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Improving the Resistance of Self Compacting Concrete exposed to Elevated Temperatures by Using Steel Fiber

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Abstract

Elevated high temperatures due to fire represents one of the most severe risks to buildings and structures, which negatively affects on the engineering properties for constituent members of these buildings. The study aims to investigate the role of steel fiber to improve of properties of self compacting concrete (SCC) at elevated temperature (25, 200, 400 and 600°C) with two different exposure durations of (0.5 and 1.5 hours). Specimens were exposed to temperature and tested at age (7, 28 and 90 days) .The slump flow and T_{500mm}, L-box, and Sieve segregation resistance were conducted to investigate the fresh properties of SCC. Whereas the properties of hardened concrete were inspected using compression test, splitting tensile test, and flexural , as well as modulus of elasticity tests.

The results indicate that Elevated temperatures and increasing of exposure duration had passively influenced on hardened properties of both plain and reinforced SCC, hardened properties of two type of SCC decreased with increased temperatures and increasing of exposure duration. Also the results indicate that steel fiber used in self-compacting concrete reduced the amount of deterioration of properties of Self compacting fiber-reinforced concrete (SCFRC) at high temperature. The percentage change (improvement) for mixes with steel fiber (0.5 and 1%) with respect to mixes without steel fiber , where compressive strength ranged between (0.3-20.9%) at 200 ^{o} C, (-3.1-31.3%) at 400 ^{o} C and (-3.9-31.5%) at 600 ^{o} C. Also the best percentages of increase were in splitting tensile strength and flexural strength , the percentages of increase in splitting tensile ranged between (27-94%) at 200 ^{o} C, (39-121%) at 400 ^{o} C and (38-109%) at 600 ^{o} C. and the percentage of increase in flexural strength ranged between (68-146%) at 200 ^{o} C, (75-122%) at 400 ^{o} C and (45-109%) at 600 ^{o} C. Also the percentage of increase in static modulus of elasticity ranged between (4.3-15.5%) at 200 o C and (6.1-18.3%) at 400 ^{o} C for mixes with steel fiber (0.5 and 1%) with respect to reference mixture. It had also emerged the spalling phenomenon at parts of cylinders and prisms specimens at exposed to high temperatures (400 ^{o}C), at the duration of exposure was 1.5 hours, and the temperature (600 ^{o}C) at duration of exposure 0.5 and 1.5 hours.

Keywords: Self compacting concrete , elevated temperature , Steel Fiber , Compressive strength, Splitting tensile , Flexural strength , modulus of elasticity, spalling phenomenon .

1. Introduction

Self Compacting Concrete (SCC) is highly workable concrete that can flow through densely reinforced and complex structural elements under its own weight and adequately fill all voids without segregation, excessive bleeding, excessive air migration (air-popping), or other separation of materials, and without the need for vibration or other mechanical consolidation (TB-1500, 2005) SCC flows like “honey” and has nearly a horizontal concrete level after placing. (Dehn et al, 2000).

The mix composition of SCC are same as those used in traditional vibrated concrete, but additional care is needed in the initial selection of materials used for producing SCC. The materials are included powder materials (cement, fly ash, silica fume, ground blast furnace slag, limestone and pigments), aggregates (fine and coarse aggregate), admixtures (superplasticizers and viscosity modifying admixtures) and water. (Iures & Bob, 2010). The Selection of the type of cement used in SCC depends on the overall requirements for the concrete, such as strength, durability, etc. C3A content higher than 10% may cause problems of poor workability retention(EFNARC, 2002). To avoid excessive heat generation, Portland cement is generally partially replaced by mineral admixtures like limestone filler or fly ash. The nature and amount of filler added are chosen in order to comply with the strength and durability requirements (Ayano et al , 2002).

The rheological properties of mixtures and hardened material are improved at a higher fineness of this additive (Grzeszczyk & Podkowa, 2009). The addition of limestone filler to Portland cement has several effects on the properties of fresh and hardened concrete. Limestone filler grains act as nucleation sites for CH and C-S-H reaction products at early hydration ages, and accelerate the hydration of clinker minerals, especially C3S, resulting in an improvement in early strength (Pera et al, 1999).

Coarse aggregate properties affect aggregate-cement bond characteristics and mixing water requirements. Generally, the good quality aggregate must be used, to ensure a good bond between coarse aggregate, particles and matrix (Collepardi, 2003). According (EFNARC, 2005) Coarse aggregates conforming to EN 12620 are appropriate for the production of SCC. The maximum aggregate size should generally be limited to 12 – 20 mm, although larger sizes are being used (Jawahar et al, 2012). Fine aggregate in SCC plays a major role in the workability and stability of the mix. Particle size fractions of less than 0.125 mm should include the fines content of the paste, and should also be taken into account in calculating the water powder ratio. High volume paste in SCC mixes helps to reduce internal friction between sand particles, but a good grain size distribution is still very important (EFNARC, 2005).

Admixtures are materials added during the mixing process of concrete in small quantities related to the mass of cementitous binder, to modify the properties of fresh or hardened concrete (EFNARC, 2005).The unit water content, water-powder ratio should be selected to ensure the required performance of the self-compacting concrete , The water-powder ratio should normally be in the range of 28% to 37% by mass of cement or o. 85 to 1.15 by a volumetric ratio to cement (Manual for Mixture Proportioning of Self-compacting Concrete).

There is no standard method for SCC mix design ,but many academic institutions, admixture ready-mix, precast and contracting companies have developed their own mix proportioning methods. Mix designs often use volume as a key parameter because of the importance of the need to over fill the voids between the aggregate particles. Some methods try to fit available constituents to an optimized grading envelope (European Project Group, 2005). Mix designs of SCC must satisfy the criteria on filling ability, passing ability and segregation resistance (Goodier, 2003). The most common method of mix design is the general method developed by the University of Tokyo and since then, many attempts have been made to modify this method to suit local conditions (Hodws et al., 2001).In general, the following rules should be followed to be successful in manufacturing SCC (Collepardi, 2006),with certain methods are used ,there are many methods for design of mixes such as Rational methods (Okamura and Ozawa, 1995),and EFNARC methods (European Project Group, 2005).

Fresh properties of SCC are measured the workability tests, that are made of fresh concrete immediately after mixing including slump flow, J- ring, V funnel and L-box tests. There are many factors that influence workability such as: method and duration of transportation, quantity and characteristics of cementations materials, concrete consistency (slump), grading shape and surface texture of fine and coarse aggregates, entrained air, water content, concrete and ambient air temperatures and admixtures. A uniform distribution of aggregate particles, and presence of entrained air significantly help control segregation and improve workability (Al-Abduljabbar, 2008).

The Compressive strength of SCC depends on (water/(cement+ powder)) ratio, degree of compacting, type of cement and aggregate, age of concrete and other factors, the compressive strength increases with the decrease of (w/c+p) material ratio. In rich SCC mixes increasing the maximum size of aggregate lead to decrease the compressive strength (Al-Mishhadani et al, 2008). The experimental results showed the using silica fume and limestone dust in SCC led to a considerable improvement in splitting tensile strength(Rejeb & Mohammed, 2011). Flexural strength of SCC is more than that for normal concrete (with the same or higher amount of cement) due to the formation of new hydration products in the pores and microcracking, and less pores in microstructure of the concrete. This is due to the fact that SCC includes more paste filler powder and much water reducing admixture (Raheem , 2005).

