Effect of Fire Flame Exposure on some Properties of Fiber Reinforced High Strength Concrete

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٢٠١٣-٢٠١٤

Abstract

The increased use of high strength concrete (HSC) in buildings has resulted in concern regarding the behavior of such concrete in fire. In the present work, an attempt is made to study the effect of fire flame exposure on compressive strength and splitting tensile strength of plain and fiber reinforced high strength concrete. High strength concretes were prepared in two series, with and without steel fiber reinforcement. Plain and steel fiber reinforced high strength concrete (PHSC) and (FRHSC) were subjected to the same fire temperatures and same burning time to reveal the effect of steel fiber on concrete strength at different heat levels as well as fire duration. The concrete specimens for (PHSC) and (FRHSC) were subjected to fire flame temperature ranging between (٣٠٠- ٦٠٠ °C) at different ages ٣٠ and ٦٠ days. Three temperature levels (٣٠٠, ٥٠٠ and ٦٠٠ °C) where chosen with two exposure periods of ١.٠ and ١.٥ hours. The test specimens were cubes (١٠٠ mm) and cylinders (١٠٠*٢٠٠ mm). After burning, the concrete specimens were allowed to cool in air. The results obtained from this study indicated that damage of concrete caused by exposure to fire depends on the temperatures range and the duration of exposure to fire. Also, the results showed that (PHSC) higher rates of strength loss than (FRHSC).

الخلاصة

أدى ازدياد استخدام الخرسانة عالية المقاومة في الأبنية إلى الاهتمام فيمـا يتعلـق بسلوك هذا النوع من الخرسانة في الحريق. يشمل البحث الحالي محاولة لدراسة تأثير لهـب النار على مقاومة الانضغاط ومقاومة شد الانشطار للخرسانة عاليـة المقاومـة و المسـلحة بالألياف الحديدية .أعدت فئتين من الخرسانة عالية المقاومة مسلحة بالألياف الحديدية وخاليـة من الألياف .عرضت الخرسانة عالية المقاومة المسلحة بالألياف الحديدية والخالية من الألياف إلى نفس درجات النار ونفس وقت الحرق لمعرفة تأثير الأليـاف الحديديـة علـى مقاومـة الخرسانة عند مستويات مختلفة من الحرارة بالإضافة إلـى فتـرة الحـرق. تـم تعـريض النماذج الخرسانية إلى درجات حرارة تتراوح بين (٣٠٠ – ٦٠٠)درجـة مئويـة وبأعمـار مختلفة هي (٣٠ ، ٦٠) يوما . تم تعريض النماذج إلى ثلاث درجات حرارة ثلاثة هي (٣٠٠، ٥٠٠، ٦٠٠) درجة مئوية لفترتين تعرض هي (١, ١.٥) ساعة . كانـت نمـاذج الفحـص مكعبات (١٠٠ مم) واسطوانات (١٠٠ * ٢٠٠ مم). بعد التعرض تركت النماذج لتبرد فـي الهواء . أظهرت النتائج التي تم الحصول عليها من هذه الدراسة بان ضرر الخرسانة بسـب التعرض للنار يعتمد على مدى درجات الحرارة وفترة التعرض للنار. كذلك أظهرت النتـائج إن اكبر معدلات للفقدان في المقاومة كان في الخرسانة العالية المقاومة الخالية من الأليـاف الحديدية .

Introduction

With the development of concrete technology, high strength concrete (HSC) has been commonly utilized in many concrete structures around the world. High strength concrete offers more strength and durability compared to normal strength concrete. In economical point of view, cost studies have shown that (HSC) can carry the same compression load as normal strength concrete (NSC) at less cost. In architectural point of view, with its capacity of bearing higher load, HSC allows smaller size column to be used in high-rise construction leaving more space to be occupied.

Although high strength concrete has been shown to have a number of advantages when used in concrete structures, it suffers from one major weakness: higher brittleness. When exposed to high temperatures, (HSC) exhibits more serious degradation than normal concretes do, such as spalling and cracking (Poon et al, ٢٠٠٣).

The fiber reinforced concrete is a composite material essentially consisting of concrete reinforced by random placement of short, discontinuous and discrete fine fibers of specific geometry (Swamy et al, ١٩٧٤). Fibers have extensively been used to improve the ductility of concrete. Recently, it has been found that a number of fibers can improve residual properties of concrete after exposure to elevated temperatures (Kalifa et al, ٢٠٠١).

Literature Review

Some studies had found that (HSC) in some cases fail in a catastrophic manner during exposure to fire characterized by explosive spalling of the concrete surface. Some researchers hypothesized that the vulnerability of (HSC) to explosive spalling is partly due to its lower permeability, which limits the ability of water vapor to escape from the pores resulting in significant build-up of pore pressure within cement matrix. As heating increases, the pore pressure also increases until the internal stresses become so large as to result in explosive spalling (Phan, ١٩٩٦).

(Fanella and Naaman, ١٩٨٥) and (Ramakrishnan, ١٩٨٧) revealed the inclusion of fiber polymers to enhance of the structural properties of a given material, such as concrete. These properties include; compressive strength, fracture toughness, flexural strength, tensile strength, impact strength, resistance to fatigue, and fire resisting. The fiber acts as crack arresters, resisting the development of crack and transferring a brittle matrix into strong composite with better ductility (Ramakrishnan, ١٩٨٧).

