions of these materials.

This study involved the preparation of eleven mixes depending on the three percentages (0.35%, 0.7%, and 1%) including; reference plain shotcrete mix (FRS); three mixes of waste plastic (PET) fiber reinforced shotcrete (WFRS-0.35, WFRS-0.7, WFRS-1); three mixes of macro synthetic (polypropylene) fiber reinforced shotcrete (PFRS-0.35, PFRS-0.7, PFRS-1); three mixes of hybrid fiber reinforced shotcrete (HFRS-0.35, HFRS-0.7, HFRS-1).

Fig. 1 WPF and PPF

Table 1 - Physical properties and chemical compositions of cement

Physical Properties		
Test Type	**Test result**	**Iraqi standard No. 5/2019 Limits**
Fineness (cm^2/g)	3610	≥2500
Initial Setting (min)	195	≥45
Final Setting (min)	315	≤600
Compressive strength for 2 Days (MPa)	20	≥10
Compressive strength for 7 Days (MPa)	27	≥23
Chemical Compositions		
Oxide composition	**Content (%)**	**Iraqi standard No. 5/2019 Limits**
SiO2	20.3	-
CaO	62.7	-
MgO	2.7	≤ 5 %
Al2O3	4.5	-
SO3	2.5	≤ 2.5 %
Fe2O3	3.9	-
Loss on ignition	3.0	≤ 4 %
Insoluble residue	0.4	≤ 1.5 %
Compound	**Weight (%)**	**Iraqi Specification Limits No.5/2019**
LSF	0.94	-
SM	2.42	-
AM	1.15	-
C_3S	56.8	-
C_2S	15.3	-
C_3A	5.3	-

Table 2 - Sieve analysis for coarse and fine aggregates

Sieve Size	Passing %	Limits of Iraqi specification No.45
Coarse Aggregate		
12.5	100	100
9.5	97.22	85-100
4.75	5.7	0-25
2.36	0.91	0-5
Fine Aggregate		
4.75	99.53	90-100
2.36	87.13	75 - 100
1.18	67.93	55 - 90
600 µm	40.00	35 - 55
300 µm	9.53	8 - 30
150 µm	1.00	0 - 10

Table 3 - Dimensions and Physical properties of WPF and PPF

Property	Waste plastic fibers	PP fibers
Type	Polyethylene terephthalate (PET)	100% polyolefin
Length (mm)	27	30
Width (mm)	4	0,84
Thickness (mm)	0.29	-
Aspect Ratio	22.24	35
Color / Appearance	Crystalline Green and white	white
Tensile Strength (MPa)*	105	465
Modulus of Elasticity (Gpa) *	0.57	7.5
Density (kg/m^3) *	1.37	0,91

Table 4 Shotcrete mixtures proportion ratios

Mix	Components Kg/m3							
	Cement	Sand	Gravel	Water	Superplasticizers	Accelerator	PET Fiber	PP Fiber
FRS-0	497	880	738.4	183	3.1	22	0	0
WFRS-0.35	497	880	738.4	183	3.1	22	0.48	0
WFRS-0.7	497	880	738.4	183	3.1	22	0.96	0
WFRS-1	497	880	738.4	183	3.1	22	1.37	0
PFRS-0.35	497	880	738.4	183	3.1	22	0	0.32
PFRS-0.7	497	880	738.4	183	3.1	22	0	0.64
PFRS-1	497	880	738.4	183	3.1	22	0	0.91
HFRS-0.35	497	880	738.4	183	3.1	22	0.24	0.16
HFRS-0.7	497	880	738.4	183	3.1	22	0.48	0.32
HFRS-1	497	880	738.4	183	3.1	22	0.69	0.46

2.2. Specimens Preparation

After mixing the ingredients by using a rotary drum mixer with a capacity of 0.1 m^3, the mix delivered to the hooper of the shotcrete machine then sprayed into the prepared molds with dimensions of (500 x500 x150) mm and the second one has six prisms with interior dimensions of (100 x 100 x 350) mm for flexural strength tests as shown in Figure 1. The panels were cured using burlap until the extracting day after 3 days of casting process, after that the cores were cut off with a dimension of 75 mm in diameter and 150 mm in length according to ASTMC1604/1604M-05, then sawed to achieve the L/D equal to 2. Finally, the core specimens are transferred to the water tank until the testing day.