The Various kinds of fiber are used to reinforce concrete in structural applications, due to its high stiffness, the steel fiber is probably the most commonly used fiber material. However, synthetic fibers are gaining ground, and new materials are under continuous development (Jansson, 2011). In concrete, steel fibers have been applied to replace bar reinforcement, to decrease width of cracks, to increase tensile and flexural strength, and to improve post-cracking behavior. Steel fiber reinforcement influences the way cracks develop in concrete and may impart improved crack growth resistance, increase surface roughness of individual cracks, and a greater likelihood for crack branching and multiple crack development, due to this. Steel fiber reinforcement may be used to significantly reduce the permeability of concrete, thus improve the durability (ACI 544.5R, 2010). The bond between fiber and matrix is dependent on the aspect ratio of the fiber, typical aspect ratios range from about 20 to100. The addition of steel fibers to a cement based composition can increase significantly its post-cracking residual strength, more ductile and tougher than conventional SCC(Ambroise et al, 2001), but the fluidity and the workability have a general tendency to decrease with an increase in the fiber volume fraction of the concrete mixture (Tamrakar, 2012),(AL-Ameeri,2013).

Fibers are affected on hardened properties of concrete at different rates, fibers have little effect on compressive strength, a moderate on splitting tensile strength, but they are generally found to have more effect on the flexural strength of SCFRC them on either the compressive or splitting tensile strength (AL-Ameeri, 2013).

Concrete properties in case of unexpected fire are changed after exposure to fire. Hence, it is important to understand the change in the concrete properties due to extreme temperature exposures. As the concrete used for special purposes, the risk of exposing it to high temperature also increases. To be able to predict the response of structure after exposure to high temperature, it is essential that the strength properties of concrete subjected to high temperatures are clearly understood. High temperature causes development of cracks. These cracks like any other crack propagation may eventually cause loss of structural integrity and shorting of service life (Kulkarni & Patil, 2011).

To understand the behavior of concrete under elevated temperature, it is necessary that several factors have taken into account for each experiment. Strength of concrete, type of cement, type of aggregate, water cement ratio, density of concrete, percentage of reinforcement, cover to reinforcement .. etc are some of the important factors that affect the performance of concrete at elevated temperature (Anand & Arulraj, 2011).

At certain temperatures, there is apparent deterioration mostly due to the dehydration of C–S–H gel and increasing pore water pressure. Finer pore distribution along with poor pore connectivity that characterizes SCC and HPC keeps free and chemically bound water trapped inside the structure, leading to growing pore pressure. When high temperature and high heating rate are applied, concrete fire resistance is most likely to decrease and thus spalling to occur (Chan et al, 1999).

Information on SCC behavior at high temperature is badly required, because SCC more dense or compact microstructure, with smaller and less connected pores, may in principle make this material more heat-sensitive than ordinary conventional concrete (OCC). While the thermal effects on OCC had been extensively investigated in the last 20 years and several studies had been devoted to SCC spalling in fire (Bamonte & Gambarova , 2012).The risk of spalling for self compacting high strength concrete was greater than that of conventional high strength concrete.It had been shown that explosive spalling occurred in both the cases of SCC and OCC when the oven peak temperature of 600°C. SCC was found to spall more compared to OCC due to lower permeability and higher moisture content. SCC produced with limestone filler was found to have better performance compared to mixtures prepared with different filler materials.

At last ,this research aims to study the effect of steel fiber on hardening properties of self compacting concrete exposure to elevated temperature, for Assessing the structural safety of such structures after exposure to elevated temperature.

2. Experimental works

2.1. Materials used

Optimum proportions must be selected according to mix design methods, considering the characteristics of all materials used. The following sections provide information on the materials used in the SCC mixes:

2.1.1 Cement

Cement used in this study was ordinary Portland cement Type (I) called traditional (Mass). This cement was tested according to the Iraqi Standard Specification IQS No.472/1993 and IQS No.198/1990. The chemical and physical properties of this cement were conformed to the Iraqi specifications IQS No.5/1984.

2.1.2. Coarse aggregate

Rounded gravel of maximum single size 10 mm from (Al-Nibaee) region was used. Table (3-4) show the grading of this aggregate, which conforms to the requirements of IQS No.45/ 1984 . The specific gravity was 2.62, sulfate content 0.085 ,it is conformed to the requirements of IQS No.45/ 1984 .

2.1. 3.Fine aggregate

Natural sand conforming to Zone III of IQS No.45 / 1984 was used and its properties are found as follows: Specific gravity 2.60and the SO3 of 0.45% and fineness modulus 2.34 . It is conforming to IQS No.45 -1984 .

2.1.4. Water &Super-plasticizer

The potable water has been used for both mixing and curing of concrete. A chemical admixture based on modified polycarboxylic ether, which is known commercially (Glenium 51) was used in producing SCC as a superplasticizer admixture. It was complied with IQS No.1431-89 and ASTM C494-05 Type F.

2.1.5. Lime stone powder (LSP)

This material was used to increase the amount of powder (cement + filler). It has SO_3 of 0.64 and its specific gravity was 2.7.

2.1. 6. Fibers

In this work, type of steel fiber having geometry of cylindrical with hooked ends was used. The characteristics of the steel fiber ; length, diameter ,tensile strength, specific gravity were 35mm , 0.5 mm,1300 MPa and 7800 kg/m3 respectively. It was complied with ASTM A820M-11.

2.2.Methodology

The mix design method used in the present study was according to (EFNARC, 2005) . The details of the mixes used throughout this investigation are shown in Table (1).

Table (1) Proportions of reference plain mixture(R)

Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	LSP (kg/m^3)	Water (kg/m^3)	SP (L/m^3)	w/c	w/(c+p)
430	820	750	130	190	6.88	0.44	0.34

Fibers were added in quantities ranging from 0 to 1 % by volume of the total mixture. Fibers were fed into mixed by hand to ensure that clumping and clustering effects were minimized. Fiber content in SCFRC mixtures are detailed in Table (2).

Table (2) Fiber content in SCFRC mixtures

Mix No.	Mix Symbol	Fiber Content (Vol.%)
1	R	Reference mix without fiber
2	ST1	0.5 % steel hooked end hard-drawn wire fiber
3	ST2	1.0 % steel hooked end hard-drawn wire fiber

The mixes being cast into the tight steel molds until it's fully filled without any compaction. All specimens were demoulded after 24 hours and initial curing in tap water was performed.

The specimens are exposed to different temperatures in an electrical furnace, the specimens were tested at the ages of (7, 28 and 90 days). Three temperature levels of 200, 400 and 600 ^{o}C were chosen with two different exposure duration of 0.5 and 1.5 hours . After heating, the concrete specimens were allowed to cool inside the electrical furnace for 2 hours after end of the heating and stored in a laboratory environment about 24 hours , the test were carried out for specimens .

2.3.Fresh Concrete Tests

The fresh properties of plain SCC were tested by the procedures of (European Guidelines for self compacting concrete) . In this work three tests were used slump flow test, L-box test and sieve segregation resistance were used for assessment of fresh properties of SCC in this study.

2.4. Hardened Concrete Tests

The mechanical properties studied are compressive strength, splitting tensile strength, flexural strength. Furthermore, static modulus of elasticity test is used. The compressive strength test was performed in accordance with IQS No.348-1992 using 150 mm cube specimens. The splitting tensile strength test was carried out according to IQS No.283-1995 using Ø100 × 200 mm cylinder specimens. The test procedure given in IQS No.291-1991 was used to determine the flexural strength using 100 × 100 × 400 mm prisms. The static modulus of elasticity was performed according to IQS No.370-1993 by using test cylinders of Ø150×300 mm.

3. Results and Discussions

3.1. The fresh Properties of Self-Compacting concrete

All mixes of Self-Compacting Concrete (SCC) and Self Compacting Fiber Reinforced Concrete (SCFRC), workability tests were made of fresh concrete immediately after mixing. These tests include slump flow, L-box and sieve segregation resistance. The tests were carried out to determine the effect of different mix proportion of fibers on the filling, passing ability and segregation resistance of SCC.