The effect of transient high temperature on strength and load –deformation behavior of HSC was investigated (Castillo and Durrani, ١٩٩٠). The concrete strength varied between (٣١ to ٨٩ MPa) and the temperature exposure was in the range of ٢٣ to ٨٠٠ °C . Exposure to temperature in the range of ١٠٠ to ٣٠٠ °C was found to decrease the compressive strength of (HSC) by ١٥ to ٢٠ percent. At temperature in the range of ٤٠٠ to ٨٠٠ °C the compressive strength decrease to about to ٣٠ percent of its strength at room temperature.

(Habeeb, ٢٠٠٠) studied the effect of high temperatures (up to ٨٠٠ °C) on some mechanical properties of high strength concrete (HSC). Three design strengths were investigated (٤٠, ٦٠ and ٨٠ MPa). The investigated properties were compressive strength, flexural strength and volume changes. Ultrasonic pulse velocity (U.P.V) and dynamic modulus of elasticity (Ed) were tested also. The specimens were heated slowly to five temperature levels (١٠٠, ٣٠٠, ٥٠٠, ٦٠٠ and ٨٠٠ °C), and to three exposure periods ١, ٢ and ٤ hours without any imposed loads during heating. The specimens were then cooled slowly and tested either one day or one month after heating. He concluded that the (HSC) is more sensitive to high temperatures than (NSC).The residual compressive strength ranged between (٩٠ – ١٠٦%) at ١٠٠ °C, (٧٢-١٠٣%) at ٣٠٠ °C, (٥٥ – ٨٧%) at ٥٠٠ °C and (٢٢-٦٦%) between (٦٠٠-٨٠٠ °C). He also concluded that exposure time beyond one hour had a significant effect on the residual compressive strength of concrete; however, the effect was diminished as the level of temperature increased. Moreover, the compressive strength at age of one month after heating, suffered an additional loss than at age of one day after heating. The flexural strength was found to be more sensitive to high temperature exposure than compressive strength, the residual flexural strength was in the range of (٩٢ – ٩٨%), (٥٢-٩٨%) and (٢٩- ٤٧%) at ١٠٠° C, ٣٠٠°C and ٥٠٠°C respectively and (٢-٣٠%) at (٦٠٠ –٨٠٠ °C), as well as, at ٨٠٠ °C spalling occurred in specimens during cooling which resulted in concrete softening. The author also noticed that the (U.P.V) and (Ed) were more sensitive to elevated temperatures exposure than compressive strength.

(Mahasneh, ٢٠٠٥) studied the effect of high temperatures on some properties of Polymeric Fiber Reinforced Concrete (PFRC). The investigated properties were compressive strength, splitting tensile strength and pullout strength. The specimens were heated to various temperatures (Furnace temperature), starting from room temperature up to ١٠٠٠°C. The test results indicated that (PFRC) strength is controlled by the composite action of both fiber and concrete. This Polymeric fiber shows an increase in the ductility, fire resistance and enhancement of the composite material properties. Also This study provides a good understanding of the behavior of fiber polymers on composite concrete properties and the effect of polymeric reinforced polymer on unprotected concrete.

(Kadhum, ٢٠٠٦) carried out on experimental program to study the effect of fire flame on compressive strength of steel fiber reinforced normal concrete. The steel fibers properties (٢٥* ٠.٢٥mm) were used and one volume fraction (٠.٧٥%). The ultimate tensile strength of the fibers was found to be ١١٠٠ MPa, Two mixes were used; mix١ contained ٠.٧٥% of crimped fibers, mix٢ no fiber. Concrete cubes (١٥٠*١٥٠*١٥٠mm)were used. The specimens were exposed to three temperatures levels(٣٠٠, ٥٠٠, and ٧٠٠ °C) without any imposed load. The specimens were burnt by direct fire flame from a net of methane burners inside a brick stove with three exposure periods of (٠.٥, ١.٠ and ٢.٠ hours). The test results showed that the compressive strength decrease with increasing of the temperature. The author also found that the residual compressive strength of steel fibers reinforcement concrete after exposure to fire is higher than residual compressive strength of plain concrete.

Experimental Work

Program of Work

This research was designed to study the effect of fire exposure on compressive strength and splitting tensile strength of high strength concrete with and without steel fibers reinforcement.

The test specimens used were (١٠٠*١٠٠*١٠٠ mm) cubes and (١٠٠ * ٢٠٠ mm) cylinders. The compressive strength test was conducted according to (B.S ١٨٨١: Part ١١٦: ١٩٨٣) and the splitting tensile strength was determined according to procedure outlined in (ASTM C- ٤٩٦) specification.

Materials and mixes

Cement:

The cement used in this study was Alqaseem Ordinary Portland Cement (OPC) manufactured in Saudia Arabia. The chemical composition and physical properties of cement complied with the Iraqi specification (IQS No.٥ ١٩٨٤).

Aggregate

The fine aggregate used was Al-Ekhaider natural sand zone ٢ with fineness modulus of ٢.٩. The grading, physical and chemical properties of fine aggregate conform to Iraqi specification (IQS No. ٤٥ /١٩٨٤).

Crushed gravel obtained from AL-Nebai source was used as coarse aggregate. The maximum coarse aggregate size was chosen to be ١٤ mm.

Superplasticizer:

High range water reducing agent (HRWR) called Glenium ٥١(Sulfonated melamine – formaldehyde) was used in this work. This superplasticizer is conformed to (ASTM C-٤٩٤) classified as type F, it has acceleration effect on the HSC .The dosage for Glenium ٥١ was ٠.٨ liters per ١٠٠ Kg of cement . The typical properties are shown in Table (١).