Fig. 2 Preparation processes of the core specimens

3. Results and Discussions

3.1. Fresh properties results

Immediately after finishing the mixing process, the fresh properties of shotcrete mixes including differing proportions of fibers were assessed using tests like slump flow, flow time (T_{50}) (see Fig. 3), and segregation resistance. Table 1 shows the results of fresh properties for all mixes.

Fig. 3 [A] Slump wood Plate, [B] Raising cone test, [C] Measuring the diameter

Mix	Slump Flow (mm)		T_{50} (second)		Segregation Index (%)	
	Value	Change%	Value	Change%	Value	Change%
FRS-0	720	-	3	-	9.54	-
WFRS-0.35	500	-30.5	3.16	5.3	2.38	-75
WFRS-0.7	540	-25	2.68	-10.6	1.16	-87.8
WFRS-1	550	-23.6	2.5	-16.6	0.21	-97.8
PFRS-0.35	780	8.3	2.2	-26.6	0.21	-97.8
PFRS-0.7	530	-26.38	3.68	22.6	0.21	-97.8
PFRS-1	510	-29.16	2.8	-6.6	0.1	-98.95
HFRS-0.35	730	1.38	3.17	5.6	0.46	-95.2
HFRS-0.7	730	1.38	2.2	-26.6	2.13	-77.7
HFRS-1	450	-37.5	2	-33.3	1.04	-89.1

3.1.1 Slump flow

The flowability and filling ability of Shotcrete mixtures comprising various types and volumes of fiber are often assessed using a slump flow test. This test was carried out in accordance with ASTM C1611/C1611M-18. Figure 4 shows the results of the tests that indicate that waste plastic fiber has a negative impact on the slump flow value of shotcrete compared to the FRS-0. Incorporation of 1% fiber into the shotcrete mix decreased the slump flow diameter from 720mm for the reference mix to 550mm, 510mm, and 450mm for waste plastic, polypropylene, and hybrid fiber, respectively, which can be interpreted according to agglomerates of fibers with high content and caused an obstruction of the flow (Guler et al., 2021). However, a slight increase in slump flow diameter was observed with a low percentage of polypropylene and hybrid fiber by about 1.38%.

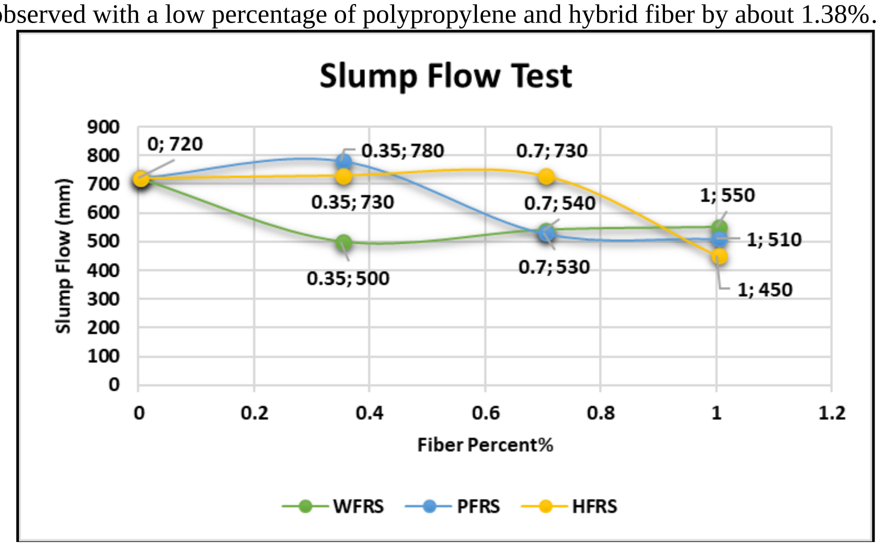

Fig. 4 Slump flow test results

3.1.2 Flow Time (T_{50})

An indication of the rate of Shotcrete concrete flowability and viscosity could be achieved by conducting the T_{50} test, which measures the speed of flow by utilizing a timer to estimate the scattering time until it reaches a diameter of 50 cm. The results of time of flow (T_{50}) shown in Figure 5 ranged from 2 to 3.68. When the percentage of waste fiber and hybrid fiber increased over 0.35%, the time of flow (T50) reduced because the mix lost its viscosity and became stiffer due to the increase in friction between aggregates and fibers with high content.