3.1.1. Slump Flow and T500 Test

Table (3) shows the results of slump flow test. The values of (D) represent the diameter of spread (slump flow). A good workability achieved for the reference mixture (R) is proportioned at the upper level of self compatibility, in order to remain within the given limits after the addition of the fibers. Based on the slump flow diameter (SF) of slump flow test, SCC is classified into three categories: SF1 (550-650mm), SF2 (660-750mm), and SF3 (760-850mm) according to (EFNARC, 2005). All mixtures had a slump-flow ranged between (670-740 mm), all the mixtures were in the SF2 class. Significant decrease in slump flow diameter has been observed with incorporating steel fibers in SCC mixes. Adding steel fibers increases the resistance to flow and reduces the flowability due to increasing the interlocking and friction between fibers and aggregate (Al-Musawee, 2011),(AL-Ameeri,2013). Slump flow diameter decreases with the increase in steel fiber content of the concrete mixtures with respect to plain mixtures (Mahmoud, 2012).

Segregation and bleeding were visually checked during the slump flow test and were not observed in any of the mixtures. During the slump flow test, time required to reach 500mm diameter was also measured and recorded as (Slump Flow Time) T_{500mm} (sec), which indicates the speed of flow and hence the viscosity of self-compacting concrete. According to the (EFNARC, 2005), SCC can be classified as VS1 for $T_{500} \leq 2$ sec or VS2 for $T_{500} > 2$ sec. The results of T_{500mm} range between (2-3.14) sec as shown in Table (1). All mixtures were in the VS2 class which is characterized by the viscosity of concrete with high segregation resistance. Including steel fibers in SCC mixtures resulted in an increase in T_{500} values. The increasing percentage was found to be increased with increase in fiber content . From the results in Table (3), it can be observed that the reference mixture (R) gives more workability than mixes with 0.5% and 1% steel fibers by 2.7 % and 9.5% for slump-flow, and by 14 % and 57 % for T_{500mm} respectively. The flow behavior of steel fiber-reinforced concrete differs from that of plain self-compacting concrete, the fiber inclusion reduced the fluidity, which is the ability of fresh concrete to flow and fill the mold, these results are consistent with (Gencel et al, 2011).

Table (3): Results of fresh properties of SCC and SCFRC

Test	Volume fiber fraction (V_f)% by Vol.			Limitations (EFNARC 2005)
	R 0%	ST1 0.5%	ST2 1%	
Slump-flow (mm)	740	720	670	600-800
T500 mm (sec)	2	2.28	3.14	2-5
Blocking ratios (H2/H1)	0.95	0.84	0.8	0.8-1
Sieve segregation resistance %	14.7	10.5	8.5	20% Max.

3.1.2. L-Box Test

L-Box with 2 bars was used in this study to assess passing ability of mixes. Blocking ratio results (H2/H1) were shown in Table (3). The results of blocking ratio ranged between (0.8-0.95) for all SCC mixes. According to (EFNARC, 2005), a blocking ratio (H2/H1) of more than or equal to 0.8 represents a good passing ability. All mixtures had a good passing ability with blocking ratio ≥ 0.8. A minimum acceptable value of 0.8 can give some indication of easier flow. The high value of blocking ratio (H2/H1) indicates excellent deformability, without blocking and excellent capability of this highly flowable concrete to self-compacting. The reduction percentage in blocking ratio for SCC reinforced with 0.5 (% by Vol.), was (11.58%) and for SCC reinforced with

1% (%by Vol.), was (15.79%) relative to their corresponding reference mixture (R).

The decrease percentage increased with increase in steel fiber content. Higher steel fiber content, the lower blocking ratio, when increasing fiber content increases the interlocking of the fibers to each other. Blocking mainly depends on the size, shape and content of coarse aggregate (Okamura, 1997). The distribution of fibers and coarse aggregates was mainly determined by their relative size (Johnston, 1996). A reduction in coarse aggregate content and lowering the size is both effective in inhibiting blocking, these results are consistent with (Mahmoud, 2012).

3.1.1 Sieve Segregation Resistance (SR) Test

Segregation resistance is very important in SCC mixes. It is conducted by sieve method. The results of SCC mixes are shown in Table (3). No blocking or segregation behaviour was observed in all mixes. According to (EFNARC, 2005), a segregation resistance classes SR1 (≤ 20) and SR2 (≤ 15). All the mixtures had segregation resistance (≤ 15), for SCC reinforced with (0.5% by Vol.), was (10.5%) and for SCC reinforced with (1%by Vol.), was (8.5%) relative to their corresponding reference mixture (R). The mixes with steel fiber had more segregation resistance than mixes without steel fiber, it may due to steel fiber making the mix higher viscosity compared with a mix without steel fiber (AL-Ameeri,2013).

3.2.The effect of steel fiber on hardened properties of SCC exposure to elevated temperatures

3.2.1 Compressive Strength

The compressive strength is one of the most important properties of hardened concrete. The results are shown in Table (4) indicate that all specimens exhibited a continuous increase in compressive strength with progress in age. This increase in compressive strength with age is due to the continuity of hydration process which forms a new hydration product within the concrete mass (Neville, 1995). Also results are indicate that compressive strength of SCC decreasing with increasing temperatures and period of duration for all mixes.

Table (4) Test results of compressive strength (fcu) of SCC and SCFRC

Temp. °C	Duration Hour	Compressive Strength (MPa)								
		7 days			28 days			90 days		
		Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%		
		0	0. 5	1	0	0. 5	1	0	0. 5	1
25 (1)	-	21.6	22.5	23.9	29.5	31.5	33.2	39.4	40.7	42
200 (2)	0.5	20.4	21.9	21.4	23.7	25.2	28.6	35.9	36.6	38.2
	1.5	20.5	21.8	22.9	23.9	26.5	28.9	36.6	36.7	38.7
400 (3)	0.5	16.9	17.3	18.4	19.4	21.3	24.8	32.7	31.7	33.8
	1.5	15.7	16.7	17.4	17.6	20.8	23.1	31.6	30.7	33
600 (4)	0.5	13	14.7	14.2	16.9	18.9	20.7	28	28	29.8
	1.5	12.9	13.2	12.4	14.6	17.9	19.2	26.4	26.5	28.4

Where the percentage residual of compressive strength values for the mixes of SCC (R, ST1 and ST2), exposed to elevated temperature (200, 400, and 600 ° C) with respect to mix at temperature 25 ° C for ages (7, 28, and 90 days) are reported in Table (5) and Fig.(1) through Fig. (3).

It can be noticed that the compressive strength suffers a noticeable deterioration when exposed specimens to elevated temperatures, it due to a lot of physical and chemical changes in concrete. where the Heating to reach a temperature of 200 °C does not have significant effects on the compressive strength of concretes, a small loss of strength was observed. It was associated to an evaporation of free water as well as to an increasing in porosity of the tested concretes. This porosity increases due to expansion of the pore diameters and therefore leads to an increase in permeability. When temperatures reach the 300ºC, the calcium hydroxide in the cement will begin to dehydrate generating more water vapor and also bringing about significant reduction in the compressive strength of self compacting concrete in range of 300ºC and 600ºC (Kulkarni & Patil , 2011).

