EFFECT OF FIRE FLAME EXPOSURE ON THE COMPRESSIVE STRENGTH OF FIBRE REINFORCED CONCRETE

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Abstract

Fibre reinforced concrete is a relatively new materials which has certain advantages such as ductility. In the present work ,an attempt is made to study the effect of fire flame on the compressive strength of fibre reinforced concrete. The concrete specimens were subjected to fire flame temperature ranging between (25-700)ºC at different ages 30 ,60 and 90 days. Three temperature levels 300 ,500 and 700ºC were chosen with three different exposure periods of 0.5 ,1.0 and 2.0 hours. The test specimens were cubes (150 mm) .After burning ,the concrete specimens were allowed to cool in air. The test results showed that the compressive strength decreases when the fire flame temperatures were increased.

Mathematical models for the prediction of compressive strength after exposure to fire flame were developed in this study with a good correlation factor using data of mechanical properties of fibre reinforced concrete before fire flame exposure .

1- Introduction

In the structural design of buildings , in addition to the normal gravity and lateral loads ,it is in many cases necessary to design the structure to safely resist exposure to fire .However it is usually necessary to guard against structural collapse for a given period of time (1) .

Recent interest has been shown in the use of steel fibre reinforced concrete since the tensile strength of the composite is higher than that of plain concrete and the use of fibres may lead to reductions in the amount of cracking under serviceability conditions .

Several investigations have shown that deterioration in the compressive strength of concrete under high temperature exposure takes place .There are indeed rare researches about temperature gradient and exposure time of the concrete indirect contact with the fire flames . In this study there is an attempt to investigate the effect temperature gradient and exposure time of steel fibre reinforced concrete to fire flame on compressive strength.

2- Literature Review

2.1 Fire Effect on the Mechanical Properties of Concrete

Purkiss(2) carried out on experimental program to study the mechanical properties of steel fibre reinforced concrete at elevated temperatures . The steel fibres (20*0.25mm) were used and two volume fractions (0.75% and 1.5%) were considered for the plain fibres but only 0.75% for crimped fibres . The ultimate tensile strength of the fibres was found to be 1815 MPa ,Four mixes were used ; mix1 contains0.75 % of plain fibres ,mix2, 0.75% crimped, mix3: 1.5 % plain and ,mix4 no fibres. Concrete cubes (100*100*100nm) were used. The specimens were exposed to six temperature levels, 300, 400, 500, 600, 700 and 800ºC with out any imposed load. A proprietary kiln type of furnace was used to heat the specimens. The specimens were heated to the temperature, allowed to soak at the temperature for1.0 hour then allowed to cool.

Oven dried for at least 48 hours before testing and then all specimens were tested at age of 6 months after heating .The test results showed that the compressive strength and splitting tensile strength decrease with increasing of the temperature. He found that the residual compressive strength of fibre reinforced concrete is sensibly independent of fibre type and fibre content, and below 600C is considerably higher than that for plain concrete. He also found that there is a similar trend for splitting tensile strength of fibre reinforced concrete. The author also found there is for all the mixes tested , a reasonable correlation between loss in pulse velocity and loss in flexural strength or cube strength.

Umran [3] investigated the fire flame exposure effect on some mechanical properties of concrete. The specimens were subjected to fire flame ranging between (25- 700 ْ C) , Three temperature levels of (400,500, and 700 ْ C) were chosen with four different exposure duration of 0.5 ,1.0,1.5 and 2.0 hour without any imposed loads during heating . The specimens were heated and cooled under the same regime and tested after exposure to fire flame at ages (30 ,60 and 90 days) .Compressive strength of 150mm cubes and flexural strength of (100*100*400 mm)prisms were measured . Ultrasonic pulse velocity (U.P.V) and dynamic modulus of elasticity (Ed) were tested also .He found that the residual compressive strength ranged between (70-85%) at 400 ْ C, (59-78%)at 500 ْ C and (43-62%)at 700 ْ C. The flexural strength was found to be mere sensitive to fire flame exposure than the compressive strength .The residual flexural strength was in the range of (67-78%) at 400 ْ C, (40-67%) at 500 ْ C and (20-45%) at 700 ْ C . He also found that the ultrasonic pulse velocity (U.P.V) and dynamic modulus of elasticity (Ed) were more sensitive to fire flame than compressive strength .He also noticed that exposure time after one hour has a significant effect on residual compressive strength of concrete .