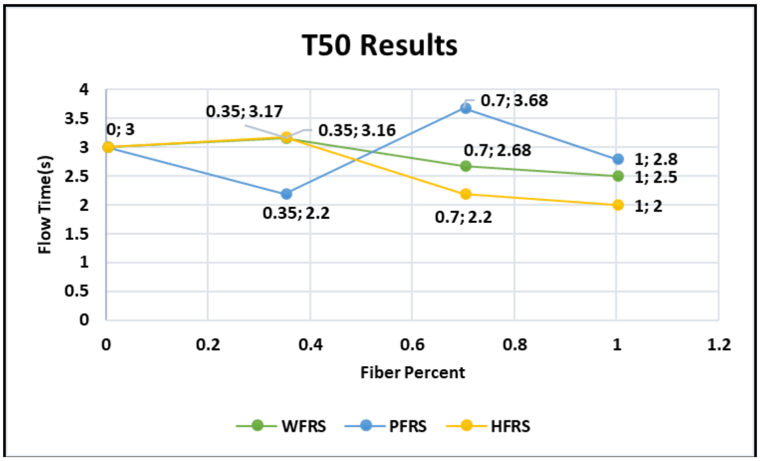

Fig. 5 T_{50} results

3.1.3 Segregation index

This test is frequently used to assess the segregation resistance of concrete. European Guidelines 2005 and EFNARC 2002 were followed in performing these tests. The results in Figure 6 showed a high decrease in the segregation index (SI) of shotcrete mix containing fibers compared to the reference mix due to the forming of a fiber network that led to a decrease in the passing ability and filling ability. All results showed that all mixes had a segregation index below 15%, which satisfies the limitations of EFNARS. This result agrees with the study findings of (Amer Mohammed Enad, 2022).

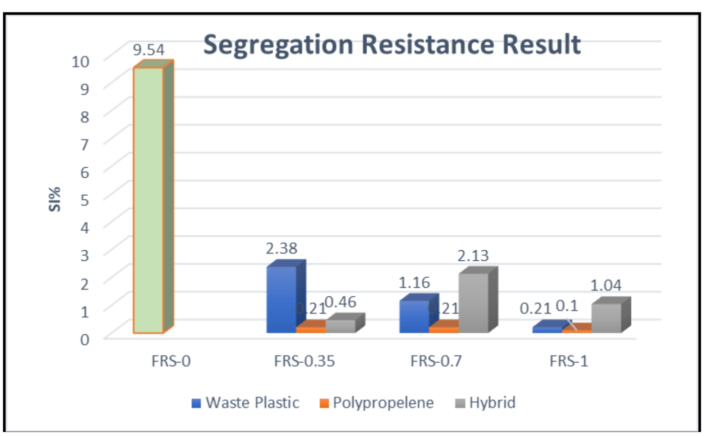

Fig. 6 Effect of fiber on the segregation resistance

3.2. Hardened Properties Results

The specimen was removed from the water tank after 28 days of curing. The dry density, void percentages, water absorption in hardened shotcrete were tested by using core samples and calculated according to the ASTM C 642. Table 5 shows the effect of fibers on the dry density, water absorption and air voids

Table 5 - Effect of fibers on the dry density, water absorption and air voids

Mix	Dry Density (kg/m^3)		Water Absorption %		Air Voids %	
	value	Change%	value	Change%	value	Change%
FRS-0	2299.4	-	2.67		6.52	-
WFRS-0.35	2285.7	-0.596	3.33	24.79	7.61	16.75
WFRS-0.7	2253.8	-1.983	3.38	26.79	8.01	22.82
WFRS-1	2279.0	-0.887	3.36	26.12	7.86	20.52
PFRS-0.35	2359.2	2.6	3.04	14.00	7.37	13.06
PFRS-0.7	2314.6	0.663	3.25	21.77	7.53	15.37
PFRS-1	2246.6	-2.296	3.68	38.06	8.47	29.91
HFRS-0.35	2307.5	0.353	3.269	22.38	7.73	18.55
HFRS-0.7	2333.9	1.50	3.04	13.91	7.10	8.82
HFRS-1	2236.0	-2.754	3.69	38.18	9.02	38.23

3.2.1 Air voids

As shown in Figure 7, incorporation of fibers into the shotcrete mix caused increase in the percentage of air voids that lead to absorb more water compared to the reference mixes without fibers. HFRS-1 had the highest air void value of 9.02 percent. These results are compatible with the result of dry density. In other words, while samples have low density, they also have high air voids. (Doukakis, 2013) showed that there is a significant formation of air voids in self-compacted concrete reinforced with fiber.

