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Effect of Polypropylene Fibers on Strength and Thermal Resistance of Concrete

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Abstract
In this paper, the effect of Polypropylene Fibers added to concrete on strength and thermal resistance of high strength concrete has been investigated. Therefore, five tests have been carried out to reach this goal which it includes; effect of weight percent of polypropylene fibers on mechanical properties of concrete, effect of fiber's length on the strength of high strength concrete, effect of fiber's volume on the thermal stability of high strength concrete, examine the phenomenon of spalling concrete high resistance against heating, determine the changing of compressive strength of high strength concrete in different temperatures. The results present that the compressive strength has declined with the percentage of fiber concrete after 0.7 kg/m^3 . Moreover, in all cases the tensile strength and concrete's bending strength will be increased by fiber content.

Keywords: Polypropylene Fibers; Strength; Thermal Resistance; High Strength Concrete.

1-Introduction

Concrete pavement is mostly used for road surfaces, bridge decks, airfield runways and parking lots. Concrete pavement endures dynamical loads and subjects to rigorous environment. In recent years, the research and development in the field of cementitous materials have been focused increasingly on their durability and service life. Obviously, concrete pavement also requires good durability as well as strength. Durability of this kind of pavement includes frost resistance, impact resistance, permeability and abrasion resistance [1]. The freezing and thawing is one of the major problems of the concrete pavements in cold climates. Numerous studies on the frost resistance of concrete have been carried out to improve the durability and to prolong the service life of concrete in the world [2, 3, 4]. Many of these investigations have shown that durability parameters are especially related to the concrete air void system and to the bond between the aggregates and matrix [5, 6]. It is commonly believed that mineral admixtures can significantly improve permeation-related durability of concrete, and air entrainment can enhance frost resistance, although it also causes a reduction in strength of concrete [6]. It is also reported that pozzolans could make microstructure of concrete more compact and improve frost resistance [7]. The effect of pozzolans is mainly to improve the interfacial transition zone, resulting in a reduction in porosity of this zone [8, 9]. In this study, the strength and thermal resistance of concrete that filled by polypropylene fibers (PP) has been investigated. Therefore, the concrete will be mixed by various mass of fiber. In following, the methodology will be presented and the laboratory work procedure will be presented for all specimens.

2- Experimental program

The water to cement ratio has to ranged between 0.23 to 0.32 for making high-strength concrete. Gravimetric method was used for making concrete because it is more accurate than the volumetric method. The concrete construction was performed according to ASTM-C192 standard. The aggregate grading curve has been performed according to standard criteria DIN EN 13230-2 [10]. Abrasion resistance of aggregates has been performed in accordance with ASTM D based approach ASTM-C131 and thus it was limited to 40 percent [11]. On the other hand, the sand must be used according to the standard ASTM-C289 to satisfy quality which is necessary in the absence of reaction with alkali [12]. The cement has to satisfy ASTM-C150 [13]. In this study, the superplasticizer (GLENIUM-110P) produced by O-BASF was used. Table (1) shows the characteristics of the concrete mixtures design.

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table 1: the materials and mixes specification of the concrete

.No	Water	cement	coarse aggregate	fine aggregate	Microsilica	Superplasticizer	Compressive strength (MPa)
HS1	151	520	1153	600	64	11	76.67
HS2	170	567	955	653	0	8	66.02
HS3	130	513	1080	685	43	16	85.74
HS4	144	564	1065	593	89	20	82.30
HS5	125	545	1103	589	52	18	77.47
HS6	135	500	1110	700	30	14	90.10
HS7	158	568	1068	617	0	12	65.84
HS8	151	519	1122	579	62	9	93.64
HS9	165	535	1158	597	80	19	80.30
HS10	150	500	937	758	0	6	65.17
HS11	150	500	1004	822	25	7	78.49
HS12	150	500	1016	760	75	6	82.29
HS13	150	500	1233	617	25	8	81.43
HS14	150	475	1066	710	24	5	76.21
HS15	156	487	1068	676	47	11	64.46
HS16	150	500	1234	617	0	8	71.79

The standard format 15 * 30 cm was used to build the specimens. Portland cement type 1, washed sand with a fineness modulus of 2.9, silica crushed sand, Microsilica and superplasticizer was used to make concrete specimens. Aggregate was used with size of 10 mm. Microsilica and sand was used in ratio between 0 and 15 percent and 33 and 45 percent of cement respectively. Table (2) shows the chemical analysis of cement and silica fume. Also, the polypropylene fibers properties which used in this study are listed as Table (3).