Table (5) Percentage residual of Compressive Strength % of SCC and SCFRC

Residual Compressive Strength %	Duration Hour	Percentage residual of Compressive Strength %								
		7 days			28 days			90 days		
		Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%		
		0	0.5	1	0	0.5	1	0	0.5	1
(2) / (1)	0.5	94	97	90	80	80	86	91	90	91
	1.5	95	97	96	81	84	87	93	90	92
(3) / (1)	0.5	78	77	77	66	68	75	83	78	80
	1.5	73	74	73	60	66	70	80	75	79
(4) / (1)	0.5	60	65	59	57	60	62	71	69	71
	1.5	60	59	52	49	57	58	67	65	68

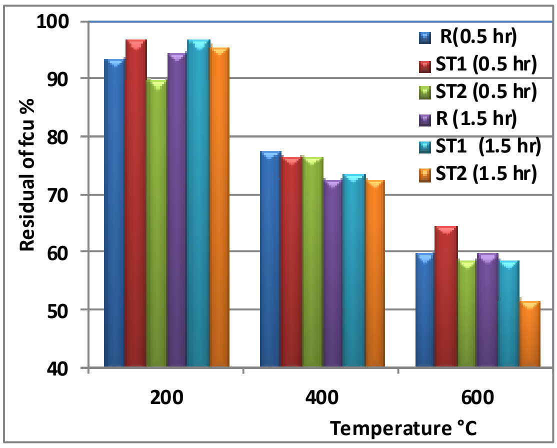

Fig.(1) The percentage of residual compressive strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 7 days

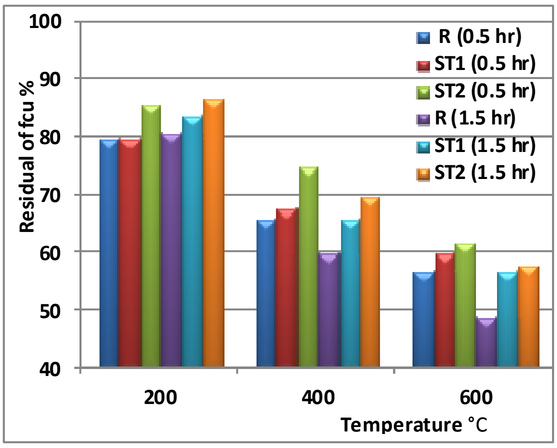

Fig.(2) The percentage of residual compressive strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 28 days

It is observed that the color of specimens changed to gray, and color change increased when temperature and the period of exposure increased. The induction of color change meaning loss in mechanical properties. The decreasing in compressive strength of concrete is attributed to the break-down of interfacial bond due to incompatible volume change between cement paste and aggregate during heating and cooling (Venecanin, 1997), and the formation of relatively week hydration products (dehydration of the calcium –silica hydrate in cement paste). It can be conducted that the temperature had a great effect on the cement rather than the filler material. The limestone powder is produced from crushed limestone and needs a high temperature about (700-1000^{o}C) for complete analyzing to (CaO) and (CO$_2$), therefore, it is a heat absorbing material (Neville, 1995).

Also ,the relation between steel fiber content and compressive strengths at elevated temperature are summarized in Table (6) & plotted in Figs.(4) through (6), for two exposure period and at all ages. It was observed the compressive strength increases with steel fiber content, for all mixes (ST1 and ST2) with respect to SCC (without steel fiber) at ages (7, 28, and 90 days). It can be seen that introducing steel fiber positive affected the compressive strength.

It has been found that steel fibers improving the residual compressive strength of SCC after exposure to elevated temperatures. Steel fibers had been used to minimize the damage due to elevated high temperature for (ST1 and ST2) mixes and, it has been used to reduce spalling and cracking. This might be attributed to their bond to the matrix which can be enhanced by mechanical anchorage or surface roughness(Mon,2010).

Table (6) The percentage of change in compressive strength (*fcu*) of SCFRC with respect to SCC

Temp. °C	Duration Hour	The percentage of change in compressive strength (fcu) %					
		7 days		28 days		90 days	
		ST1/R %	ST2/R %	ST1/R %	ST2/R %	ST1/R %	ST2/R %
25	-	4.2	10.6	6.8	12.5	3.2	6.6
200	0.5	7.4	4.9	6.3	20.7	2	6.4
	1.5	6.3	11.7	10.9	20.9	0.3	5.7
400	0.5	2.4	8.9	9.8	27.8	-3.1	3.4
	1.5	6.4	10.8	18.2	31.3	-2.8	4.4
600	0.5	13	9.2	11.8	22.5	0	6.4
	1.5	2.3	-3.9	22.6	31.5	0.4	7.6

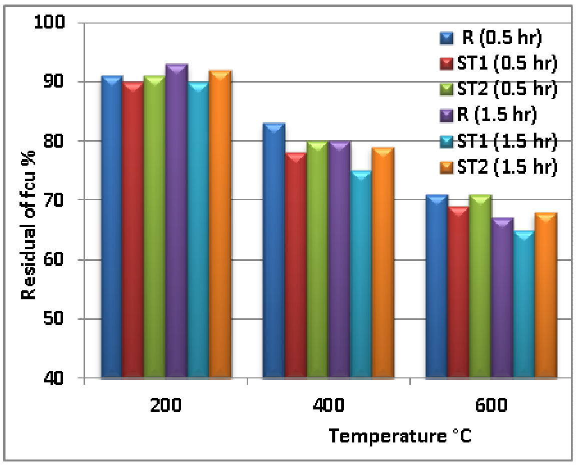

Fig.(3) The percentage of residual compressive strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 90days.

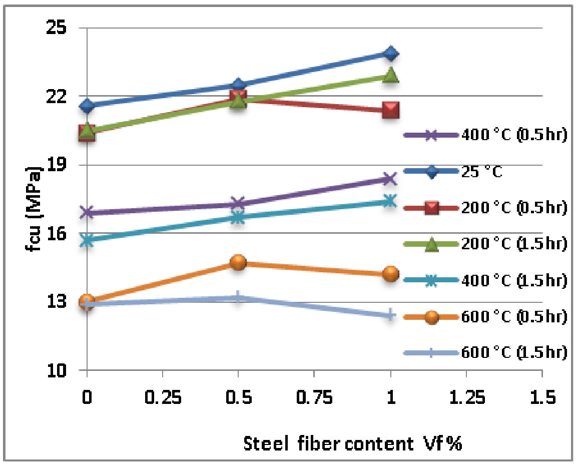

Fig.(4) Effect of steel fiber content on compressive strength of SCC with different temperature and period of exposure at 7 days.

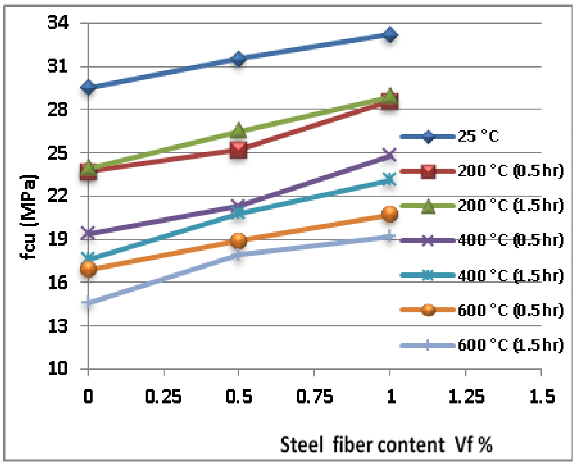

Fig.(5)Effect of steel fiber content on compressive strength of SCC with different temperature and period of exposure at 28 days.

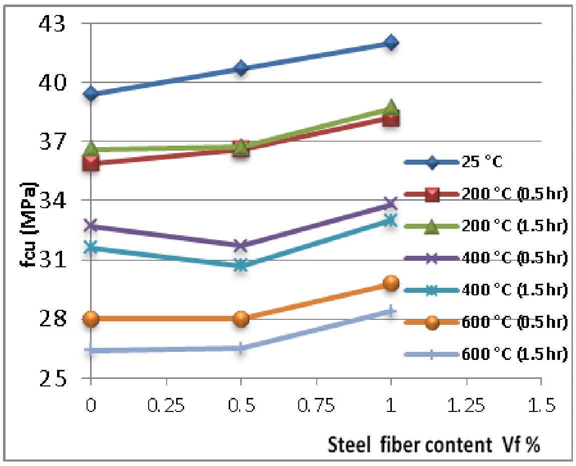

Fig.(6) Effect of steel fiber content on compressive strength of SCC with different temperature and period of exposure at 90 days.

3.2.2. Splitting Tensile Strength

The results indicate that all specimens exhibited a continuous increase in splitting tensile strength with progress in age. The splitting tensile strength results are summarized in Table (7), show the relation between splitting tensile strengths and elevated temperature for all specimens. It observed that splitting tensile strength decreases with increasing temperatures.