3.2.2 Water absorption

As illustrated in Figure 8, the high absorption achieved was 3.69% when using waste plastic fiber in combination with polypropylene fiber by volume fraction of 1%. That may be due to the formation of tiny pores along the length of the fibers that lead to increased pore connectivity. (Ismail, Rusly, & Deraman, 2020)conducted that the addition of nylon fibers lead to increase the rate of water absorption due to the pores that formed by presence of fiber in concrete.

3.2.3 Dry density

It can be seen in Figure 9, the incorporating fibers caused a decrease in dry density by about 0.596%, 1.983%, 0.887% for 0.35%, 0.7%, 1%waste plastic, 2.296% for 1% polypropylene fiber, and 2.754% for 1% hybrid fiber compared to the FRS-0. These results showed that 1% for all types of fiber can cause a decrease in the unit weight of shotcrete that leads to ease in the shooting process of the mix and a decrease in the dead load of the structure.

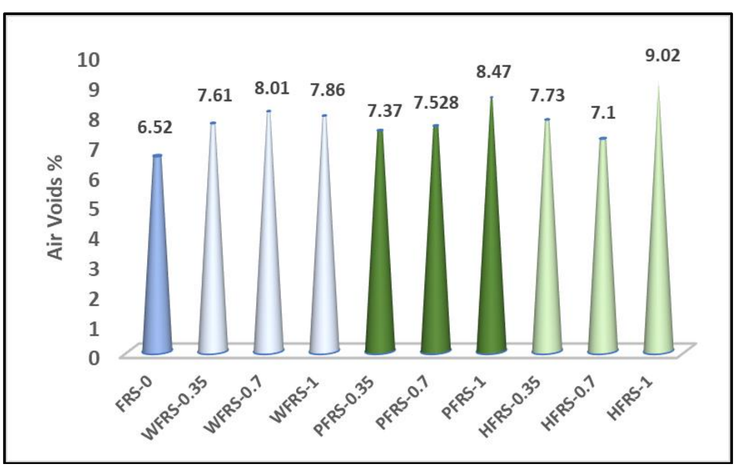

Fig. 7 Effect of fiber on the Air Voids.