TABLE 2: THE CHEMICAL ANALYSIS OF CEMENT AND SILICA FUME

Oxidized	Cement	Silica fume
SiO_2	21	91.10
Al_2O_3	4.60	1.55
Fe_2O_3	3.20	2.00
CaO	64.50	2.42
MgO	2.00	0.06
SO_3	2.90	0.45
$Na_2O + K_2O$	1.00	-
LOI	1.50	2.10

The sand was poured into the mixer to construct concrete samples according to the instructions ASTM-C192. Water was added less than 1/5 ratio of mixing in which the sand was evenly moisten. Then sand was added to the consumer. While rotation of the mixture, the cement and Microsilica was added to the mixture, then the rest of water was poured into the mixing device. After adding water to the mixture, mixing continued for 3 minutes, then it was paused for 3 minutes, and then continues for 2 minutes. The concrete compaction was performed in two layers with a vibrator. The specimens were formed in a metal mold in wet conditions for 24 hours. The immersing of the specimens carried out in water under laboratory conditions for 28 days. In this study, we examined five test series include effect of weight percent of polypropylene fibers on mechanical properties of concrete, effect of fiber's length on the strength of concrete, effect of fiber's volume on the thermal stability of high strength concrete, examine the phenomenon of spalling concrete high resistance against heating, determine the changing of compressive strength of high strength concrete in different temperatures.

Table 3: The characteristic of polypropylene fibers

Characteristic	Value
Elasticity of Modulus(N/mm^2)	3900-3500
Density(kg/dm^3)	0.91
Length(mm)	12
Diameter (μm)	18
Combustion Temp. (^{0}C)	360
attack Alkali	hight
length increase Percent	15
absorption moisture Percent	0
strength tensile(N/mm^2)	300
Melting point (^{0}C)	160-165

3-The Effect of Polypropylene on Mechanical Properties of concrete

According to King and Batsvn (1987), samples were produced by adding various weight percent to investigate the effect of PP fiber Weight-percent [14]. In the case of fiber concrete making, fiber concrete mixes for about a minute according to ACI to ensure mixing of concrete with fibers. The mixture samples into has been spilled to 15 cm cube molds for compression strength and 15 * 30 cm cylindrical mold testing to tensile strength and 15 * 15 * 60 cm prismatic form for flexural strength testing. Compressive strength testing has been carried out by Multifunctional Control Console with a maximum load of 3000 KN and load velocity 0.25 N/mm^2s. The Brazilian test wasall the specimens decreased and the amount of time VB increased by increasing the amount of fiber. The Fibers have a performed on cylindrical specimens by the same device. The results have been presented in Table (4), in which density of low specific gravity replace in part of concrete to reduce weight of concrete. On the other hand, it would be expected the fluidity of the concrete reduced by the creation of space and increase the porosity of concrete. The best value of this parameter is 46.2 seconds in compared to the control sample that shows an increase 51 percent

Table 4: The effect of fiber on density and VB

Fiber(kg/m^3)	Density(ton/m^3)	VB (s)
0	2.42	30.5
0.7	2.40	46.2
0.9	2.39	49
1.5	2.38	48
2	2.37	53
4	2.36	55

3-1-Compression Strength Test

Table (5) represents the results of the 28 days compressive strength test for different fiber content. The results present that the compressive strength has declined with the percentage of fiber concrete after 0.7 kg/m^3 in which compressive strength is also lower than the control specimen. This can reduce the negative impact of space that is created by fibers in concrete.
The compressive strength is greatly reduced after the fiber content of 2 kg/m3 or greater than this value.

