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Flow ability and Mechanical Properties of Shotcrete concrete incorporated with Waste Plastic Fibers

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ABSTRACT

Polyethylene terephthalate (PET) fiber is a green-friendly fiber that is capable of enhancing the mechanical properties of wet-mixing shotcrete. The main purpose of this study is to see how varied volumes of waste plastic fibers (WPF) affect the flowability and mechanical properties of wet-mix shotcrete. For this aim, a variety of experimental tests based on WPF content were chosen. Fresh and mechanical tests included slump, T500, density, compressive strength, and splitting strength were applied. The results shown a improved in shotcrete performance as the WPF content increased. Among all fitting correlations, density and compressive strength revealed the strongest linear ship association. Due to greater interlocking between WPF and concrete matrix, WPF was a major use in enhancing splitting tensile strength. WPF had the most influence on splitting strength, with 23–31 percent, 7–23 percent, and 6–38 percent for 7, 14, and 28-day, respectively.

1. Introduction

Shotcrete is commonly used for the repair and rehabilitation of structures. It is widely employed for the protection of soil and rock slopes. Conventionally, to control shrinkage cracking of the shotcrete layer, steel meshes are placed before shotcreting is carried out. A more effective technique, however, is to incorporate short fibers into the shotcrete mix. With large surface area per volume, fibers are very effective for crack control. Also, by removing the procedure of steel mesh laying, construction efficiency is improved (Qiao & Zhou, 2017).

Since the early 1970s, fibers have been utilized to strengthen shotcrete. Due to the fact that normal concrete is nearly identical to shotcrete except for the application, fiber reinforced shotcrete gained popularity pretty rapidly. Fiber reinforced shotcrete (FRS) is defined as "mortar or concrete containing discontinuous discrete fibers that is pneumatically projected onto a surface at a high velocity." Shotcrete is made of steel, glass, and synthetic fibers, with steel being the most common. The addition of WPF to concrete mixtures may improve their mechanical properties (Gagnon & Jolin, 2017). Cheng et al. demonstrated the construction of a sustainable lightweight wet-mix shotcrete by substituting a type of byproduct for natural coarse gravel (walnut). To improve the performance of the lightweight wet-mix shotcrete, fibers derived from dumped polyethylene terephthalate

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(PET) bottles were incorporated into the composite. This study discovered that by increasing the amount of walnut shell in casting concrete, compressive and splitting tensile strengths decrease, while slump and pressure drop decreased marginally. Additionally, a sufficient amount of walnut shell can enhance the shootability of fresh concrete with a low rebound rate and a greater build-up thickness (Cheng et al., 2017). Irwan et al. (Irwan et al., 2013) discovered that incorporating WPF into concrete increased its splitting tensile and compressive strengths. Fadhil and Yaseen (Fadhil & Yaseen, 2015) showed that when concrete panels were mixed with WPF, the splitting tensile strength and impact resistance rose by 34.27 percent and 157.14 percent, respectively, when compared to plain concrete.

Rebound is a common problem, in which the shotcrete material bounds off the shooting surface when shotcreting. Wet-mix process is somewhat better than dry-mix process in this aspect. In this research, due to the concern of rebound and fiber dispersion, The wet-mix process has been chosen for all experiments. There have been limited research on the use of WPF in wet-mix shotcrete (Armengaud et al., 2017; Cheng et al., 2017; Cui et al., 2019; Jolin & Beaupré, 2003; Yun et al., 2015). Wet-mix shotcrete can improve the stability of surrounding rock in underground roadways, reducing mine tragedies including pneumoconiosis and roof collapse (Armengaud et al., 2017; Khooshechin & Tanzadeh, 2018; Yang et al., 2017; Yun et al., 2015). The purpose of this study was to explore the fresh and mechanical properties of wet-mix shotcrete with varying WPF percentages (0.25, 0.5, 0.75, 1.0, and 1.25)% by volume replacement of mix.

2. Experimental program

2.1. Materials Used

Table 1 shows the physical and chemical properties of used Ordinary Portland cement (OPC). The results confirmed Iraqi standard no. 5 /1984 Limit (Iraqi Specifications, 1984). In addition to coarse and fine aggregates physical properties and grading of according to the Iraqi standard specification (I.Q.S.) No.45/ 1984 (Iraqi Specification, 1984) have been listed in Table 2. The study also used MasterGlenium® 51 as superplasticizers and SikaRapid®-1 as hardening accelerator to achieve shotcrete requirement in terms of flowability and other fresh properties.