Table (١) : Typical Properties of Super plasticizer

Form	Viscous liquid
Colour	Light brown
Relative density	١.١ @ ٢٠ºC
pH	٦.٦
Viscosity	١٢٨ cps @٢٠ºC
Transport	Not classified as dangerous
Labelling	No hazard label required
Dosage	٠.٥ to ٠.٨ liters per ١٠٠ Kg of cement

Water:

Tap water was used for mixing and curing of concrete through out the investigation.

Fibers

Crimped steel fibers were used in this investigation and the properties of these fibers are presented in Table (٢).

Table (٢): Properties of steel fibers

Density kg/m٣	Tensile strength(MPa)	Length (mm)	Diameter (mm)	Steel Fiber Addition (%)	Aspect ratio
٧٨٤٠	١١٠٠	٢٥	٠.٣	١.٥	٧٥

Mix Design and Proportions

One target design strength of ٨٠ MPa. The proportions of the concrete mix are summarized in Table (٣). The high strength concrete was made under controlled laboratory conditions.

Table (٣): Mix Proportions

Weight proportion Cement : Sand : Gravel	W/C Ratio	Mix proportion kg/m٣ Cement :Sand :Gravel: Water	Superplasti-cizer (liter/١٠٠ kg cem	Slump mm
١.٠ : ١.٢ : ١.٨	٠.٣	٥٥٠ : ٦٦٠ : ٩٩٠ : ١٦٥	٠.٨	١٥٠

Concrete Mixing and Casting

The concrete was mixed using an electrical drum type mixer with a maximum capacity ٠.١m³. The interior surface of the mixer was cleaned and moistened before placing the materials. Materials were put in the pan of the mixer, firstly coarse and fine aggregates were mixed together with amount of mixing water (١/٤ mixing water without superplacticizer) for ١ minute. Meanwhile the superplacticizer was mixed with the remaining water (٣/٤ of mixing water). Half of cement and half of mixing water (with superplacticizer) were added as mixing proceeded for ٤ minutes to make a homogeneous mix. Finally, the remaining (cement and water) were added to the mix as mixing proceeds for ٢ minutes. ١.٥% of steel fibers content was used; the steel fibers were fed continuously to the mixer for a period of ٢ to ٦ minute.

After mixing, the concrete was poured into the moulds and compacted using a vibrating table till no air bubbles emerged from the surface of the concrete. Then, the specimens were leveled by hand trawling and covered with polyethylene sheet.

Burning and Cooling

The concrete specimens were burnt by direct fire flame as shown in Plate (١) from a net of methane burners with dimensions of (٨٠٠ * ٨٠٠mm) as shown in Plate (٢). The bare flame was intended to simulate the heating conditions in an actual fire. When the target temperature was reached, the digital thermometer continuously recorded the temperature. After burning, the concrete specimens were allowed to cool for ٤ hours and stored in the laboratory environment about ٢٠ hours.

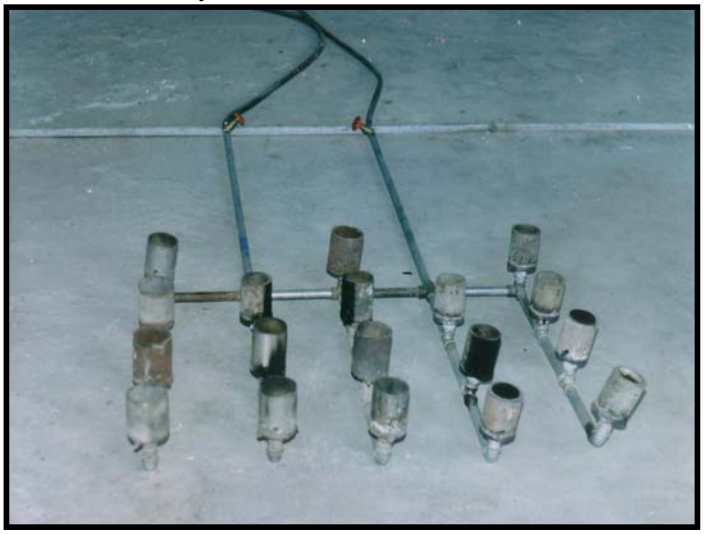


Plate (١): Burning of Concrete specimens

Plate (٢): The Network of Burners

Results and Discussion

١-The Density

Table (٤) shows the effect of the exposure to fire flame on the density of plain (PHSC) and steel fibers reinforced concrete (FRHSC), while Figures (١) and (٢) show the relations between fire temperature and density.

It can be seen from Table (٤) and Figures that the density behaved as the following:

١. At ٣٠٠ °C fire flame temperature and for all ages and all periods of exposure, the reduction in density was ranged between (٦.٢ – ٨.٦ %) and (٤.٣ - ٧%) for (PHSC) and (FRHSC) if compared with initial density before exposure to fire.

٢. At ٥٠٠ °C, a further reduction took place, which was ranged between (٨- ٩.٦ %) and (٦.٦- ٨.٤%) for (PHSC) and (FRHSC) respectively.

٣. At ٦٠٠ °C, the reduction in density was (٨ -١١.٥ %) and (٧.٥ -٩.٢ %) for (PHSC) and (FRHSC) respectively. The loss in density of plain concrete (PHSC) was more than that in density of steel fiber reinforced concrete (FRHSC) at all fire temperature levels, these results confirmed that of (Kadhum, ٢٠٠٦). High temperature induces loss in density, by vaporization of the free water, loss of combined and adsorbed water.