Table 5: The Results of Compressive Strength Changes of Samples with Fiber Content

Compressive Strength (28 days)				Middle	Fiber (kg/m^3)
52.83	54	50.29	48.88	51.5	0
48.88	54.22	51.11	55.55	52.44	0.7
46.66	50.22	48.88	51.11	49.22	0.9
46.66	44.44	45.77	48.88	46.44	1.5
45.55	46.66	41.11	44.44	44.44	2
43.33	40	44.44	41.11	42.22	4

3-2-Tensile Strength Testing

Table (6) shows the result of Tensile Strength Test 28 days for specimens with different fiber content. The results of the indirect tensile test, or Brazilian test, indicating that in all cases the tensile strength of concrete has been increasing by fiber content. This fact is reversed in high fiber weight content (more than 2 kg/m^3). For interpretation of this fact we could say a certain level of fiber weight has a meaning role. However, tensile strength decreases due to reduced density and increased porosity in high values of fiber content. In fiber content equal to 2 kg/m3 and more than this amount, tensile strength as well as compressive strength is greatly reduced, in which tensile strength was reduced under the resistance value of the control specimen.

Table 6: The Results of Tensile Strength Changes of Samples with Fiber Content

Fiber (kg/m^3)	Tensile Strength						
	Middle	Days 28					
0	3.96	3.96	3.82	3.39	3.54	4.81	4.24
0.7	5.54	5.80	5.52	5.38	5.66	5.09	5.80
0.9	5.40	5.80	5.56	5.52	5.02	5.09	5.30
1.5	5.30	5.52	4.81	5.94	5.94	4.67	4.95
2	4.12	4.10	3.82	4.53	4.38	4.24	3.68
4	3.96	3.96	3.25	2.83	4.53	3.04	4.10

3-3- Bending Strength Testing

Table (8) shows the results of bending strength test at 28 days. The results of the single-point bending test indicate that concrete's bending strength will be increased by fiber content. However, as mentioned above, this increase is reversed for high fiber content.

Table 7: The Results of Bending Strength Changes of Samples with Fiber Content

Fiber (kg/m^3)	Bending Strength			
	Middle	Days ۲۸		
0	2.67	2.70	2.61	2.70
0.7	2.95	2.95	3.00	2.89
0.9	2.81	2.74	2.89	2.80
1.5	2.86	2.81	2.90	2.88

4- Effect of fiber's length on strength

In this part the effect of fiber length on strength of high strength concrete has been investigated. Figure (1) shows the results of strength test of 7 and 28 days concrete. The results of the tests indicate that compressive strength increases with fibers content. In condition fiber length is 12 mm, the compressive strength is greater than fiber length is 6 and 19 mm. As a result, in condition fiber length is 12 mm, fiber could be prevented from advancing cracks because the fibers have a bridge role in the maintenance of the concrete. While increasing the length to 19 mm, facilitated the formation of cracks due to more holes in concrete. Obviously, the strength of the specimens with 28 day is more than 7 days concrete.