Table 1 – Physical and chemical compositions for used cement

Test Type	Content	Iraqi standard No. 5/1984 Limits
Fineness (m2/kg)	3610	⩾2300
Initial Setting (min)	195	⩾45
Final Setting (min)	315	≤600
Compressive strength for 3 Days (MPa)	20	≥15
Compressive strength for 7 Days (MPa)	27	≥23
Chemical Compositions		
SiO_2	20.3	-
CaO	62.7	-
MgO	2.7	5 % Max.
Al_2O_3	4.5	-
SO_3	2.5	2.8 % Max.
Fe_2O_3	3.9	-
Loss on ignition	3.0	4 % Max.
Insoluble residue	0.4	1.5 % Max.
C_3S	56.8	-
C_2S	15.3	-
C_3A	5.3	-

Table 2 – Sieve analysis for coarse and fine aggregates

Sieve Size (mm)	Passing %	Iraqi standard No. 45/ 1984 Limit
Coarse Aggregate		
12.5	100	100
9.5	99.07	85-100
4.75	1.27	0-25
2.36	0.00	0-5
Fine Aggregate (Zone 2)		
4.75	99.53	90-100
2.36	87.13	75 - 100
1.18	67.93	55 - 90
600 µm	40.00	35 - 59
300 µm	9.53	8 - 30
150 µm	1.00	0 - 10

2.2. Mix Procedure

The shotcrete mix proportion used in this study was fixed in terms of cement, water, coarse aggregate, fine aggregates, and additives. But the content of WPF was variable (0.25, 0.5, 0.75, 1.0, 1.25) % by volume replacement of mix. The dimensions and physical properties of WPF are given in Table 3. The six shotcrete mixtures presented in Table 4 were developed according to ACI PRC-506-16 (American Concrete Institute, 2016) using large number of trial mixes including the control mix without WPF in order to obtain optimum shotcrete mix. The objective was to have optimum compressive strength. The control concrete specimens without WPF underwent the same tests as to compare the results with those of the specimens with WPF. Table 4 states that the amount of WPF in concrete mixes was (0.25, 0.5, 0.75, 1.0 and 1.25)%. The selection of the amount of WPF for each concrete was mostly based on previous studies that stated the minimum and maximum amount of WPF in concrete (Al-Hadithi & Hilal, 2016; Hama & Hilal, 2017; Khatab et al., 2019). Superplasticizer was added to reduce the water. Thus, the w/cm ratio was decreased to 0.414. In addition, Accelerator was used to make the mixture more hardened after been threw out from the machine.

Table 3 – Dimensions and Physical properties of WPF

Fiber's type	Length (mm)	Width (mm)	Thickness (mm)	Aspect	Tensile Strength (MPa)	Density (kg/m3)	Water absorption
WPF	27	4	0.29	22	220	1375	0.00

Table 4 – Shotcrete mixtures proportion ratios

Mix Code	C. (kg/m^3)	G. (kg/m^3)	S. (kg/m^3)	W. (kg/m^3)	Acc. (kg/m^3)	S.P (kg/m^3)	WPF (kg/m^3)
SC0.00	497.0	738.4	880.0	206.0	22.00	3.10	0
SC0.25	495.8	736.5	877.8	205.5	21.95	3.10	3.44
SC0.50	494.5	734.7	875.6	205.0	21.98	3.09	6.88
SC0.75	493.3	732.9	873.4	204.5	21.84	3.08	10.31
SC1.00	492.0	731.0	871.2	203.9	21.78	3.07	13.75
SC1.25	490.8	729.2	869.0	203.4	21.73	3.07	17.19

* C = Cement, G = Gravel, S = Sand, W = Water, Acc.= Accelerator, S.P = Superplasticizer, and WPF = Waste Plastic Fibers

3. Results and discussion

3.1. Slump Test

The slump flow test for all the concrete mixtures were conducted using standards and procedure of ASTM C1611/C1611M-18 (ASTM C1611 / C1611M-18, 2018). This test determines the flow of the concrete mixture after it has been mixed. This is an important test to conduct since there is a higher risk of segregation of aggregate and bleeding of the mix (Dolch, 1996; Neville, 2012). The results of slump flow and T_{500} of concrete mixtures obtained are shown in Figure 1. It can be seen that between the control mix (SC0.00) and WPF mixes the slump flow did in fact increase. While the slump flow for 0.75% WFP replacement (SC0.075) shows an increase in slump.