2.2 Fire Flame Effect on Non – Destructive Test .

2.2.1 Ultrasonic pulse velocity (U.P.V)

The Ultrasonic test is a useful tool for assessing the uniformity of concrete and detecting cracks , voids ,or honeycombing .It gives useful information about the size of micro – cracked zone and on crack growth and the interior Structure of the concrete element (4,5) .

The pulse velocity of concrete is affected by variety of factors ; the composition and maturity of concrete , the geometry of section being tested , and conditions at test time all affect the measured pulse velocity of Portland cement concrete (6,7) .

2.2.2 Rebound Method

The surface hardness of concrete members is tested by the " Schmidt Rebound hammer " . This testing hammer estimates the surface hardness by the rebound number which can be taken as a measure of the concrete strength and percentage of voids (8,9)

A considerable number of research works had dealt with the effect of fire on the non- destructive testing of the concrete .

Katwan and Abdul – Hammed [10] presented an evaluation study of a fire, which took place at AL- Nahda, intersection on the army canal at Baghdad city. The fire resulted from collision of benzene tanker with tunnel deck slab and continued for more than three hours. They estimated the retained strength of concrete at fire exposed area by using semi destructive testes, such as concrete cores or non-destructive tests, such as ultrasonic pulse velocity and Schmidt hammer. It was found that the actual compressive strength was equivalent to 23Mpa. They found that the actual compressive of concrete as obtained from the project document was more than 35 MPa, was estimated that the ratio between strength after and before fire was less than 0.66. They found that the structure was still capable of sustaining the loads recommended by the specifications of state organization for Roads and Bridges after carrying out loading test before putting the intersection back into service.

Essa [11] studied the effect of burning by fire flame on the properties of concrete, the investigated properties were concrete compressive strength and density, Ultrasonic pulse velocity (U.P.V) and rebound hammer (R) were tested also. The tested specimens were heated to two temperature levels 500 ̊C (achieved by subjecting the cubes to direct flame from petroleum gas burner) and 800ºC (achieved by using a special oven). The heating durations were 1 and 2 hours from the specimen's exposure to 500ºC, while it was 1 hour for the specimens exposure to 800C. He found that the reduction in density ranged between 10-14 % and 22-24 % at 500 ºC, when the periods were 1and 2 hours respectively. The author concluded that the reduction in compressive strength ranged between (23-31%) and 39% at 500 C, when the periods of burning were 1 and 2 hours respectively. At 800C the reduction at 1 hours was 77% from the original strength ,More over , the Ultrasonic pulse velocity (U.P.V) and Rebound hammer (R) decreased at 500 ̊ C (16-32%) ,(39-50%) and about (11-12%), (16-21%) for exposure periods 1 and 2 hours respectively. At exposure to 800 ̊ C and 1.0 hours exposure time the reduction in (U.P.V) was 50% while that in rebound number was a bout 18.5% .

3. Experimental Work

3-1 Program of Work:

This research was designed to study the effect of fire flame on the compressive strength of steel fibre reinforced concrete.

The test specimens used were (150mm) cubes. The compressive strength test was conducted according to BS 1881: Part 116: 1983 [12] .

It was found from other researches as Purkiss and Nahab (2, 13), that the inclusion of crimped steel fibres improves the compressive strength of concrete. Crimped steel fibres were mixed with concrete by (0.7-1.0 %) volume fraction.