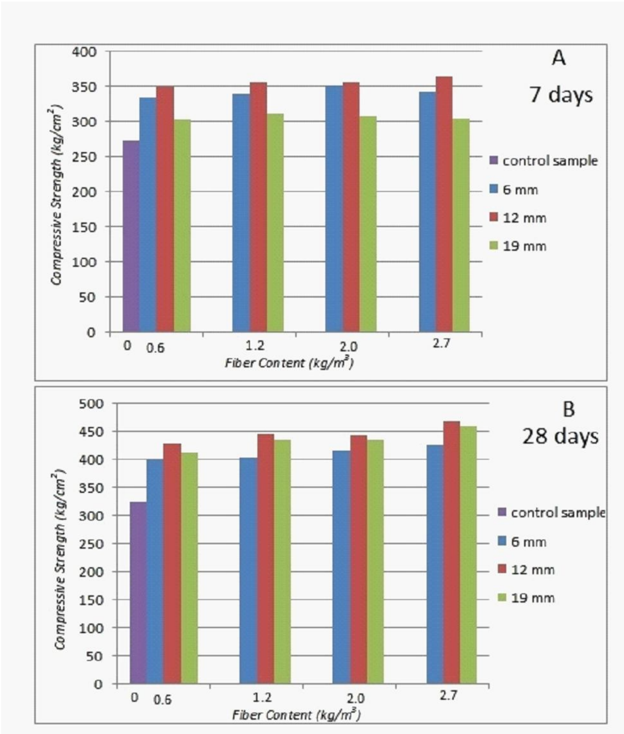

Figure 1: the results of strength test; a: 7 days concrete, and b: 28 days concrete

5- Effect of fiber volume on thermal stability

specimens are in the cube form with the dimensions of 250 mm, fiber length 6, 12, and 19 mm with fiber content of 9.6, 1.2, 2, 2.7 kg per cubic meter. The initial slump was 40 to 50 mm without adding fiber and lubricant. Time of drying concrete was 7 and 28 days. The thermal test was carried out in oven at 500 °C for 8 hours for sample which contain 10 mm fiber and the various fiber content. After that compressive strength tests were performed on them. Experiments which shows in Figure (2) indicate the compressive strength is desired even after composition in oven at 500 °C for 8 hours.

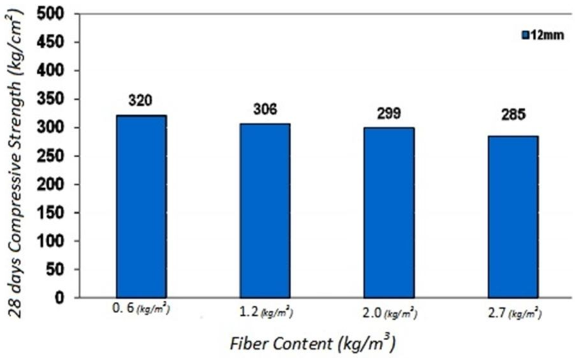

Figure 2: thermal stability of concrete in deferent fiber content

6- The phenomenon of spalling and mass reduction

To build the specimens, a standard cylindrical mold was used in dimension 15 * 30 cm. The cylindrical mold concretes were made in six mixtures divided to 3 specimens at 800 °C and 3 samples as control specimens at ambient temperature. After specimens curing in water, they were placed in ambient to dry for 24 hours, then the dried samples were weighed. Finally, the samples were placed in an electric furnace. The research aimed at temperature of 800 °C at a rate of approximately 2 °C increase per minute. Therefore, the samples were warmed to reach 800 °C for 1 hour and then they slowly cooled at room temperature for 24 hours. Figure (3) shows examples of concrete after heating test. Examples include HS1, HS2, HS7, HS8, HS10, and HS16 were broke into two pieces upon heating. As can be seen from Figure (3), this separation is occurred in the upper one-third to one-fourth of the samples. Moreover, the samples that don't break into two pieces were cracked in the same place.

