IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 3 Ver. IV (May- Jun. 2016), PP 24-28
www.iosrjournals.org

The Effect of Heat on the Compressive Strength of Silica Fume Concrete (SFC)

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Abstract: *This paper investigates the effect of silica fume (SF) content on the compressive strength of concrete at high elevated temperatures .Effects of key variables such as (SF) content , several high temperatures and the exposure time to heat were studied .An experimental program was conducted to achieve the required objects.*
60 cubes were tested under axial compressive loads. They were divided as follows. 15 cubes without (SF)as a reference , 45 cubes were cast to study the effect of silica fume content and the time of exposure to heat at several high temperatures. It was found that the content of silica fume has a great effect on improving the behavior of concrete at high elevated temperatures.
Keywords: *silica fume – elevated temperatures and compressive strength.*

I. Introduction

Concrete can be exposed to elevated temperatures during fire or when it is close to furnaces and reactors . the mechanical properties of concrete , such as strength , elastic modulus and volume deformation , decrease remarkably upon heating resulting in a decrease in the structural quality of concrete . high temperature is one of the most important physical deterioration processes that influence the durability of concrete structures and may result in undesirable structural failures ,When exposed to high temperature , the chemical composition and physical structure of the concrete change considerably . Dehydration , including the release of chemically bound water from calcium silicate hydrate , becomes significant above 110 co . the dehydration of the matrix and the thermal expansion of the aggregate give rise to internal stresses , and beginning at 300 co , micro – cracks begin to pierce through the material . Ca(OH)2 , one of the most important compounds in cement paste , dissociates at around 530 co , resulting in the shrinkage of concrete [1].

Investigations of the performance of silica fume (SF) in concrete began since the 1950 s[2] . During the previous decades , enormous researchers evaluated the effects of the partial replacement of cement by SF on the properties of concrete . Silica fume is a by-product resulting from the reduction of high-purity quartz with coal in electric arc furnaces in the manufacture of ferro-silicon alloys and silicon metal [3].

Nowadays , it has been well known that the use of SF can significantly improve the mechanical properties as well as durability of high strength concrete (HSC). The very high content of amorphous silicon dioxide and very fine spherical particles are the main reasons for its high pozzolanic activity[2].

The advantages of SF caused SF being the most well-known additive material for HSC in recent years. Several research works have been done to investigate the behavior of HSC containing SF after exposure to elevated temperatures[4],[5],[6],[7],[8],[9],[10]and [11]. The main aim of these works was evaluating the potential of HSC containing SF for explosive spalling.

Hertz[4] suggested 10% of cement replacing by SF as an upper limit of SF content to avoid spalling . However , different researchers have reported inconsistently the relative residual compressive strength of concretes containing SF after subjecting to high temperatures [5],[6],[7],[8],[9],[10]and [11] . Hertz[5] reported that the residual compressive strengths of the special 170-MPa concretes containing 14-20% SF increased after heating up to 350 co and then decreased rapidly at higher temperatures . Phan and Carino [6] reported that concretes containing 10% SF showed better performance than OPC concretes at 100 and 200 co , whereas higher relative strength losses were observed in the SF concretes in comparison with the OPC concretes after subjects to 300 and 450 co . They showed that the relative residual strengths of concretes were increased approximately 13.6% and 6.1% by replacing of cement with 10% SF at w/c of 0.33 after heating to 100 and 200 co , respectively, whereas the relative strengths of the SF concretes were 9.1% and 7.3% lower than those of the OPC concretes at 300 and 450 co , respectively . Sarshar and Khoury [7] reported no significant advantages of the cement replacing by 10% SF at elevated temperatures . Poon et al . [8] observed the higher relative residual strengths of the SF concretes than those of the OPC concretes at 200co , whereas the relative residual strengths of all of the concretes at 400 co were approximately the same . Above 400 co , the SF concretes showed significant strength losses in comparison with the OPC concretes . Some investigators reported that the OPC concretes showed superior behavior in comparison with the SF concretes under elevated temperatures [9] and [10] .

Ali Behnood and Hassan Ziari [12] studied the effect of silica fume addition on the properties of high-strength concrete after exposure to high temperature . The results showed that the rates of strength loss for concrete specimens containing 6% and 10% SF had no significant effect on the relative residual compressive strength at 100 and 200 co , whereas the amount of SF had considerable influences on the residual compressive strength above 300 co similar to the response at 600 co . The optimum dosage of SF and w/c was found to be 6% and 0.35 respectively.