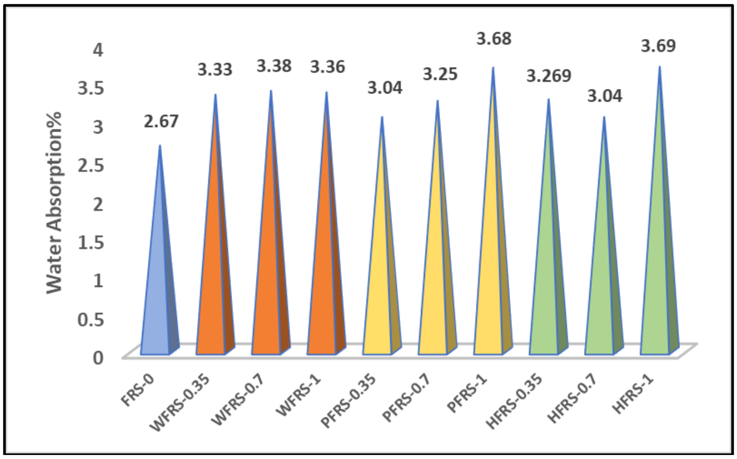

Fig. 8 Effect of fibers on the water Absorption

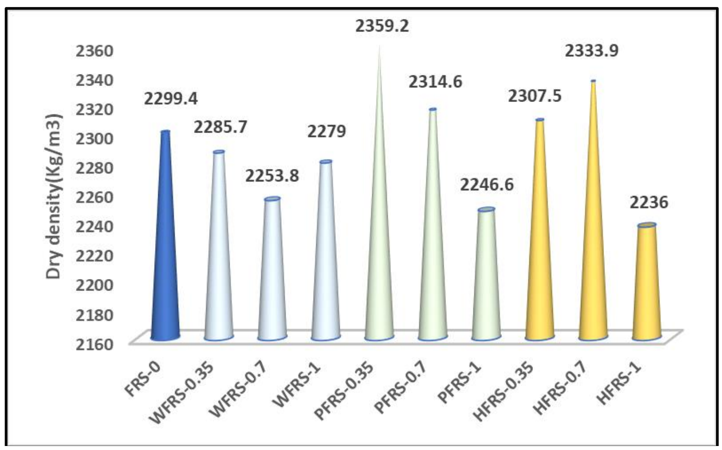

Fig. 9 Effect of fiber on the dry density of shotcrete

3.2.4 Ultrasonic pulse velocity (UPV)

This test was conducted using 75*150mm core specimens in accordance with ASTM C597-16 to categorize the quality of concrete as shown in Figure 10. The test result sowed in Figure 10. The UPV method categorized all prepared mixes as a good quality concrete with a range of pulse velocity between 3.73 and 4.09 km/s addition of fibers led to a decrease in the ultrasonic pulse velocity of shotcrete as it scattered the transmission of waves and elongated the path inside the structure of the matrix. Rahamani ("Rahmani, E., et al., On the mechanical properties of concrete containing waste PET particles. 2013. 47: p. 1302-1308.,") showed that any addition of PET fiber and an increase in the content of PET fiber in concrete can make the concrete porous and cause a decrease in UPV.

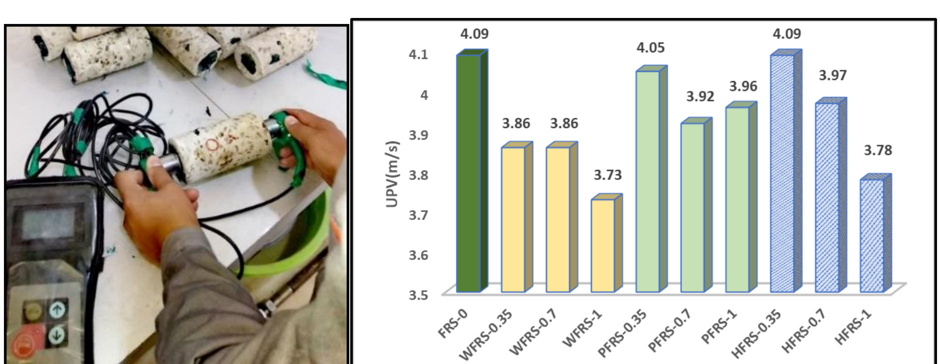

Fig. 10 Ultrasonic pulse velocity test and results

3.2.5 Compressive strength

The compressive strength was conducted on three (3) samples for each mix to calculate the compressive strength 28 days according to ASTM C1604 as shown in Figure 11.

Fig. 11 Compressive testing of specimens

As shown in Table 6 and Figure 12, the Compressive strength values for all shotcrete mixes containing waste plastic fiber have a tendency to decrease below the values for the reference shotcrete mix at 28 days of curing, including both waste plastic fiber reinforced shotcrete and hybrid fiber reinforced shotcrete. (Mohammed & Hammadi, 2018) showed that the addition of WP fiber to concrete lead to decrease the compressive strength of concrete. The apparent loss of compressive strength with increasing WF concentration may be attributed to microcracks that developed as a result of the increasing porosity of the matrix(Yang, Yue, Liu, & Tong, 2015).

Table - 6 Mechanical properties results

	Compressive Strength (Mpa)		Flexural strength (Mpa)	
Mix Symbol	**Value**	**Percentile Increase (%)**	**Value**	**Percentile Increase (%)**
FRS-0	34.53	-	3.85	-
WFRS-0.35	29.37	-14.9	4.74	23.11
WFRS-0.7	30.27	-12.33	4.16	8.1
WFRS-1	27.31	-20.9	3.78	-1.8
PFRS-0.35	37.37	8.2	4.59	19.2
PFRS-0.7	35.48	2.8	5.13	33.2
PFRS-1	35.89	3.9	6.24	62
HFRS-0.35	29.14	-15.6	5.13	33.2
HFRS-0.7	32.2	-6.75	5	29.9
HFRS-1	34.03	-1.5	4.41	14.55