Figure 3: Schematic of concrete's samples after heating test

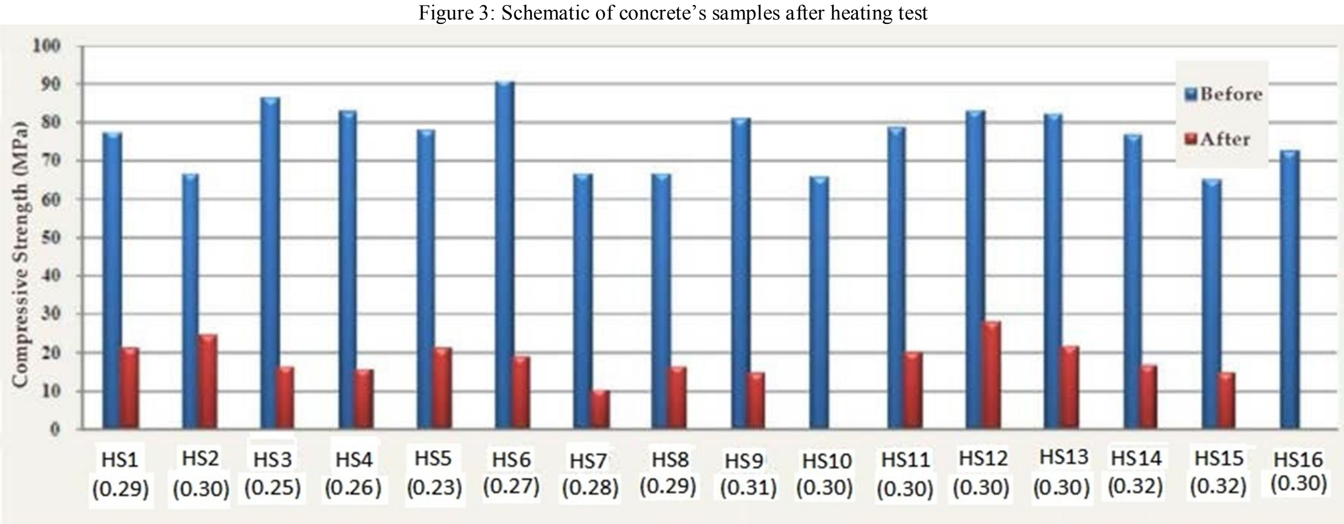

Figure 4: The Comparison Of Compressive Strength Of Concrete's Specimens Exposed To High Temperatures Versus Control Specimens

Table 8: The results of the residual strength of

No	%Mass of Reduction	%Reduction of Compressive
HS01	11.54	72.65
HS02	11.04	63.00
HS03	22.08	81.13
HS04	27.89	81.60
HS05	23.36	73.50
HS06	15.42	79.36
HS07	22.75	85.26
HS08	19.25	82.52
HS09	14.10	82.73
HS10	19.85	٧٧.٤٠
HS11	20.78	74.64
HS12	22.54	66.15
HS13	13.94	73.74
HS14	14.51	78.30
HS15	18.60	78.61
HS16	15.48	76.25

SCALING

6-Changes in Compressive Strength at Different Temperatures

In this section, reducing the strength of high strength concrete at temperatures of 100, 200, 400, 600, and 800 °C has been investigated. The specimens in 20 * 10 cm were analyzed at five mixture samples in which three samples were tested at each temperature. The samples were treated for 90 minutes at final temperature to ensure all content reach to temperature. All of them contain polypropylene fibers to avoid scaling and to ensure the compressive strength tests performed without any doubt. Therefore, the samples were contained 2% by volume of polypropylene fibers in accordance with regulations to make recommendations Europe [38] to prevent scaling. The main cause of non-scaling is synthetic fibers in concrete. With increasing temperature, polypropylene fiber concrete melts at 160 to 180 °C in which this creates a hole in the concrete. These holes let out of the vapor pressure. The results of the residual strength of scaling are shown in Figure (5). The important fact was the incidence of early cracking and scaling in the furnace. The scaling in most cases was started by increasing temperature in the furnace in 20 minutes early. In this test all cases were scaled but some of them were exploded.

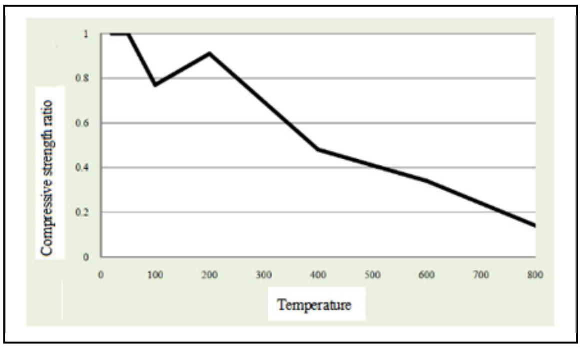

Figure 5: Average coppressive strength reduce

7-Conclusion

Based on the results of experiments in this study, the following primary conclusions can be obtained.

. The compressive strength of concrete can be increased by using PP fiber as a substitute to cement materials partially.
. Compressive strength of concrete increases as the fiber content increases.
. All concrete's specimens will cracked or more than broken by heating to 800 °C.

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