Table (7) Test results of splitting tensile strength (ft) of SCC and SCFRC

Temp. °C	Duration Hour	Splitting tensile Strength (MPa)								
		7 days			28 days			90 days		
		Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%		
		0	0. 5	1	0	0. 5	1	0	0. 5	1
25 (1)	-	2	3.7	3.9	3.4	4.3	5.3	3.9	5.5	5.9
200 (2)	0.5	1.9	3.6	3.4	3.3	4.2	4.9	3.8	5.3	5.6
	1.5	1.7	3.1	3.3	3.2	4.1	4.7	3.6	5.1	5.4
400 (3)	0.5	1.4	2.8	3.1	2.8	3.9	4.1	2.9	4.6	4.9
	1.5	1.3	2.5	2.7	2.5	3.5	3.7	2.6	4.2	4.3
600 (4)	0.5	1.1	2.2	2.3	2.1	2.9	3.4	2.4	3.7	3.9
	1.5	1	1.8	2	1.7	2.6	2.9	2.1	3.3	3.4

While Table (8) and Figs.(7) through (9), show the percentage residual splitting tensile strength values for the mixes of SCC (R ,ST1 and ST2), exposed to elevated temperature (200, 400, and 600°C) at ages (7, 28, and 90 days) with respect to specimens tested at 25 °C. When specimens exposure to temperatures the tensile strength showed significant losses with increasing in the exposed temperature, similar to the compressive strength. The results indicate that splitting tensile strength was more sensitive to elevated temperature due to compressive strength (Obeed ,2007).

Table (8) Percentage residual Splitting tensile Strength % of SCC and SCFRC

Residual Splitting tensile %	Duration Hour	Percentage residual splitting tensile Strength %								
		7 days			28 days			90 days		
		Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%		
		0	0.5	1	0	0.5	1	0	0.5	1
(2) / (1)	0.5	95	97	87	97	98	92	97	96	95
	1.5	85	84	85	94	95	89	92	93	92
(3) / (1)	0.5	70	76	79	82	91	77	74	84	3
	1.5	65	68	69	74	81	70	67	76	73
(4) / (1)	0.5	55	59	59	62	67	64	62	67	66
	1.5	50	49	51	50	60	55	54	60	58

Table (9) & plotted in Figs.(10) through (12), show the relation between steel fiber content and splitting tensile strengths at elevated temperature for two exposure period and at all ages. It was observed that splitting tensile strength increases with steel fiber content, for all mixes (ST1 and ST2) with respect to SCC (without steel fiber) at ages (7, 28, and 90 days).

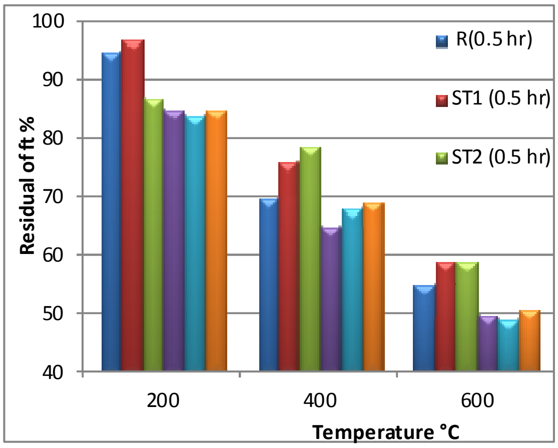

Fig.(7) The percentage of residual Splitting tensile strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 7 days

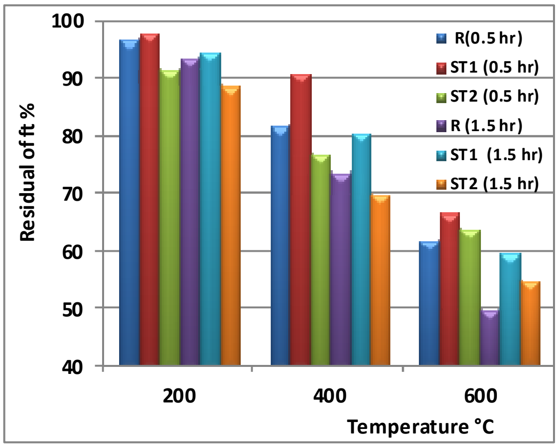

Fig.(8) The percentage of residual Splitting tensile strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 28 days

The increase in fiber content leads to an increase in the tensile strength of concrete. On the other hand, with an increasing in fiber content, the fibers become more densely spaced, and they may hinder growth of micro cracks within the brittle matrix and increase the splitting tensile strength of the fiber reinforced concrete. Moreover, the improved bonding of fiber-matrix provided by the shape of the steel fiber, hooked ends, boosted pullout strength and thus, yielded high increment in strength due to inclusion of fibers (Mon, 2010).

It has been found that steel fibers improve the residual splitting tensile strength of SCC after exposure to elevated temperatures. Steel fibers are seen to be useful to reduce the damage, spalling and cracking due effect of high temperature for (ST1 and ST2) mixes. The splitting tensile strength of some specimens up to more than 100 % if it compared with specimens without steel fiber at early ages (7 days), it because water content reducing in concrete due to hydration process of cement is complete and increasing dry shrinkage cause decreased in splitting tensile strength at late ages.

Table (9) The percentage of change in Splitting tensile strength (*ft*) of SCFRC with respect to SCC

Temp. °C	Duration Hour	The percentage of change in Splitting tensile strength (*ft*) %					
		7 days		28 days		90 days	
		ST1/R %	ST2/R %	ST1/R %	ST2/R %	ST1/R %	ST2/R %
25	-	85	95	26	56	41	51
200	0.5	89	79	27	48	39	47
	1.5	82	94	28	47	42	50
400	0.5	100	121	39	46	59	69
	1.5	92	108	40	48	62	65
600	0.5	100	109	38	62	54	63
	1.5	80	100	53	71	57	62

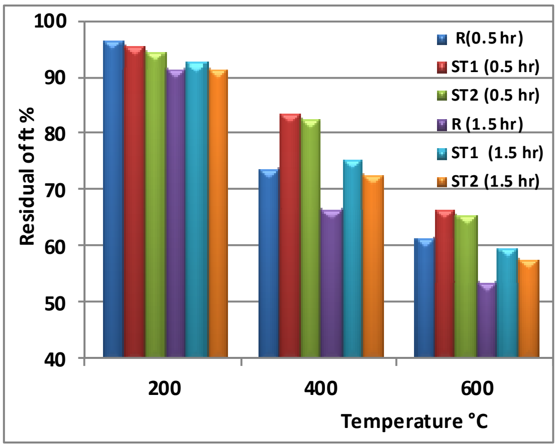

Fig.(9) The percentage of residual Splitting tensile strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 90 days

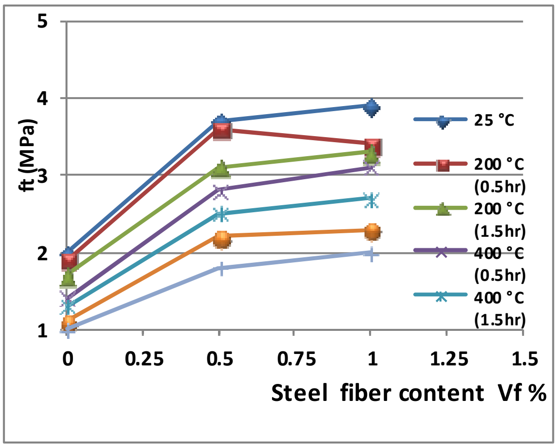

Fig.(10) Effect of steel fiber content on Splitting tensile strength of SCC with different temperature and period of exposure at 7 days.

