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EXPERIMENTAL STUDY OF THE EFFECT OF SUPER PLASTICIZER ON HIGH STRENGTH CONCRETE UNDER FIRE

Fatin I. Al-haydery

Assistant Lecturer, Mathematic Department, College of Education Missan University, Maysan, Iraq.

Abstract: Additives have gained wide use in the last few years, especially those required to manufacture high-strength concrete (HSC). Fire resistance is one of the characteristics that need to be satisfied with the design of structures. The main objective of this work was to study experimentally the performance of high-strength concrete (HSC) with Glenium51(GL51) additives subjected to fire. This study examined the influence of different parameters, as the additive's percentage and time of the burn. The results of 84 cubes without and with GL51 before and after burn and the results of 6 cylinders explain that HSC is improved by using GL51.

Keywords: *fire resistance, high-strength concrete, Glenium51, tensile splitting strength, compressive strength, ACI 318.*

1. Introduction

Generally, the concrete has a special feature other than building materials. This is the ability of fire-resistive properties. In the design of concrete structures, the effects of fire should be including. The structure has to able to withstand dead and live loads without fall down when the temperature rises. Where the elevated in temperature causes a decrease in the modulus of elasticity and strength in both the concrete and steel reinforcement. Besides, widened fires lead to the expansion of the components of structural, and this need to resisted the strains and stresses induced from it. Sometimes, in the design of structures, requirements of building code of fire resistance are disregarded. This misguided might too expensive mistakes. Where not unexpectedly to found a smaller thickness than require of satisfying ACI 318 requirements than by the building code for 2-hour fire resistance. Perfect and safe design need to make the fire considerations as a part of the preliminary designing phase [1].

According to the safety produced by using the concrete in building, if the considerations fire safety to be taken in the design, so it was widely applied. For the members of structural, the resistance of ratings took as the fire safety requirements specifying. A nonhomogeneous of concrete materials associated with the performance

* *Corresponding Author:* fatin.haydree@gmail.com

of fire was controlled through several factors. Which were; the cement paste, aggregate, and the proportions of the mix (w/c ratio that has permeability affects). The standardized design of fire resistance noted that the two characteristics of concrete which were; density and chemical composition have an important effect. Where the concrete classified (in the previous three decades) as normal and lightweight only. This led to producing the third type of concrete was a high-strength concrete (HSC). Finally, the type of aggregate has a serious effect on fire resistance [2].

The ACI 216.1 latest edition [3] dealing with the resistance of fire for concrete according to the value of compressive strength. Where classified concrete as normal strength (NSC) up to a compressive strength value 83 MPa. And a high-strength concrete (HSC) if a compressive strength value excess 83 MPa. on the other hand, some standards and codes use strength limits much lower values (even up to 55 MPa) for classifying a concrete as HSC. In spite of that, the property of HSC has led to extensive use in columns of buildings especially a high-rise. Also, concrete structural members (mainly NSC) show good behavior under fire conditions. Where the output of many studies showed that well-defined differences between the characteristics of NSC and HSC at elevated temperatures. Moreover, when HSC undergo rapid heating, concern was developed related to the appearance of explosive spalling, as in the case of a fire. Spalling is the phenomenon in which chunks of concrete fall off from the surface of a concrete structure when exposed to high and rapidly rising temperature. Spalling happens when the pore pressure in a concrete layer, because of evaporated moisture, greater than the tensile strength of concrete. This potential risk found primarily in HSC and ultra-high performance of concrete (HPC). Ultra HPC pointed to the concrete with the significant existence of dense bonding materials. As silica fume has strength over 100MPa. Where these materials added to get low permeability attempted to improve durability, but this may lead to problems of spalling under fire case [2].

The present study explains the effect of super plasticizer (Glenium 51) on the behavior of HSC under different time of burn. Experimental investigation on 84 cubes with and without GL51 under 1 hr, 2 hr and 3 hr burn was carried out.

2. The Experimental Works

2.1. Materials

Special attention must be given for production of HSC requires high quality materials. Moreover, HSC mix design proportioning is more critical than NSC. Following are detailed descriptions of the materials used.

2.1.1. Cement

The select type of cement is a very important material for the product of HSC. Resisting Portland Cement Type5 manufactured by AL-Smawa Iraqi factory was used. This cement conformed with the requirements of Iraqi specification (IQS) No.5/1984 [4]. The chemical and physical properties are shown in Tables 1 and 2.