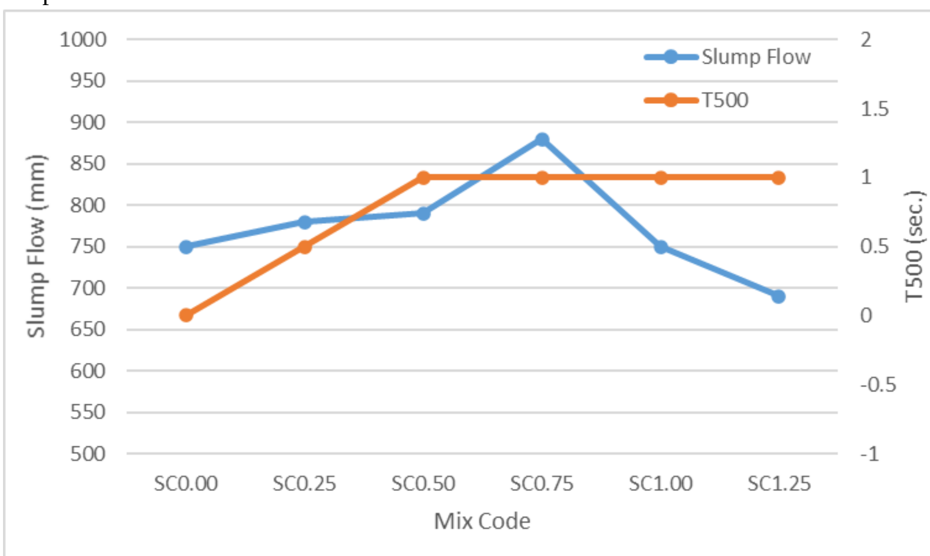

Fig. 1 Slump flow and T500 tests results for all mixtures

Regarding the water to cement ratio of 0.414 and also the slump selection of 880 mm for shotcrete with a SC0.75 mix code containing 0.75 percent WPF. It is not essential to incorporate a superplasticizer into the mixing plan, and this shotcrete is appropriate for spraying through a nozzle in accordance with ACI PRC-506-16 (American Concrete Institute, 2016).

3.2. Dry Density

Shotcrete dry density was measured in hardened phase only. The dry density was determined by weighing the specimens and dividing the weight by the measured volume of the specimen. Dry density was measured according to ASTM C642-13 (ASTM C642-13, 2013) at age of 28-day as shown in Tables 5.

Table 5 – Dry density test results for all mixtures

Mix Code	Dry weight (gm)	Submerged Weight (gm)	Saturated Weight (gm)	Dry Density (kg/m^3)
SC0.00	12483	7307	12587	2364
SC0.25	12483	7317	12588	2368
SC0.50	12583	7387	12681	2377
SC0.75	12527	7353	12633	2373
SC1.00	12464	7276	12562	2358
SC1.25	12457	7253	12543	2355