When the tensile stress is transferred to fibers, the transfer can arrest the propagating macro cracks and substantially improve. Crack control plays a crucial role in the performance of concrete in service. The loads may overstress hardened concrete from cracking, leading from cracking to substantial failure in concrete. Thus, incorporation of discrete fibers in vulnerable concrete is useful and effective. The resulting fiber-reinforced concrete exhibits satisfactory resistance to crack formation and propagation (Gencel et al, 2011).

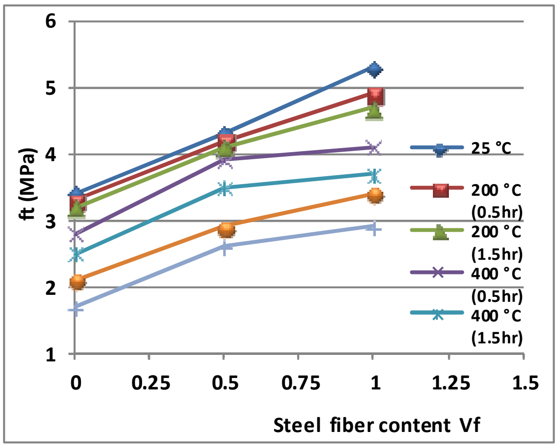

Fig.(11) Effect of steel fiber content on Splitting tensile strength of SCC with different temperature and period of exposure at 28 days.

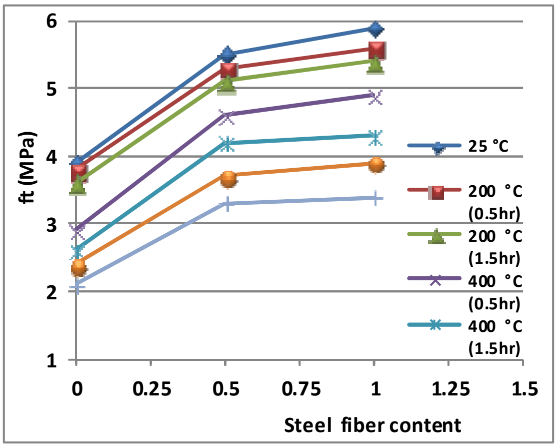

Fig.(12) Effect of steel fiber content on Splitting tensile strength of SCC with different temperature and period of exposure at 90 days.

3.2.3 Flexural Strength

Similar to compressive and tensile strengths of concrete, the results indicate that all specimens exhibited a continuous increase in flexural strength with progress in age ,as shown in Table (10), show the relationship between flexural strength and elevated temperature at (200, 400 and 600° C), for all specimens.

Table (10) Test results of Flexural strength (*fr*) of SCC and SCFRC

Temp. °C	Duration Hour	Flexural Strength (MPa)								
		7 days			28 days			90 days		
		Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%		
		0	0. 5	1	0	0. 5	1	0	0. 5	1
25 (1)	-	5.6	8.5	9.1	6.4	9.5	13.1	6.9	9.8	13.6
200 (2)	0.5	4.7	8.4	8.9	5.2	9.4	12.8	5.7	9.6	13.4
	1.5	4.5	8.1	8.7	5	9.2	11.9	5.4	9.4	12.4
400 (3)	0.5	3.9	7.4	8.1	4.9	8.9	10.4	5.1	9	11.3
	1.5	3.6	6.9	7.8	4.8	8.4	9.3	4.9	8.7	10.6
600 (4)	0.5	3.5	5.7	7	4.3	7.7	8.6	4.6	8.1	9.1
	1.5	3.3	4.8	6.9	4.1	6.8	7.8	4.2	7.9	8.2

It can be seen that flexural strength decreases with increasing temperatures. The percentage residual flexural strength is summarized in Table (11) and Figs.(13) through (15), for mixes of SCC (R ,ST1 and ST2), exposed to high elevated temperature (200 ,400 and 600° C) at ages (7, 28 and 90 days). The more reduction flexural strengths took place when the temperature increased to 600 °C and for periods of exposure (0.5 and 1.5 hours).

It can be seen that flexural strengths decrease with high temperature as a result of the dry shrinkage of concrete cause decomposition of cement compounds leading to the occurrence of cracks inside specimens which reduces the flexural strengths (Neville, 1995).

Table (11) Percentage residual Flexural Strength % of SCC and SCFRC

Residual Flexural Strength %	Duration Hour	Percentage residual Flexural Strength %								
		7 days			28 days			90 days		
		Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%			Volume fiber fraction (*Vf*)%		
		0	0.5	1	0	0.5	1	0	0.5	1
(2) / (1)	0.5	84	99	98	81	99	98	83	98	99
	1.5	80	95	96	78	97	91	78	96	91
(3) / (1)	0.5	70	87	89	77	94	79	74	92	83
	1.5	64	81	86	75	88	71	71	89	78
(4) / (1)	0.5	63	67	77	67	81	66	67	83	67
	1.5	59	56	76	64	72	60	61	81	60

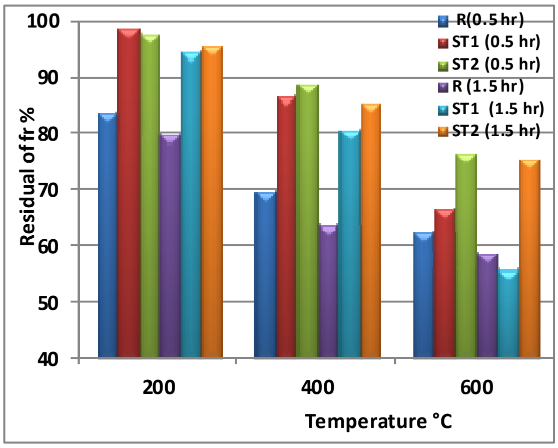

Fig.(13) The percentage of residual Flexural strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 7 days

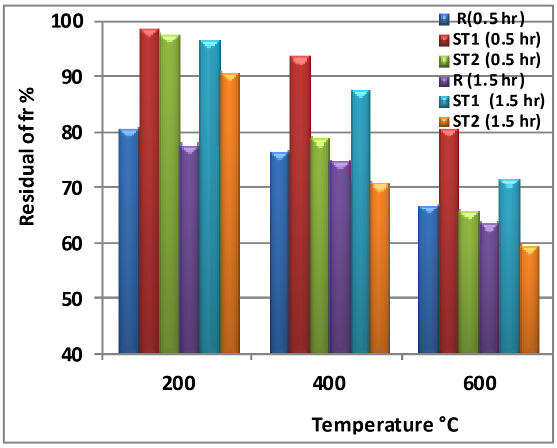

Fig.(14) The percentage of residual Flexural strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 28 days

In general the number of concrete prism specimens was spalling more than cubes and cylinders (100*200 mm) specimens after exposure high temperature .

Explosive spalling occurs in both cases of SCC and SCFRC when the oven peak temperature of 600°C is maintained. This might be too low permeability of SCC due to its denser structure, water vapor is very limited to evaporate out of SCC. Therefore many micro cracks were produced in internal structures of specimens between aggregate and cement paste and these cracks increase causing explosive spalling of the specimens. SCC is bound to spall more compared to NC due to lower permeability and higher moisture content (Anagnostopoulos et al, 2009).

The relation between steel fiber content and flexural strength at elevated temperature are summarized in Table (12) and Figs.(16) through (18), for two exposure period and at all ages. For all mixes (ST1 and ST2) with respect to SCC (without steel fiber) at ages (7, 28, and 90 days), the flexural strength increases with steel fiber content.