Table (٤): Test values of density of plain and fibers reinforced high strength concrete specimens before and after exposure to fire flame.

Age at Exposure (days)	Period of Exposure (hours)	Density ($kg/m^٣$)				Ratios (pa/pb)			Steel Fiber Content
		Temperature $^{\circ}C$							
		٢٥ (a)	٣٠٠ (b)	٥٠٠ (c)	٦٠٠ (d)	b/a	c/a	d/a	
٣٠	١.٠	٢٤٤٠(١)	٢٢٦٠	٢٢٢١	٢١٩٦	٠.٩٢٦	٠.٩١	٠.٩٠	No Fibers
		٢٤٩٠(٢)	٢٣٤٨	٢٣٣٠	٢٢٩١	٠.٩٤٣	٠.٩٢٥	٠.٩٢	١.٥% Steel Fibers Content
	١.٥		٢٢٢٨	٢٢٠٦	٢١٦٠	٠.٩١٤	٠.٩٠٤	٠.٨٨٥	No Fibers
			٢٣١٦	٢٢٨١	٢٢٦١	٠.٩٣	٠.٩١٦	٠.٩٠٨	١.٥% Steel Fibers Content
٦٠	١.٠	٢٤٣٦(١)	٢٢٨٥	٢٢٤١	٢٢٢٤	٠.٩٣٨	٠.٩٢	٠.٩١٢	No Fibers
		٢٤٨٤(٢)	٢٣٧٧	٢٣٦١	٢٣٢٤	٠.٩٥٧	٠.٩٣٤	٠.٩٢٥	١.٥% Steel Fibers Content
	١.٥		٢٢٥٦	٢٢١٧	٢١٨٦	٠.٩٢٦	٠.٩١	٠.٨٩	No Fibers
			٢٣٣٥	٢٣٠٠	٢٢٨٠	٠.٩٤	٠.٩٢٦	٠.٩١٨	١.٥% Steel Fibers Content

pa:- The density of (PHSC) and (FRHSC) after exposure to fire flame.

pb:- The density of (PHSC) and (FRHSC) before exposure to fire flame.

(١):- The density of (PHSC) at ٢٥ $^{\circ}C$.

(٢):- The density of (FRHSC) at ٢٥ $^{\circ}C$.

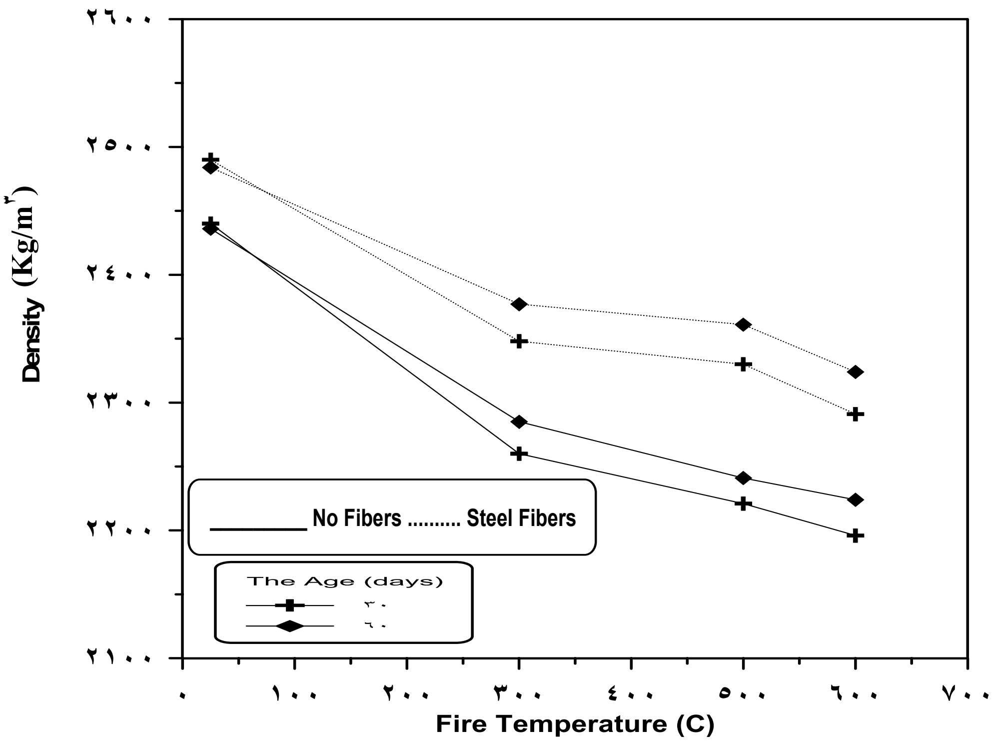


Figure (١): The effect of fire temperatures on the density of plain and Steel fiber reinforced concrete at ١٠ hour period of exposure.