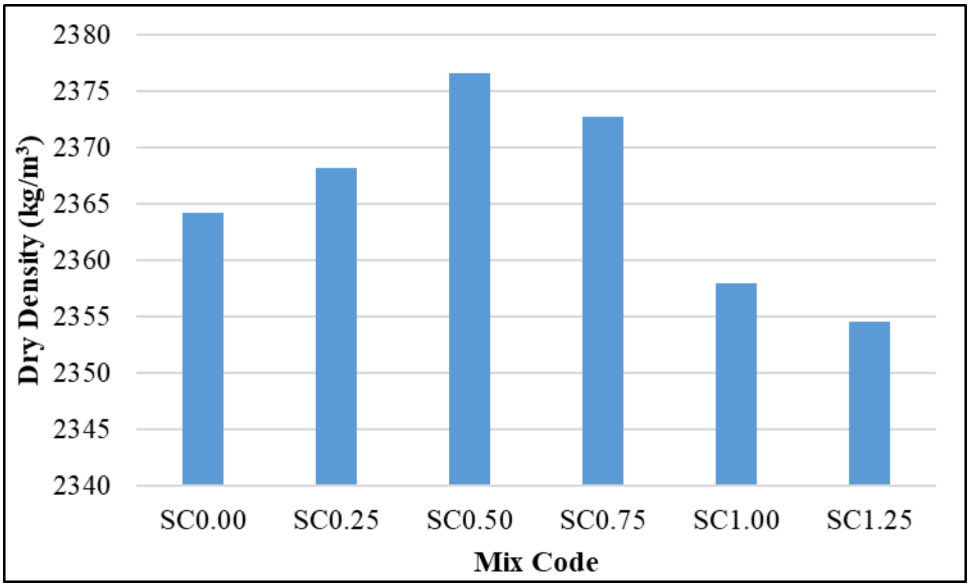

Fig. 2 Effect of WFP content on dry density of shotcrete

Figure 2 shows oven dry densities for all mixes. The control specimen (SC0.00) concrete has heavier density than SC1.00 and SC1.25 with 1.00 and 1.25 % of WFP, respectively. This occurs because the density of WFP is lower than that of cement. Moreover, SC0.25, SC0.50, and SC0.75 have higher density compared to the control specimen (SC0.00) due to replacement of voids with WPF in specific content (0.50%). After that the content of WPF behave in reverse in term of dry density.

3.3. Compressive Strength

Table 6 shows the summary of compressive strengths for all mixtures. Compressive strengths at ages 7, 14, and 28-day after curing are shown Table 6. Compressive strength data are mean values for three 150*300 mm cylindrical specimens made from each combination.

Table 6 – Compressive strength test results for all mixtures at 7, 14, 28-day

Mix Code	7-day	Reduction (%)	14-day	Reduction (%)	28-day	Reduction (%)
SC0.00	27.6	-	32.4	-	40.2	-
SC0.25	24.3	11.8	30.5	5.8	36.0	10.4
SC0.50	20.5	25.5	30.0	7.3	31.3	22.2
SC0.75	21.4	22.4	28.8	11.2	30.3	24.7
SC1.00	20.7	24.9	24.9	23.3	25.3	36.9
SC1.25	19.2	30.4	23.3	28.0	24.4	44.3

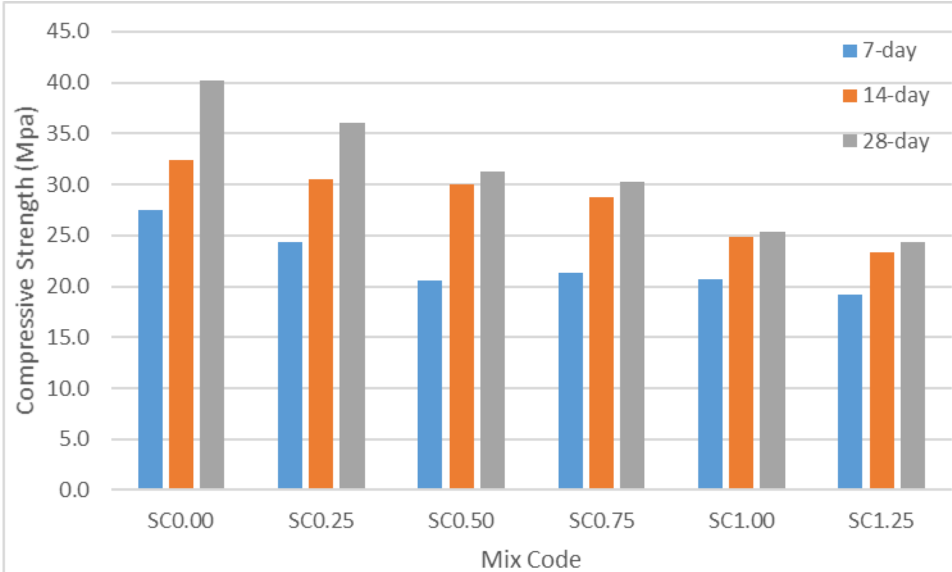

Fig. 3 Compressive strength test results of all mixtures for 7, 14, and 28-day

Overall, it can be seen from Figure 3 that the use of WPF does not enhance the compressive strength of the shotcrete and the increase in WPF content further have the same effect on the compressive strength as noted in SC0.25, SC0.50, SC0.75, SC1.00, and SC1.25 specimens. From the comparison into the effects of increasing WPF content, the (0.25, 0.5, 0.75, 1.0, and 1.25)% WPF increase had caused the compressive strength to decrease. Additionally, the gradual decrease in compressive strength values with increasing proportions of plastic waste fibers can be attributed to the weak binding force between the surface of the plastic waste and the cement paste, as well as the fact that plastic particles do not naturally absorb water in areas where cement hydration is inhibited by restricting water movement (Hilal et al., 2018; Silva et al., 2013; Topçu & Uygunoğlu, 2010).