Table (12) The percentage of change in Flexural strength (*fr*) of SCFRC with respect to SCC

Temp. °C	Duration Hour	The percentage of change in Flexural Strength (*fr*) %					
		7 days		28 days		90 days	
		ST1/R %	ST2/R %	ST1/R %	ST2/R %	ST1/R %	ST2/R %
25	-	52	63	48	105	42	97
200	0.5	79	89	81	146	68	135
	1.5	80	93	84	138	74	130
400	0.5	90	108	82	112	76	122
	1.5	92	117	75	94	78	116
600	0.5	63	100	79	100	76	98
	1.5	45	109	66	90	88	90

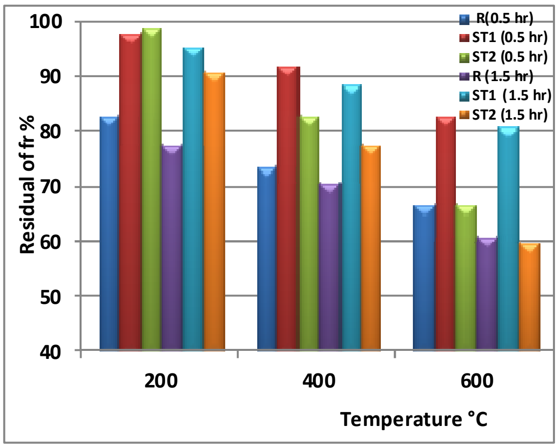

Fig.(15) The percentage of residual Flexural strength (with respect to specimen at 25°C for mix R, ST1 and ST2)at 90 days

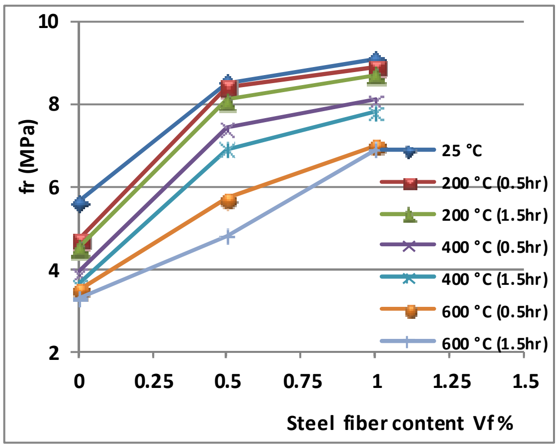

Fig.(16) Effect of steel fiber content on Flexural strength of SCC with different temperature and period of exposure at 7 days.

Steel fiber reinforced concretes have better to flexural strength than concretes without steel fibers. This is mainly due to the increasing in crack resistance of the composite and to the ability of fibers to resist forces after the concrete matrix has failed. Also, the percentage of increase in flexural strength was found to be increased with the increase in fiber content. This behavior is mainly attributed to the role of steel fibers in releasing fracture energy around crack tips which is required to extent crack growing by transferring it from one side to another side (Teng & Shah, 1986).

Steel fibers are seen to be useful in minimizing the damage effect of high temperature for (ST1 and ST2) mixes more than compressive and splitting tensile strength. Steel fibers had been used to reduce spalling and cracking. Steel fibers were generally more effective on flexural strength than compressive and splitting tensile strength. Increase in flexural strength of some specimens up to more than 100% compared to specimens without steel fiber, for all ages and all exposure periods.

The superior performance in flexural strength for specimens with steel fibers arises from the improved fiber - matrix bond provided by using steel fiber with hooked ends (Banthia & Trottier, 1994). In the typical fractured surfaces of fiber reinforced concrete, hooks at ends of steel fibers were noted to be straightened out. Thus, the performance of steel fibers in concrete matrix is governed by positive locking of end hook and the bond characteristics after straightening of the fibers.

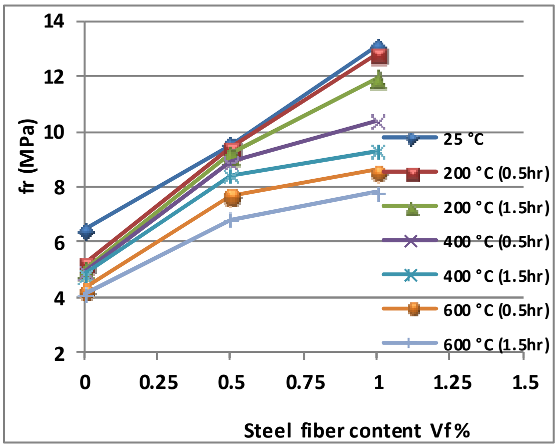

Fig.(17) Effect of steel fiber content on Flexural strength of SCC with different temperature and period of exposure at 28days.

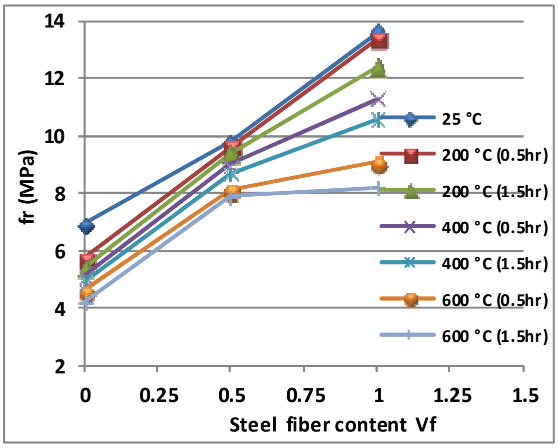

Fig.(18) Effect of steel fiber content on Flexural strength of SCC with different temperature and period of exposure at 90 days.

3.2.4. Static Modulus of Elasticity

Results indicate that all specimens exhibited a continuous increase in modulus of elasticity with progress in age. The results of this test are listed in Table (13), show the relationship between modulus of elasticity and elevated temperature (200, 400 and 600° C), for all specimens. It can be seen modulus of elasticity decrease with increasing temperatures.

Table (13) Test results of modulus of elasticity (*Ec*) of SCC and SCFRC

Temp. °C	Duration Hour	Modulus of Elasticity (GPa)					
		28 days			90 days		
		Volume fiber fraction(*Vf*) %			Volume fiber fraction(*Vf*) %		
		0	0. 5	1	0	0. 5	1
25 (1)	-	21.9	24.5	26.6	24.9	26.7	28.3
200 (2)	0.5	21.3	24	24.6	24	25.2	26.7
	1.5	20.7	22.7	22.9	23.5	24.5	25.5
400 (3)	0.5	17.9	19	20.7	20.8	23.8	24.6
	1.5	-	-	-	-	-	-
600 (4)	0.5	-	-	-	-	-	-
	1.5	-	-	-	-	-	-

(-) : Specimen was destroyed

While Table (14) and Figs.(19) and (21), show the percentage residual modulus of elasticity values for the mixes of SCC (R ,ST1 and ST2), exposed to elevated temperature (200, 400 and 600° C) at ages (28 and 90 days). While Table (4-16) and Figs.(4-52) and (4-54), show the percentage residual modulus of elasticity values for the mixes of SCC (R ,ST1 and ST2), exposed to elevated temperature (200, 400 and 600° C) at ages (28 and 90 days).

It was found that all specimens were destroyed when raising temperature to 600°C of exposure.

Table (14) Percentage residual of modulus of elasticity (*Ec*)% of SCC and SCFRC

Temp. °C	Duration Hour	Percentage residual of modulus of elasticity (*Ec*)%					
		28 days			90 days		
		Volume fiber fraction(*Vf*) %			Volume fiber fraction(*Vf*) %		
		0	0. 5	1	0	0. 5	1
(2) / (1)	0.5	97	98	92	96	94	94
	1.5	95	93	86	94	92	90
(3) / (1)	0.5	82	78	78	84	89	87
	1.5	-	-	-	-	-	-
(4) / (1)	0.5	-	-	-	-	-	-
	1.5	-	-	-	-	-	-

(-) :Specimen was destroyed

Compressive strength effect on modulus of elasticity, similar to compressive strength the modulus of elasticity showed significant losses with an increase in the exposed temperature. The decrease in modulus of elasticity is due to the increase in porous volume of concrete and also to the cracking of the interfacial transition zone (Tolentino et al, 2002).

In general the cylinders (150*300 mm) specimens were spalling more than cubes specimens after exposure high temperature as shown in Plate (1). This might be to water vapor is very limited to evaporate out of SCC and cement paste preventing water escape under high temperatures therefore internal pressure causes micro cracks in internal structures and occurs explosively. The higher period of exposure to temperatures and the lower the permeability of the SCC, the greater the risk of SCC of explosive spalling.