Table 1. The chemical properties for Resisting Portland Cement Type5

Sample	Insoluble %	Loss on ignition %	MgO %	Fe2O3 %	SO3 %	C3A %	L.S.F.
1	1.25	2.0	4.2	4.8	1.0	3.3	0.99
Specification	≤ 1.5	≤ 4.0	≤ 5.0	-	≤ 2.5	≤ 3.5	0.66-1.02

Table 2. The physical properties for Resisting Portland Cement Type5

No.	The Test	Results	Requirements Specification [4]
1	Fineness (m^2/kg).	280	> 250
2	Time of setting -Initial time. - Final time.	113 min 229 min	> 45 min < 600 min
3	Compressive strength (MPa): - 3 days age. - 7 days age.	15.2 MPa 23.3 MPa	> 15 MPa > 23 MPa
4	Elongation	0.63	< 0.8

2.1.2. Fine Aggregate

Natural sand from Sanam mountain (south Basra City) was used as fine aggregate. The sand complied with IQS 45:1984 [5]. The fine aggregate has particle with a rounded shape and smooth texture with a fineness modulus, specific gravity, and absorption of 2.45, 2.72, and 2.3% respectively were within the requirements of IQS 45/1984. Table 3 shows the grading of the fine aggregate.

Table 3. The grading of the fine aggregate

Sieve Size (mm)	Percentage Passing from Sieves %	
	Results of stock	requirements of Iraqi specification[5]
10	100	100
4.75	94.8	100-90
2.36	87.2	100-75
1.18	74.6	90-55
0.6	54.8	59-35
0.3	18.7	30-8
0.15	4.2	10-0
No.200	1.4	≤ 5
SO3 %	0.44	≤ 0.5

2.1.3. Coarse Aggregate

Crushed gravel from Chlat (East Maysan) region was used with a maximum size of 14mm. The specific gravity and absorption were 2.70 and 0.7% respectively. The coarse aggregate grading was within the requirement of the IQS 45/1984, as shown in Table 4.

Table 4. The grading of the coarse aggregate.

Sieve Size (mm)	Percentage Passing from Sieves %	
	Results of stock	requirements of Iraqi specification
37.5	100	100
19.0	95.3	100-90
9.5	34.8	60-30
4.75	2.3	10-0
No.200	0.4	≤ 3
SO_3 %	0.1	≤ 0.1

2.1.4. Water

Reverse osmosis (RO) water was used for both mixing and curing of concrete.

2.1.5. Super Plasticizer

In this work Glenium51 super plasticizer was used, its composition is based on poly carboxylate ether. The specification is shown in Table 5, and conformed to the requirements of types A and F ASTM C494[6].

Table 5. The specification of Glenium51.

No.	*Specification of Glenium51*
1	New generation polycarboxlic ether hyperplasticiser for high performance concrete.
2	Description: Developed for applications in the premixed and precast concrete industries where the highest durability and performance. Free from chlorides and complies with AS 1478.1-2000 type HWR and ASTM C494 Types A and F. Flow able concrete with greatly reduced water demand.

2.1.6. Concrete Mix

The mix design method used in the present study is according to ACI211[7]. Three HSC mixes were designed as shown in Table 6, which had different percentages of Glenium51.

Table 6. Concrete mix

Mix No.	W/C ratio	Cement	Sand	Gravel	GL51(L/m^3)	Slump test
1	0.35	1	1.3	2.5	0	30 mm
2	0.35	1	1.3	2.5	1	90 mm
3	0.35	1	1.3	2.5	2	160mm

2.2 Curing and age of Testing

In general, curing and testing were done in two serial ages 7 days and 28 days, six cubes with 7 days curing were tested at the seventh day, six cubes with 28 days curing were tested at the twenty-eighth day, 72 cubes with curing were burned at the twenty-eighth day then tested at the twenty-ninth day. six cylinders with 28 days curing were burned at the twenty-eighth day then tested at the twenty-ninth day (Note: the compressive strength for all cubes and cylinder testing at twenty-ninth day were reduced to find the compressive strength at 28 days by reduction factor).

2.3. Instrument used in testing

There are many instruments used during the mixing and testing of the concrete specimens as follows:

1. Central mixing and Agitating truck.
2. Cone for slump test.
3. Compressive Machine (capacity=2000 KN).
4. Fire-tube gas.

3. Tests

3.1. Slump Testing (Fresh Concrete)

The slump test was used as a guideline to fix the concrete mix by using the additive of GL51. The first trial mix was prepared without using GL51, where the fresh concrete slump test is shown in Fig.1. The second trial mix was done by using the additive GL51 ($1L/m^3$) conforming to the mix design, the testing slump is shown in Fig.2. The third trial mix was done by using GL51 ($2L/m^3$), this mix was canceled because it gave an unaccepted slump. Table 6 included the results of the slump tests.