3.4. Splitting Tensile Strength

The presence of WPF enhanced the splitting tensile strength significantly. The fibers of waste plastic have a considerable effect on the resistance to indirect tension. Figure 4 illustrates the splitting tensile strength test results. As shown in Table 7, the resilience of specimens to splitting increases as the WPF content increases.

Table 7 – Splitting tensile strength test results for all mixtures at 7, 14, 28-day

Mix Code	7-day	Increase (%)	14-day	Increase (%)	28-day	Increase (%)
SC0.00	2.6	-	3.1	-	3.2	-
SC0.25	3.2	23.1	3.3	6.5	3.4	6.2
SC0.50	3.4	30.8	3.6	16.1	3.8	18.8
SC0.75	3.2	23.1	3.5	12.9	3.9	21.9
SC1.00	3.3	26.9	3.7	19.4	4.1	28.1
SC1.25	3.4	30.8	3.8	22.6	4.4	37.5

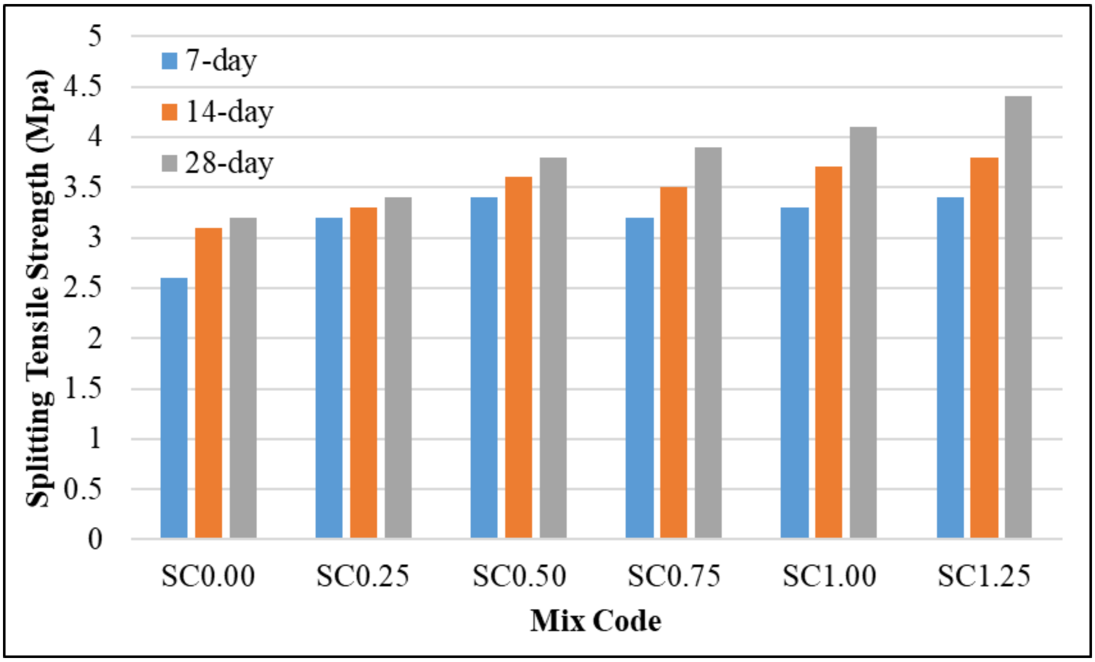

Fig. 4 Splitting tensile strength test results of all mixtures for 7, 14, and 28-day

The splitting strength improved in the range of 23–31%, 7–23% and 6–38% for 7, 14, and 28-day respectively. A noticeable increase of 30.8% and 37.5% in strength was observed in the 1.25% WPF contents for 7 and 28-day, respectively. Several studies were in concur with these results (Cui et al., 2019; Duarte et al., 2019; Hilal et al., 2018; Irwan et al., 2013; Khatab et al., 2019).

4. Conclusions

Several tests were carried out in order to examine the effects of different WPF contents on the flowability and mechanical properties of wet-mix shotcrete. The percentage changes in shotcrete properties with increasing WPF content were (0.25, 0.5, 0.75, 1.0, and 1.25)%. It was discovered that raising WPF concentrations to 0.75 and 0.5 percent increased slump flow and density but decreased compressive strength. More than 0.75 percent WPF tended to agglomerate concrete particles, reducing slump and density, and resulting in weak adhesion between WPF and concrete matrix. WPF had the most influence on splitting strength, with 23–31 percent, 7–23 percent, and 6–38 percent for 7, 14, and 28-day splits, respectively.

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