The high temperatures and the lower the permeability of the concrete, the greater the risk of SCC of explosive spalling. It is probable that the dense hardened cement paste (SCC) prevents free water from escaping, causing considerable internal vapor pressure.

Plate (1)Spalling cylinder specimen due to elevated temperature 600 °C

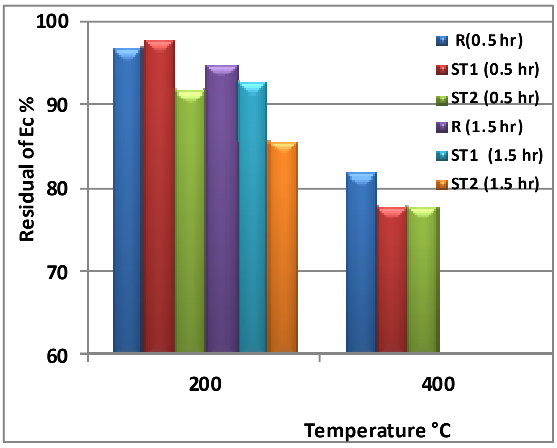

Fig.(19) The percentage of residual modulus of elasticity (with respect to specimen at 25°C for mix R, ST1 and ST2)at 28days

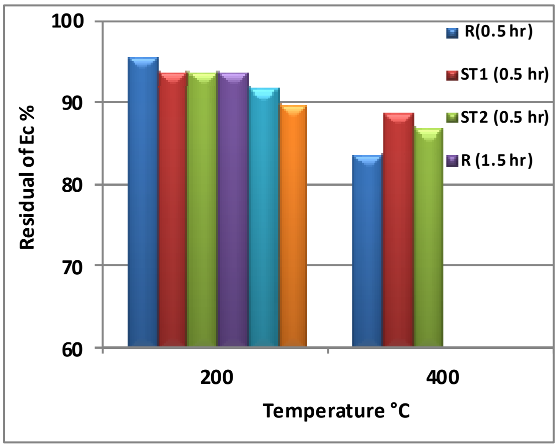

Fig.(20) The percentage of residual modulus of elasticity (with respect to specimen at 25°C for mix R, ST1 and ST2)at 90days

Table (15) and Figs.(22) and (23), show the relation between steel fiber content and modulus of elasticity at elevated temperature, for two exposure period and for all ages. It can be seen that steel fibers protect specimens against spalling for certain limits of temperature. Concrete mixes reinforced with steel fibers consistently show higher values of modulus of elasticity than non-fiber mixes, of between 2 and 3 GPa , after exposure to temperature.

Table (15)The percentage of increase in modulus of elasticity (*Ec*) % of SCFRC with respect to SCC

Temp. °C	Duration Hour	The percentage of increase in modulus of elasticity (*Ec*) %			
		28 days		90 days	
		ST1/R %	ST2/R %	ST1/R %	ST2/R %
25	-	11.9	21.5	7.2	13.7
200	0.5	12.7	15.5	5	11.3
	1.5	9.7	10.6	4.3	8.5
400	0.5	6.1	15.6	14.4	18.3
	1.5	-	-	-	-
600	0.5	-	-	-	-
	1.5	-	-	-	-

(-) :Specimen was destroyed

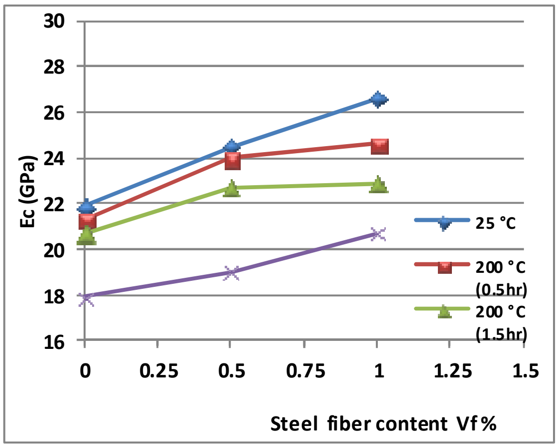

Fig.(21) Effect of steel fiber content on Modulus of elasticity of SCC with different temperature and period of exposure at 28days.

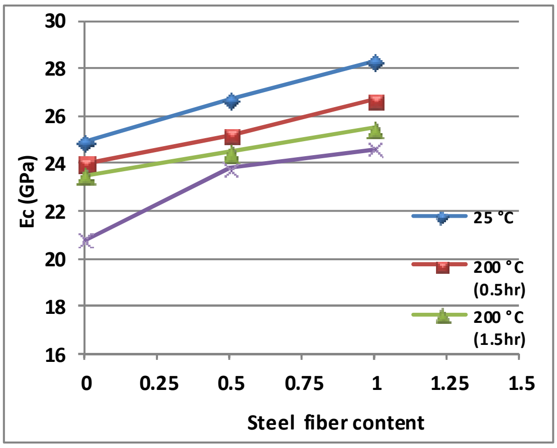

Fig.(21) Effect of steel fiber content on Modulus of elasticity of SCC with different temperature and period of exposure at 90 days.

4. Conclusions

According to the experimental results presented in the preceding above , temperatures do affect the SCC and SCFRC in a hardened state. On the basis of the observations made in the present work, the following conclusions were found:

1. Overall, slump flow diameter (flowability) and L-Box blocking ratios (passing ability) decrease with the increase in steel fiber content of the concrete mixtures with respect to plain mixtures. Slump flow time T_{500mm} and Sieve segregation resistance % increases with increase in steel fiber content of the concrete mixtures with respect to plain mixtures.
2. The residual compressive strength ranged between (80-97%) at 200 °C, (60-83%) at 400 °C and (49-71%) at 600 °C for mixes (R, ST1 and ST2) at all ages, and the percentage of change in compressive strength of (ST1 and ST2) with respect to SCC ranged between (0.3-20.9%) at 200 °C, (-3.1-31.3%) at 400 °C and (-3.9-31.5) at 600 °C for all ages.
3. The splitting tensile strength was more sensitive to temperature than the compressive strength. Residual splitting tensile strength ranged between (84-98%) at 200 ° C, (65-91%) at 400 °C and (49-67%) at 600 °C for mixes (R, ST1 and ST2) at all ages, and the percentage of increase in splitting tensile strength of (ST1 and ST2) with respect to SCC ranged between (27-94%) at 200 °C, (39-121%) at 400 °C and (38-109) at 600 °C for all ages.
4. The flexural strength was very sensitive to temperatures. Residual flexural strengths ranged between (78-99%) at 200 °C, (64-94%) at 400°C and (56-83%) at 600 °C for mixes (R, ST1 and ST2) at all ages, and the percentage of increase in flexural strength of (ST1 and ST2) with respect to SCC ranged between (68-146%) at 200 °C, (75-122%) at 400 °C and (45-109) at 600 °C for all ages.
5. The residual modulus of elasticity ranged between (86-98%) at 200 °C and (78-89%) at 400 °C for mixes (R, ST1 and ST2) at all ages, and the percentage of increase in modulus of elasticity of (ST1 and ST2) with respect to SCC ranged between (4.3-15.5%) at 200 °C and (6.1-18.3%) at 400 °C for all ages.
6. Deterioration in strength increases with increases in periods of exposure to elevated temperatures for all mixes and ages.
7. Spalling occurs when specimens are exposed to high temperatures at 400 °C and for long period of exposure. Specimens that have more effect by spalling are cylindrical (150*300mm) and prisms (100*100*400mm).
8. The highest steel fiber content (1% by Vol.) improves hardened properties against the high temperatures but the worst effect is on fresh properties of SCC. As well as, 0.5% steel fiber content was

sufficient for achieving satisfying performance in fresh and hardened properties of SCC.

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