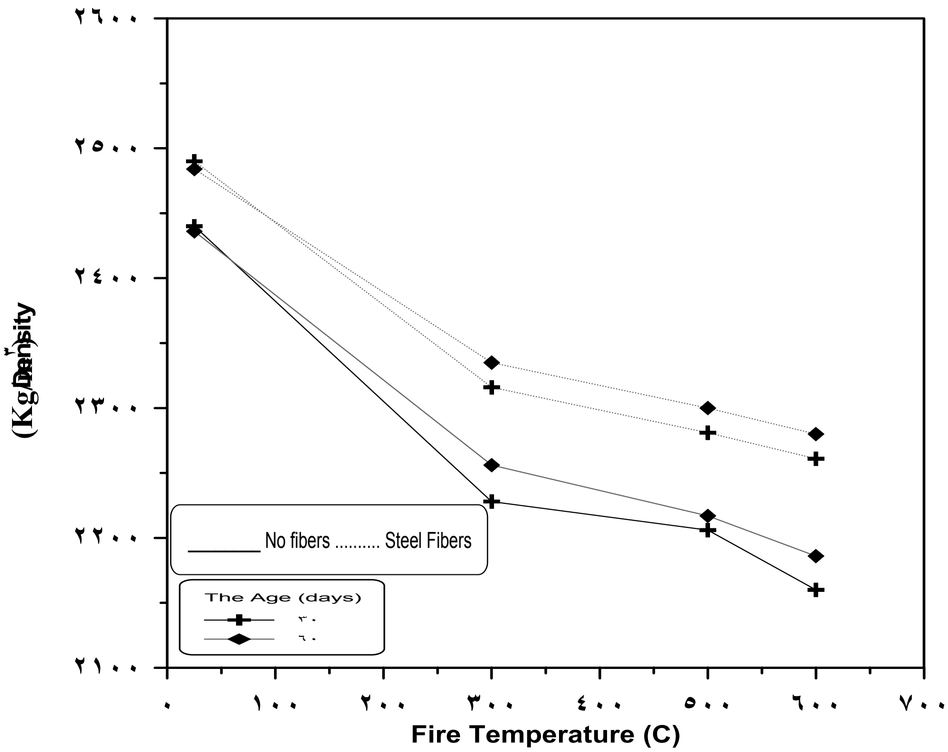


Figure (٢): The effect of fire temperatures on the density of plain and Steel fiber reinforced concrete at ١.٥ hour period of exposure.

٢- Compressive Strength

Concrete cubes (١٠٠*١٠٠*١٠٠mm) were tested at ages ٣٠ and ٦٠ days. The compressive strength results are summarized in Table (٥). Comparing with the use of steel fibers which resulted in an increase in the compressive strength before exposure to fire, the increase of compressive strength was about (٦.٨ and ٧.٧ %) at ages of ٣٠ and ٦٠ days respectively. Figures (٣) and (٤) show the relation between compressive strengths and fire flame temperatures for both plain and composite concrete (PHSC and FRHSC). The percentage of residual compressive strengths were (٣٦ - ٧٨ %) for PHSC and (٤٩ - ٨٩ %) for FRHSC for all periods of exposure. The loss in strength can be attributed to fact that more dense microstructure of high strength concrete, which favors steam – pressure build ups, followed by high tensile stresses (Habeeb, ٢٠٠٠). It is clear from the obtained results that the exposure time of ١.٥ hours has significant effect on the residual strength of concrete for all levels of fire temperatures. Also it can be observed that the effect of fire flame at ٣٠ days was more than at ٦٠ days age, this may be due to the complete hydration of the cement at later age.

From above Figures it can be seen that the (PHSC) series concretes showed the highest losses in strength after exposure to fire. It can be seen from results that the use of steel fibers slightly reduced the rate of degradation of compressive strength, these results confirmed with that obtained by other investigators, (Kadhum, ٢٠٠٦) and (Mahasneh, ٢٠٠٥).

Compare the two cases (with and without steel fibers), it is clear that at a ٣٠٠ °C, the increase in compressive strength was about (٢١.٤ and ٢٣.٠%) and (١٩.٨ and ٢٢.٢%) at ages of ٣٠ and ٦٠ days and exposure period ١.٠ and ١.٥ respectively. At temperature of ٥٠٠ °C, the effect of fibers is clear in increasing the compressive strength of (٣١.٧ and ٣٣.٠%) and (٢٩.٨ and ٣١.٦%) at ages of ٣٠ and ٦٠ days and exposure period ١.٠ and ١.٥ respectively. At temperature of ٦٠٠°C and exposure period ١.٠, ١.٥ hour and at age of ٣٠ and ٦٠ days, the effect of fibers is clear in increasing the compressive strength of (٤٩.٧ and ٥١%) and (٤٧.٣ and ٤٩.١%) respectively compare with that for non- fibred concrete. From the results, it can be concluded that the concrete with steel fiber resist fire more than that without fiber at a temperature of ٦٠٠°C. This can figure out that this kind of fiber (steel) is good on the temperature of ٦٠٠°C.

Table (٥) : Test values of compressive strength of plain and fibers reinforced high strength concrete specimens before and after exposure to fire flame.