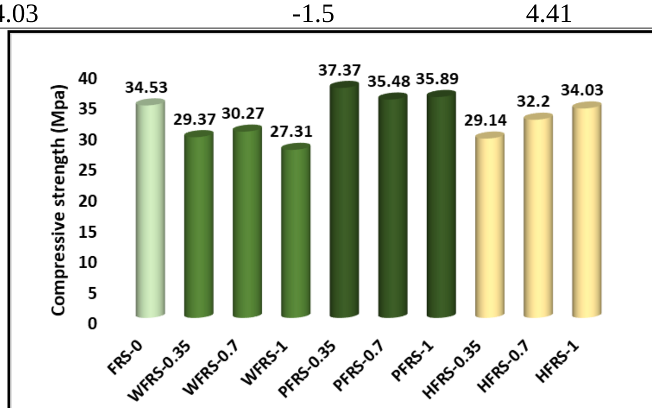

Figure 12 Compressive strength results

In contrast, a noticeable improvement in the compressive strength results of mixes that incorporating of polypropylene fibers by about 8.2%, 2.8%, and 3.9% for fiber percentages of 0.35, 0.7, and 1.0%, respectively. UPV test can be considered a good indicator to the compressive strength of shotcrete and that clear in Figure 13 that shown a correlation coefficient equal to 0.6354.

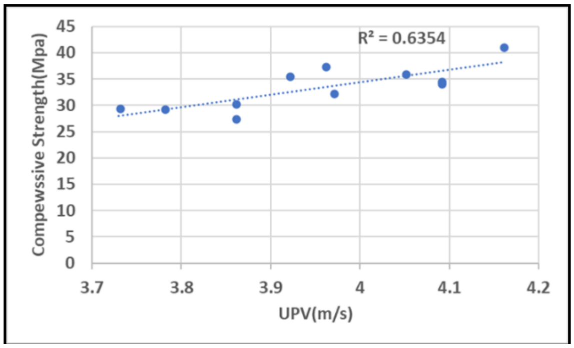

Figure 13 UPV and compressive strength relationship

3.2.6 Flexural strength

Flexural strength test was executed using concrete prisms aged 28 days. The prisms with dimensions of (100× 100× 350) mm were tested according to ASTM C1609 and ASTM C78-02 as Shown in Figure 14.

Figure 14 Flexural test machine and Specimens tested

As illustrated in Table 6 and Figure 15, the flexural strength tended to increase with the addition of fibers, except for when mixed with 1% waste plastic fiber, which decreased slightly by 1.8%. The highest increase in flexural strength at 28 days was 62% with shotcrete reinforced with 1% polypropylene fiber. As a result, mixing polypropylene and waste plastic fiber in terms of hybrid fiber can give results better than using waste plastic fiber only.

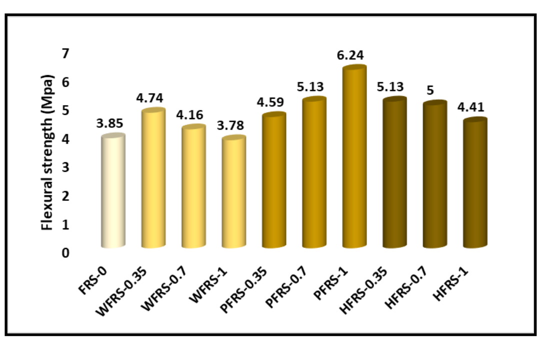

Figure 15 Flexural strength results

4. Conclusions

Some of the important points concluded from the previous section can be drawn as the following:

1. Adding of 1% of fiber led to highest decreasing in slump flow, flow time, segregation index of shotcrete mixes for all types of fiber.
2. The shotcrete mix that contains 1% hybrid fiber showed lower dry density and higher air voids and water absorption values of 2236 kg/m^3, 9.02%, and 3.69%, respectively.
3. All types of fiber led to decrease ultrasonic pulse velocity and increased air voids and water absorption.
4. Compressive strength of shotcrete decreased slightly with waste plastic fiber and increased with incorporating of polypropylene fibers by about 8.2%, 2.8%, and 3.9% for fiber percentages of 0.35, 0.7, and 1.0%, respectively. There is a good correlation between compressive strength tests and ultrasonic pulse velocity.
5. Flexural strength enhanced with all types of plastic fiber except the 1% of waste plastic fibers that caused a slight decrease by about 1.8%.

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