II. Materials

Local materials were used in concrete mixes and tested according to Egyptian Standard Specifications (ESS) and American Standard of Testing Materials (ASTM). Gravel as coarse aggregate was used with maximum size 25mm and the particle shape is approximately round. Fine aggregate used in this research was natural sand and it composed mainly of siliceous material .Ordinary Portland cement was tested to assure its compliance with ESS 373 – 1991.Supper- plasticizer was added to keep the water cement ratio = 0.5 with slump ranges from (7-11) cm .Silica fume used in this study was provided from Egyptian Ferro Alloys Company in Edufu ,Aswan ,Egypt.The chemical analysis and the physical properties of the used silica fume are shown in table (1) as obtained from the manufacturer

Table (1): Chemical Analysis and Physical Properties of the Used Silica Fume.

Description of test	Test results %	ASTM limits % C1240
1. Chemical analysis		
SIO_2	93	Min . 85
Al_2O_3	0.2	-
Fe_2O_3	0.5	-
CaO	0.2	-
MgO	0.5	-
SO_3	0.15	-
L.O.I	0.7	-
Na_2O	0.2	Max . 6
K_2O	0.5	Max . 1.5
H_2O	0.5	Max . 3
2. Physical properties		
Colour	Light gray	-
Specific gravity	2.3	-
Bulk loose density , kg/m3	300	-
Specific surface area , cm^2/gm	167.000	150.000-300.000

III. Concrete Mixes Proportion

Table (2): Concrete Mixes proportion

Mix No.	Cement (kg)	Silica fume		Gravel (m^3)	Sand (m^3)	Water (lit)	Super plast. (kg)
		%	kg				
1	500	0	0	0.8	0.4	250	2.5
2	475	5%	25	0.8	0.4	237.5	3.325
3	450	10%	50	0.8	0.4	225	3.6
4	425	15%	75	0.8	0.4	212.5	4.25

Four mixes were used as follows, one mix without silica fume as a control mix, three mixes with different contents of (SF) to study the effect of silica fume content on the compressive concrete at high elevated temperatures .

These mixes are identical except for the percentage of silica fume .

For all mixes the cement and silica fume content were 500 kg/m3 and the water content ratio 0.5 by weight.

Super – plasticizer per cubic meter were also used.

IV. Description Of Tested Specimens

All specimens were cubes 15*15*15 cm length. Concrete was cast vertically in the forms, and was mechanically compacted using external vibrator to ensure full compaction of concrete inside the forms.

The specimens were tested by using 1500 KN hydraulic compression machine.

V. Test Results And Discussion

The results of the compressive strength for all of the concretes at room temperature are presented in table (3) and fig (1) as it would be expected , the replacement of cement by 5% , 10% and 15% SF increased the 28-day compressive strength approximately 14% , 20% and 28% respectively .

This is due to the reaction of the SF with calcium hydroxide formed during the hydration of cement that caused the formation of calcium silicate hydrate (C-S-H) as well as filler role of very fine particles of silica fume .

Table (4) and Figure (2) give the test results of the compressive strength of the different tested concrete mixes at 150o c at heat exposure time 2 and 4 hours .

At heat exposure time 2 hours , the compressive strength of PC was 499 kg/cm2 as was 630 , 645 and 673 kg/cm2 for SFC with SF content 5% , 10 % and 15% respectively with increase of about 26 % , 29 % and 34% with respect of PC.

Also for heat exposure time 4 hours , the compressive strength of PC was 510 kg/cm2 as was 490 , 422 and 448 kg/cm2 for SFC of SF content 5 % , 10 % and 15 % respectively with reduction of about 4 % , 17 % and 12 % with respect of PC .

Table (5) and figure (3) give the test results of the compressive strength of the different tested concrete mixes at 350 co for heat exposure time 2 and 4 hours .

At heat exposure time 2 hours , the compressive strength of PC was 450 kg/cm2 as was 497 , 470 and 468 kg/cm2 for SFC with SF content 5% , 10 % and 15% respectively with increase of about 10 % , 4 % and 4% with respect of PC.