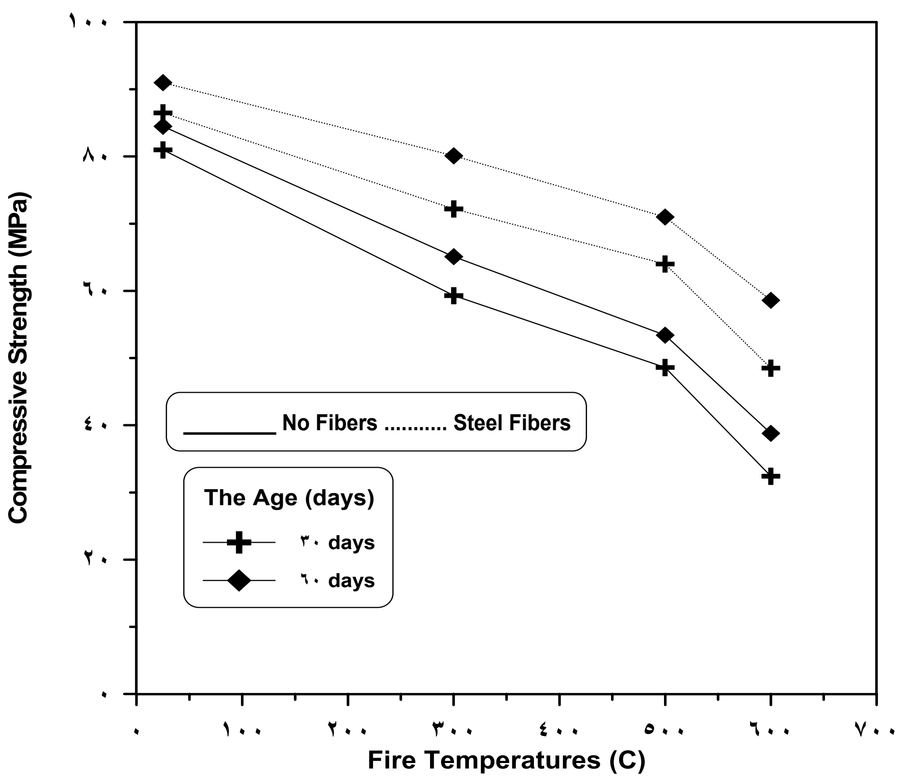
Age at Exposure (days)	Period of Exposure (hours)	Compressive Strength (MPa) Temperature °C				Ratios (fca /fcb)			Steel Fiber Content
		٢٥ (a)	٣٠٠ (b)	٥٠٠ (c)	٦٠٠ (d)	b/a	c/a	d/a	
٣٠	١.٠	٨١ (١)	٥٩.٣	٤٨.٦	٣٢.٤	٠.٧٣	٠.٦٠	٠.٤٠	No Fibers
			٧٢.٢	٦٤.٠	٤٨.٥	٠.٨٤	٠.٧٤	٠.٥٦	١.٥% Steel Fibers Content
	١.٥	٨٦.٥(٢)	٥٢.٨	٤٤.٣	٢٩.٢	٠.٦٥	٠.٥٥	٠.٣٦	No Fibers
			٦٣.٣	٥٧.٥	٤٣.٠	٠.٧٣	٠.٦٦	٠.٤٩	١.٥% Steel Fibers Content
٦٠	١.٠	٨٤.٥(١)	٦٥.١	٥٣.٤	٣٨.٨	٠.٧٨	٠.٦٤	٠.٤٦	No Fibers
		٩١(٢)	٨٠.١	٧١.٠	٥٨.٦	٠.٨٩	٠.٧٨	٠.٦٤	١.٥% Steel Fibers Content
	١.٥		٥٧.٤	٥٠.٢	٣٣.٨	٠.٦٨	٠.٥٩	٠.٤	No Fibers
			٧٠.٢	٦٦.١	٥٠.٤	٠.٧٧	٠.٧٢	٠.٥٦	١.٥% Steel Fiber Content

fca:- The compressive strength of (PHSC) and (FRHSC) after exposure to fire flame.

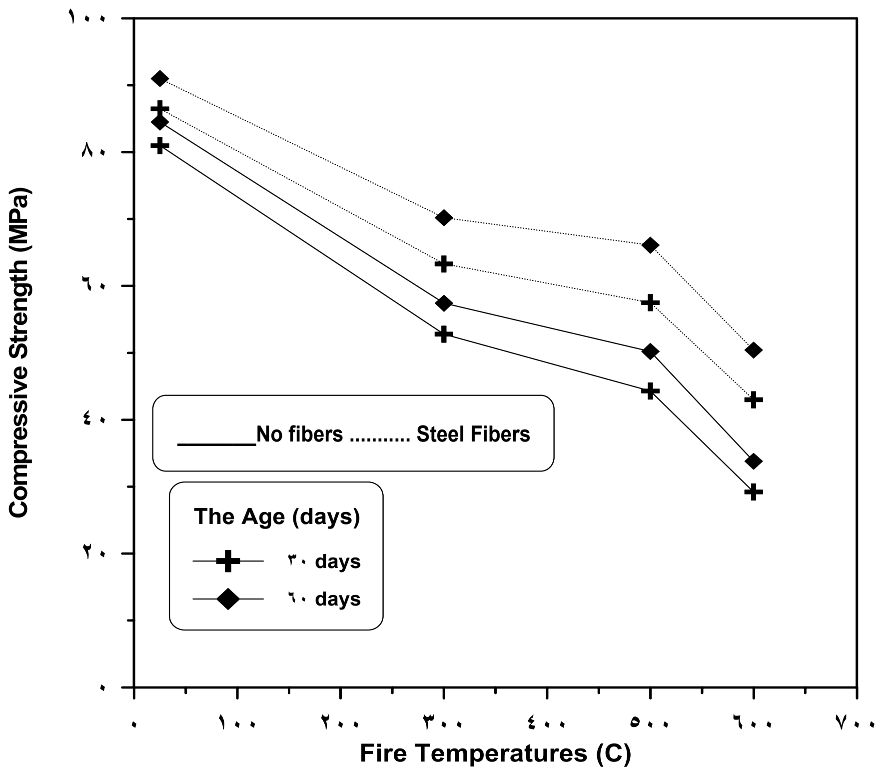
fcb:- The compressive strength of (PHSC) and (FRHSC) before exposure to fire flame.