Figure 1. The fresh concrete without GL51 gives a slump test of 30mm

Figure 2. The fresh concrete with GL51(1L/m3) gives a slump test of 90mm

3.2. Compressive strength test (Hardened Concrete)

The experimental program consisted of conducting fire resistance tests on 84 cubes of concrete without and with GL51, mixing by central mixing with the accepted test slump, and burn it in scenarios at time (1,2, and 3) hour, as shown in Fig.3. The surfaces of the cube after the fire are shown in Fig. (4 -7).

Figure 3. Method of burn

Figure 4. The surface of the cub with GL51 after 1 hr fire

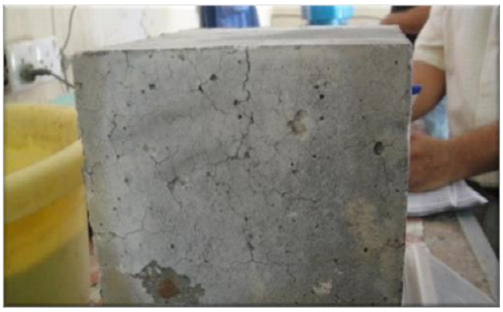

Figure 5. The surface of the cub with GL51 after 2 hr fire

Figure 6. The surface of the cub with GL51 after 3 hr fire

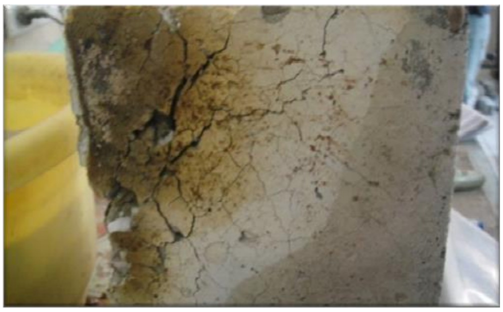

Figure 7. The surface of the cub without GL51 after 3 hr fire

The compressive strength test for cubes with and without GL51 was provided at the 7th and 28th day. Table 7 shows compressive strength measured at 7and 28 days for cubes with and without using GL51 before burning. The shapes of the cracked specimens after the compressive test are shown in Fig. 8 and 9.

Table 7. Compressive strength for cubes

No.	Compressive strength without additive (MPa)		Compressive strength with additive (MPa)	
	(7 days)	(28 days)	(7 days)	(28 days)
Cube1	32	42.5	55.4	74
Cube2	31.9	37.6	56.4	71.8
Cube3	34.4	42.9	61	58.8
Average	32.8	41	57.6	68.2

Figure 8. Cubs without GL51 after compressive strength test 28 days

Figure 9. Cubs with GL51 after compressive strength test 28 days

Fig. (10 -15) show the shape of failure for different specimens at a different time of the burn. Tables 8 and 9 show the compressive strength of cubes after burn (1hr, 2hr, and 3hr) for specimens without and with GL51 respectively. Fig.16 shows the relationship between time of burn and compressive strength for specimens without and with GL51

Figure 10. The shape of failure after loading for a cube with GL51 and fired for 1hr

Figure 11. The shape of failure after loading for cube without GL51 and fired for 1hr

Figure 12. The shape of failure after loading for a cube with GL51 and fired for 2hr

Figure 13. The shape of failure after loading for cube without GL51 and fired for 2hr

Figure 14. The shape of failure after loading for a cube with GL51 and fired for 3hr

Figure 15. The shape of failure after loading for cube without GL51 and fired for 3hr

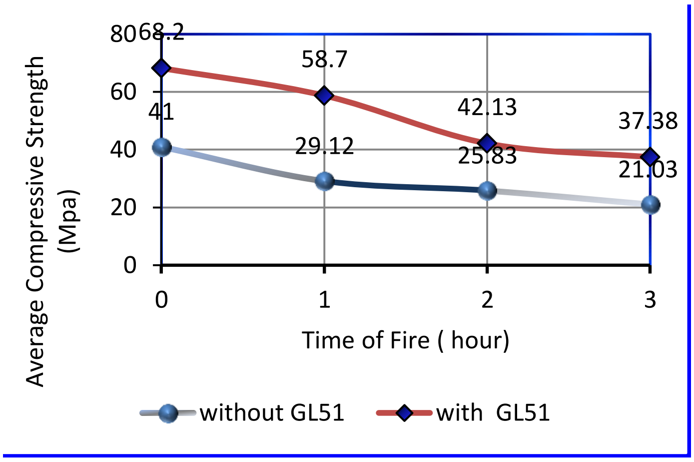

Figure 16. Average compressive strength for a cube (without/with using GL51) after-burn