Also for heat exposure time 4 hours , the compressive strength of PC was 230 kg/cm2 as was 277 , 325 and 325 kg/cm2 for SFC with SF content 5% , 10% and 15% respectively with increase of about 20% , 41% and 41% respectively with respect of PC .

Table (6) and figure (4) summarize the results of the compressive strength of SFC at 150 co and 350 co for heat exposure time 2 and 4 hours .

For heat exposure time 2 hours , the compressive strength of PC increase with about 4% at 150 co as decreases with about 5% at 350 co with respect of the compressive at 0 co as for SFC with SF content 5% the compressive strength increase with about 15% at 150 co as decreases with about 8% at 350 co . Also , the compressive strength of SFC at SF content 10% increases with about 12% as decreases with about 18% for 150 co and 350 co respectively as for SF content 15% increases 10% while decreases about 23 % at 150 co and 350 co respectively .

For heat exposure time 4 hours , the compressive strength of PC increases with about 7% at 150 co as decreases with about 52% at 350 co with respect of the compressive strength at 0 co as for SFC with SF content 5% the compressive strength decreases with about 10% and 49% at 150 co and 350 co respectively .

Also , the compressive strength of SFC with SF content 10% decreases with about 26% and 43% at 150 co and 350 co respectively as for SF content 15% decreases with about 26% and 46% .

VI. Conclusions

Based on the results of this experimental investigation , the following conclusions are drawn :

1) The replacement of cement by 5% , 10% and 15% SF increased the 28-day compressive strength approximately 14% , 20% and 28% respectively .
2) After exposure to 150 co , significant increase occurred in the compressive strength of concretes with and without SF for 2 hours heat exposure . as at 4 hours exposure the compressive strengths of 5% , 10% and 15% SFC decrease with about 4% , 17% and 12% respectively with comparison to concrete without silica fume .
3) After exposure to 350 co significant decrease occurred in the compressive strengths of all concretes decrease with about 6% , 9% , 18% and 24% respectively for 2 hours heat exposure time.
4) After exposure to 350 co it can be noticed with increasing SF content increase the loss of compressive strength .

Table (3): Results of Compressive Strength of SFC (Kg/Cm2) At Zero Temperature.

Mix No.	Silica fume content (%)	Compressive Strength (kg/cm^2)
1	0	477(control)
2	5%	544(+14%)
3	10%	575(+20.5%)
4	15%	612(+28.3%)

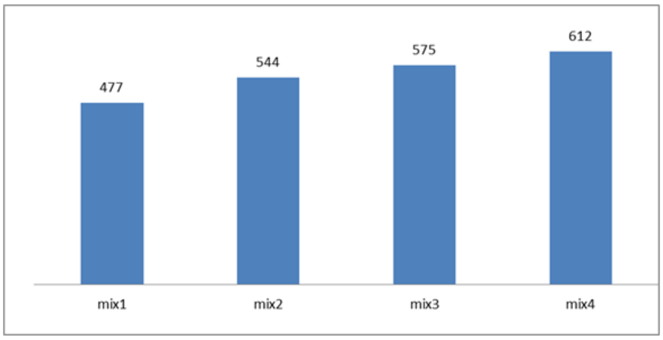

Fig. (1): The Compressive Strength (Kg/Cm2) Of SFC at 0co

Table (4): Results of Compressive Strength Of SFC (Kg/Cm2) At 150 Co.

Mix No.	Silica fume content(%)	Compressive Strength (kg/cm^2)	
		2 hours	4 hours
1	0	499(control)	510(control)
2	5%	630 +(26.25%)	490 -(3.9%)
3	10%	645 +(29.25%)	422 -(17.25%)
4	15%	673 +(34.87%)	448 -(12.15%)

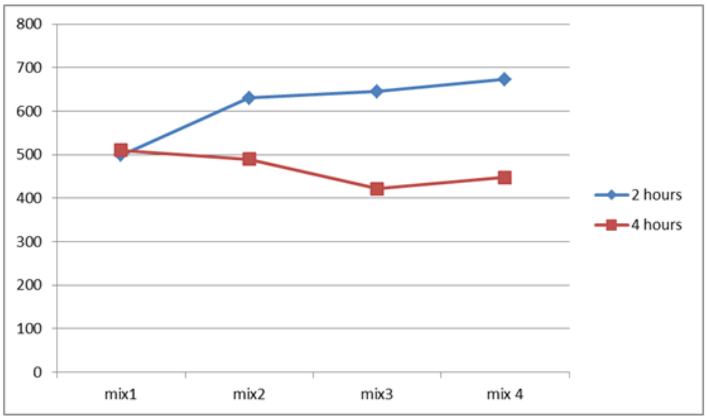

Fig (2): The Compressive Strength (Kg/Cm2) Of SFC at 150 Co.