(١):- The compressive strength of (PHSC) at ٢٥ °C.

(٢):- The compressive strength of (FRHSC) at ٢٥ °C.



Figure(٣): The effect of fire flame on the compressive strength of plain and steel fibers reinforced concrete at ١.٠ hour period of exposure.



Figure(٤): The effect of fire flame on the compressive strength of plain and steel fibers reinforced concrete at ١.٥ hour period of exposure.

٤-Splitting Tensile strength

The splitting tensile strength test results of the concrete specimens (cylinder ١٠٠×٢٠٠ mm) were tested at age (٣٠ and ٦٠ days), the results of two series are given in Table (٦). Figures (٥) and (٦) present the relation between the splitting tensile strength and fire flame temperatures for concrete cylinder with and without the addition of fiber reinforcement. The percentage of residual splitting tensile strengths were (٣٤ - ٦٨ %) for (PHSC) and (٤٣ - ٨١ %) for (FRHSC) for all periods of exposure.

It is clear from the test results that the splitting tensile strength is more sensitive to elevated temperatures than the compressive strength. It can be observed that concrete deteriorates at a faster rate when tested in tension rather than in compression. This observation conforms the results obtained by other investigators (AL-Ausi and Faiyadh, ١٩٨٥). This indicates that severe microcraking insue due to fire.

The reduction in splitting tensile strength can be attributed to the formation of tensile stresses during the contraction of hardened cement paste upon cooling, which, when superimposed onto the already existing tensile stresses formed during heating, would cause further reduction in splitting strength(Venecanin, ١٩٧٧).

It is clear that use of steel fibers which resulted in an increase the splitting tensile strength at a room temperature, the increase in the splitting tensile strength was about (٢٥ and ٢٦.٩ %) at ages of ٣٠ and ٦٠ days respectively. At temperature of ٣٠٠ °C the effect of steel fiber is clear in increasing the tensile strength of (٤٨.٦ and ٥٢.٣%) and (٤٥.٨ and ٥٠%) in compare with the value without fiber at ages of ٣٠ and ٦٠ days and exposure period ١.٠ and ١.٥ respectively. At temperature of ٥٠٠ °C, the increase in splitting tensile strength was about (٥١.٥ and ٥٤.٧ %) and (٤٦.٤ and ٥٠.٣%) at ages of ٣٠ and ٦٠ days and exposure period ١.٠ and ١.٥ respectively. At a temperature of ٦٠٠°C the effect of fiber is clear in increasing the tensile strength of (٦١.٣ and ٦٤.١%) and (٥٨.٥ and ٥٩.٤%) at ages of ٣٠ and ٦٠ days and exposure period ١.٠ and ١.٥ respectively. It can be seen that the addition of steel fibers to concrete would increase the residual splitting tensile strength of burned concrete.

Table (٦): Test values of splitting tensile strength of plain and fibers reinforced high strength concrete specimens before and after exposure to fire flame.

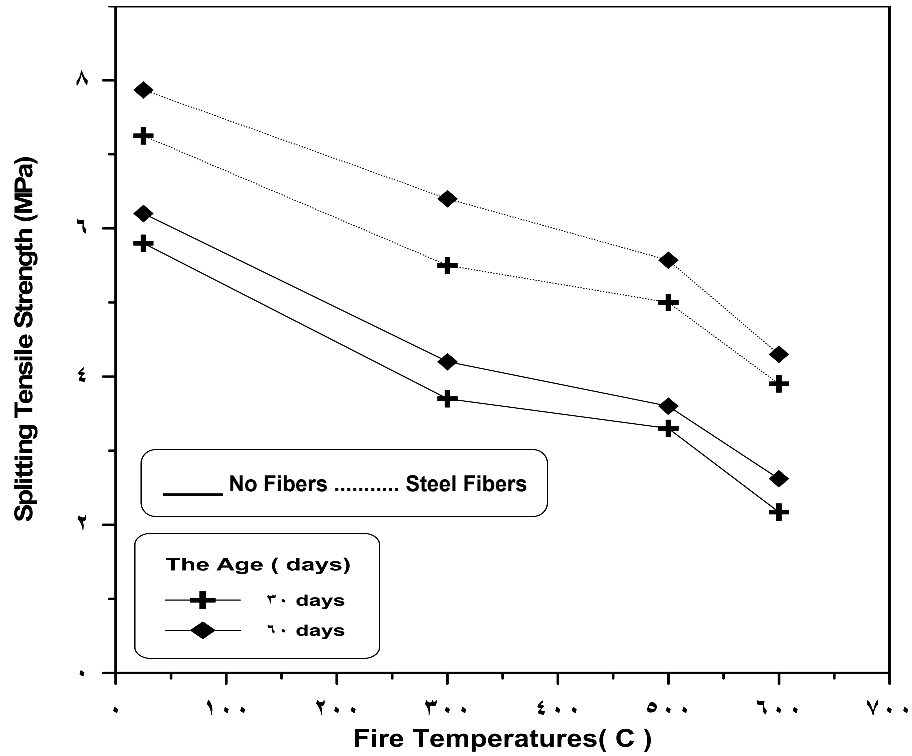
Age at Exposure (days)	Period of Exposure (hours)	Splitting Tensile Strength (MPa)				Ratios (fsa /fsb)			Steel Fiber Content
		Temperature $^{\circ}$C							
		٢٥ (a)	٣٠٠ (b)	٥٠٠ (c)	٦٠٠ (d)	b/a	c/a	d/a	
٣٠	١.٠	٥.٨[١] ٧.٢٥[٢]	٣.٧	٣.٣	٢.١٧	٠.٦٣	٠.٥٦	٠.٣٧	No Fibers
			٥.٥	٥.٠	٣.٥	٠.٧٦	٠.٦٩	٠.٤٨	١.٥% Steel Fibers
	١.٥		٣.٤٣	٢.٨	٢.٠	٠.٥٩	٠.٤٨	٠.٣٤	No Fibers
			٥.٠	٤.١	٣.١٧	٠.٦٩	٠.٥٦	٠.٤٣	١.٥% Steel Fibers
٦٠	١.٠	٦.٢[١] ٧.٨٧[٢]	٤.٢	٣.٦	٢.٦٢	٠.٦٨	٠.٥٨	٠.٤٢	No Fibers
			٦.٤	٥.٥٧	٤.٣	٠.٨١	٠.٧٠	٠.٥٤	١.٥% Steel Fibers
	١.٥		٣.٧	٣.٢٦	٢.٣٤	٠.٥٩	٠.٥٢	٠.٣٧	No Fibers
			٥.٥٥	٤.٩	٣.٧٣	٠.٧٠	٠.٦٢	٠.٤٧	١.٥% Steel Fiber