Table 8. Compressive strength for a cube (without using GL51) after-burn

Cube No.	Compressive strength(MPa)		
	1hr	2hr	3hr
1	35.9	19.1	21.6
2	21	29.2	25.8
3	39.8	33	17.8
4	20	34.6	25
5	32.9	20.3	18
6	25.1	30.5	18
7	24.8	21.1	19.2
8	25.4	23.4	21.1
9	33.4	24.3	24.3
10	29.6	25.9	23.2
11	32.8	26.5	22.4
12	36.1	23.7	21.1
Average	29.73	25.97	21.46

Table 9. Compressive strength for a cube (with using GL51) after-burn

Cube No.	*Compressive strength*(MPa)		
	1hr	2hr	3hr
1	66.4	38.8	26.3
2	66	33.1	24.6
3	50.4	54.4	30.6
4	57.3	30	37.7
5	60	41.6	49.9
6	52.1	54.9	55.2
7	62.1	51.4	46.2
8	61.3	43.8	41.2
9	55	40.6	38.4
10	54.2	39.7	33.1
11	59.3	41.2	32.7
12	61.2	37.5	33.6
Average	58.78	42.25	37.46

3.3. *Splitting tensile (hardened concrete)*

The test of tensile splitting strength was done according to BS1881 [8]. A typical estimate of the test on 150 mm diameter x 300 mm long cylindrical specimens only included. The results of the cylinder after 3hr burn are shown in Table 10. The values were compared with the values of ACI 318-08 [9]. Fig. 17 and 18 show the shape of failure for specimens after 3hr burn.

Table 10. Tensile splitting strength for 28 days after 3hr burn

No.	Without GL51			With GL51		
	p (kN)	f_{ct}(MPa)*	f_{ct} (MPa)**	p(kN)	f_{ct}(MPa)*	f_{ct} (MPa)**
1	180.2	2.55		199.4	2.82	
2	190.5	2.69	2.07	196.2	2.77	2.74
3	139	1.97		229	3.24	
Average	169.9	2.40		208.20	2.94	

* f_{ct} = (2p/πdl); p=max. load (N), d=diameter of the cylinder(mm), l=length of the cylinder(mm).
** According to ACI318, f_{ct}= 0.5 * (fc^{-})^0.5 ; fc^{-} = 0.8 f_{cu}, f_{cu}= average compressive strength for cubes (with and without GL51) after 3hr burn.

Figure 17. The shape of failure after loading for cylinder with GL51 and fired for 3hr

Figure 18. The shape of failure after loading for a cylinder with GL51 and fired for 3hr

4. Test Results

The results provided that by using GL51 the workability improved from 30 mm to 90 mm as shown in Table 6, also the compressive strength became 68.2 MPa while its value is 41MPa without GL51, as shown in Table 7. Rather than we note the ratio of increase in compressive strength throw the growth time in concrete with GL51 is 18.4% (between 7 to 28 days), while the concrete without GL51 the magnitude of increase in the compressive strength is 25% between 7 to 28 days. The results of burn cubes without GL51 were 29.73, 25.97, and 21.46 MPa in 1hr, 2hr, and 3hr as shown in Table 8. Using GL51 in a mix of concrete in the same scenario of fire given 58.78, 42.25, and 37.46 MPa as shown in Table 9. Fig. 16 shows the average of compressive strength without/with GL51. In this study splitting tensile stress (f_{ct}) is measured for cylinder burn 3hr without and with GL51 which given 2.4 and 2.94 MPa respectively while (f_{ct}) calculated from ACI318-code gives 2.07 and 2.74 MPa as shown in Table 10.

5. Conclusions

From the results of experimental work it can be concluded that:

1. W/C ratio can have reduced by using the GL51 which helps to improve the properties of HSC.
2. By adding GL51 (1L/m^3) the compressive strength in HSC is increased by 166.3% in comparison mix without GL51.
3. The concrete with GL51 gives in 7days 81.6% from its compressive strength, while the concrete without GL51 gives in 7days 78% from its compressive strength.
4. Burning of the concrete specimens for a duration of 1hr, 2hr, and 3hr gave a reduction in the compressive strength of HSC with GL51 of the order 13.8%, 38%, and 45% respectively, compared to those concrete specimens without additives GL51 which resulted in a reduction of compressive strength of the order 27.5%,36.7%, and 47.7% respectively.
5. Experiment results of splitting tensile stress (f_{ct}) for cylinders after 3hr fire (with and without GL51), gave values nearest to (f_{ct}) calculated according to ACI code.
6. In general, the behavior of concrete with GL51 for specimens in fresh concrete and hardened concrete before and after burn is better than the concrete for the same mix but without GL51

6. References

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