Table (5): Results of Compressive Strength of SFC (Kg/Cm2) At 350 Co.

Mix No.	Silica fume (%)	Compressive Strength (kg/cm2)	
		2 hours	4 hours
1	0	450(control)	230(control)
2	5%	497+(10.44%)	277+(20.43%)
3	10%	470+(4.44%)	325+(41.3%)
4	15%	468+(4%)	325+(41.3%)

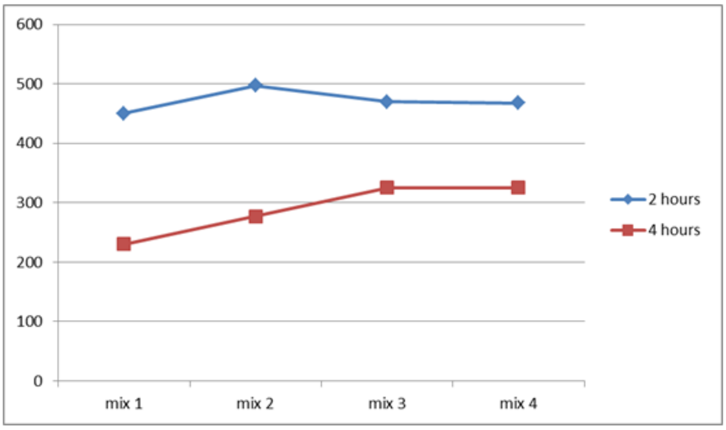

Fig (3): The Compressive Strength (Kg/Cm2) Of SFC at 350 Co.

Table (6): Summary Of Results For Tested Cubes Of SFC At High Elevated Temperatures.

Mix	Silica fume (%)	The compressive strength (kg/cm^2)				
		0 c^o	150 c^o		350 c^o	
			2 hours	4 hours	2 hours	4 hours
1	0	477(control)	499(+4.61%)	510(6.91%)	450(-5.7%)	230(-51.8%)
2	5%	544(control)	630(+15.8%)	490(-9.9%)	497(-8.6%)	277(-49.1%)
3	10%	575(control)	645(+12.17%)	422(-26.6%)	470(-18.26%)	325(-43.5%)
4	15%	612(control)	673(+10%)	448(-26.8%)	468(-23.5%)	325(-46.9%)

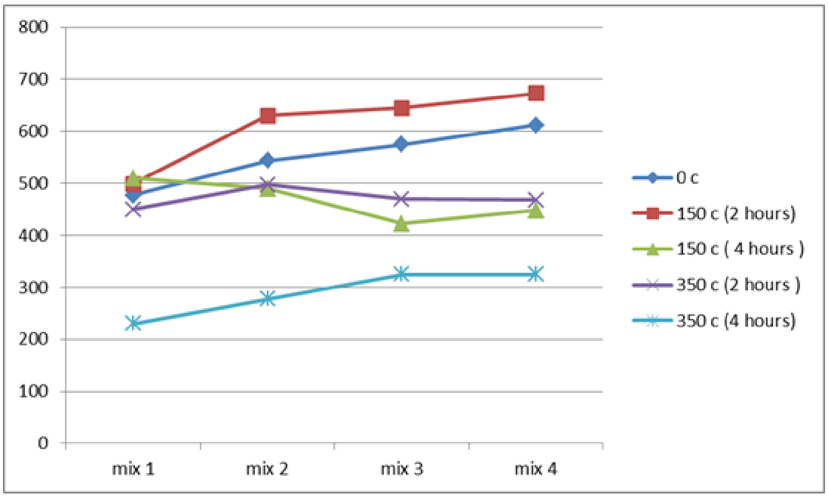

Fig. (4): The Effect of High Temperatures on the Concrete Mixes

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