fsa:- The splitting tensile strength of(PHSC) and (FRHSC) after exposure to fire flame.

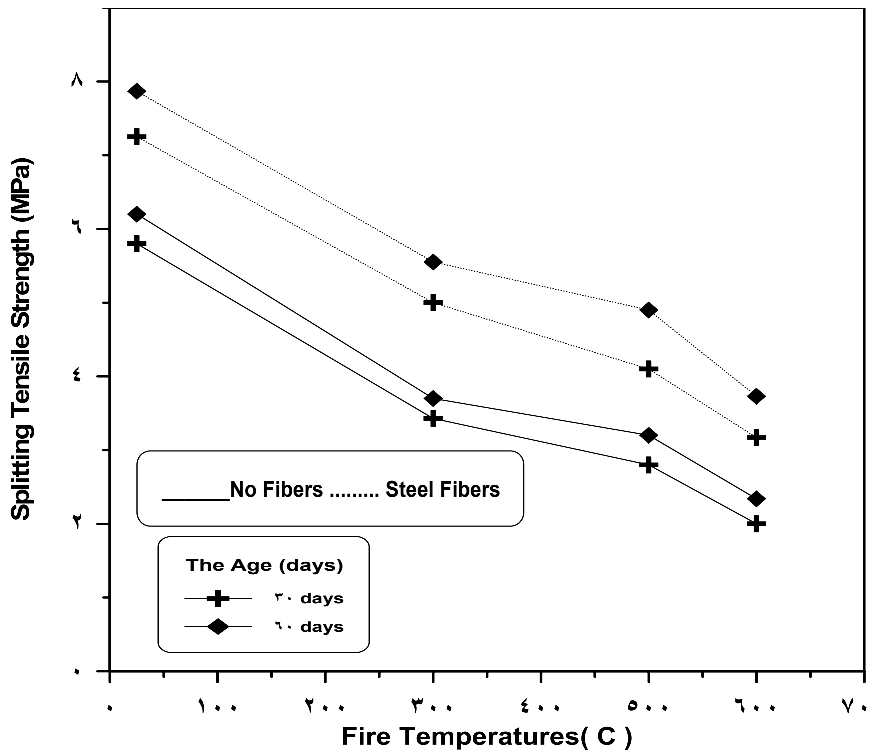
fsb:- The splitting tensile strength of (PHSC) and (FRHSC) before exposure to fire flame.

(١):- The splitting tensile strength of (PHSC) at ٢٥ $^{\circ}$C.

(٢):- The splitting tensile strength of (FRHSC) at ٢٥ $^{\circ}$C.



Figure(٥): The effect of fire flame on the splitting tensile strength of plain and steel fibers reinforced concrete at ١.٠ hour period of exposure.



Figure(٦): The effect of fire flame on the splitting tensile strength of plain and steel fibers reinforced concrete at ١.٥ hour period of exposure.

Conclusions

Based on the tests of present study, the following conclusions can be drown :

١. The density, compressive strength and splitting tensile strength of high strength concrete decrease with increasing the fire temperature for plain and steel fiber reinforced concrete.

٢. The density loss of concrete specimens increases with increasing fire temperature. The reduction in density was (٦.٢ – ٨.٦ %), (٨- ٩.٦ %) and (٨ - ١١.٥ %) for plain concrete and (٤.٣ - ٧%), (٦.٦- ٨.٤%) and (٧.٥ -٩.٢ %) for steel fiber reinforced concrete at fire temperatures of ٣٠٠ °C, ٥٠٠ °C and ٦٠٠ °C respectively. The decrease in the density with increasing in fire temperatures can be attributed to the fact that exposure to fire causes vaporization of the free water, loss of combined and adsorbed water.

٣. The compressive strength of concrete decreases with fire exposure at all ranges of temperatures. The percentage of residual compressive strengths were (٣٦ - ٧٨%) for plain concrete and (٤٩ - ٨٩%) for fiber reinforced concrete.

٤. The splitting tensile strength was more sensitive than the compressive strength. The percentage of residual splitting tensile strengths were (٣٤ -٦٨%) for plain concrete and (٤٣ -٨١%) for fiber reinforced concrete for all periods of exposure.

٥. The addition of steel fibers to concrete would increase the residual compressive and splitting strength of burned concrete.

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