3.2 Materials and Mixes

3.2.1 Cement

The cement used in this study was Ordinary Portland Cement (O.P.C) produced at Kufa factory . This cement complied with the Iraqi specification No.5 1984 [14] .The physical properties and chemical composition are presented in table (3-1)

Table (3-1): a) Physical properties of the cement

Physical Properties	Test results	IOS 5: 1984 Limits
Fineness, Blaine, cm^2/gm	3060	≥ 2300
Setting time, Vicat's method		
Initial hrs: min.	1:55	≥ 0: 45
Final hrs: min.	3:45	≤ 10: 00
Compressive strength of 70.7 mm cube, MPa		
3 days	23	≥ 15
7 days	29	≥ 23

b) Chemical composition of the cement

Oxide	(%)	IOS 5: 1984 Limits
CaO	60.26	
SiO_2	20.70	
Fe_2O_3	3.30	
Al_2O_3	6.12	
MgO	4.32	≤ 5.0
SO_3	2.34	≤ 2.8
Free lime	0.72	
L.O.I.	1.63	≤ 4.0
I.R.	0.61	≤ 1.5
Compound composition	**(%)**	**IOS 5: 1984 Limits**
C_3S	36.85	
C_2S	31.50	
C_3A	11.80	
C_4AF	8.73	
L.S.F.	0.86	0.66-1.02

3.2.2 Fine Aggregate

AL- AKhaider well- graded natural silica sand was used . The results of physical and chemical properties of the sand are listed in table [3-2] .Its grading conformed to the Iraqi specification No.45/ 1984 [15] , zone (3) .

Table (3.2) Properties of the sand

Sieve size (mm)	***Percentage Passing***	***I.O.S 45 :1984 (15) Limits , Zone3***
9.50	100	100
4.47	96	90-100
2.36	93	85-100
1.18	79	75-100
0.60	61	60-79
0.30	24	12-40
0.15	0	0-10
Properties	***Test results***	***I.O.S 45 :1984 (15) Limits , Zone3***
Sulphate content ,SO3%	0.26	≤ 0.5
Specific gravity	2.60	----
Absorption	1.70	----

3.2.3 Mix Design and Proportions

The concrete mix was designed according to British mix design method B.S. 5328: Part 2: 1991 [15].The proportions of the concrete mix are summarized in Table (3-5).

Table (3-5): Mixes Proportions

Slump (mm)	*w/c ratio*	*Mix Proportions (Kg/m³)*			
		Water	*Cement*	*Sand*	*Gravel*
60	0.45	195	435	515	1215

3-2-4 Concrete Mixing and Casting

Conventional and steel fiber concrete were mixed in a horizontal pan-type mixer of 0.1 m^3 capacity. The interior surface of mixer was cleaned and moistened before use. The aggregate and cement were first mixed dry for 60 sec, then the water was added and mixed for another 30 sec. The steel fibers were then fed continuously to the mixer for a period of 2 to 6 min. depending upon the fiber content, using a 25 mm steel sieve to separate and prevent fiber clumps from entering the mixer.

After mixing, the concrete was poured into the moulds and compacted using a vibrating table. The specimens were left for about 30 min before they were leveled by hand trowelling.

3-2-5 Coarse Aggregate

The gravel used was brought from AL – Nibaii area with a maximum size of 19mm. The grading and other Properties of this type of aggregate were tested and shown in Table [3-3].

Table (3.3) Properties of the gravel

Sieve size (mm)	Percentage Passing	I.O.S 45 :1984 (15) Limits , Zone(3)
37.5	100	100
20.0	96	95-100
9.50	51	30-60
4.75	2	0-10
Properties	Test results	I.O.S 45 :1984 (15) Limits
SulphateContent,SO3(%)	0.08	≤ 0.1
Specific gravity	2.64	----
Absorption	0.6	----

3.2.6 Water:

Tap water was used through this work for both mixing and curing concrete.

3.2.7 Fibres

Crimped steel fibres were used in this investigation and the Properties of these fibres are presented in table [3.4]

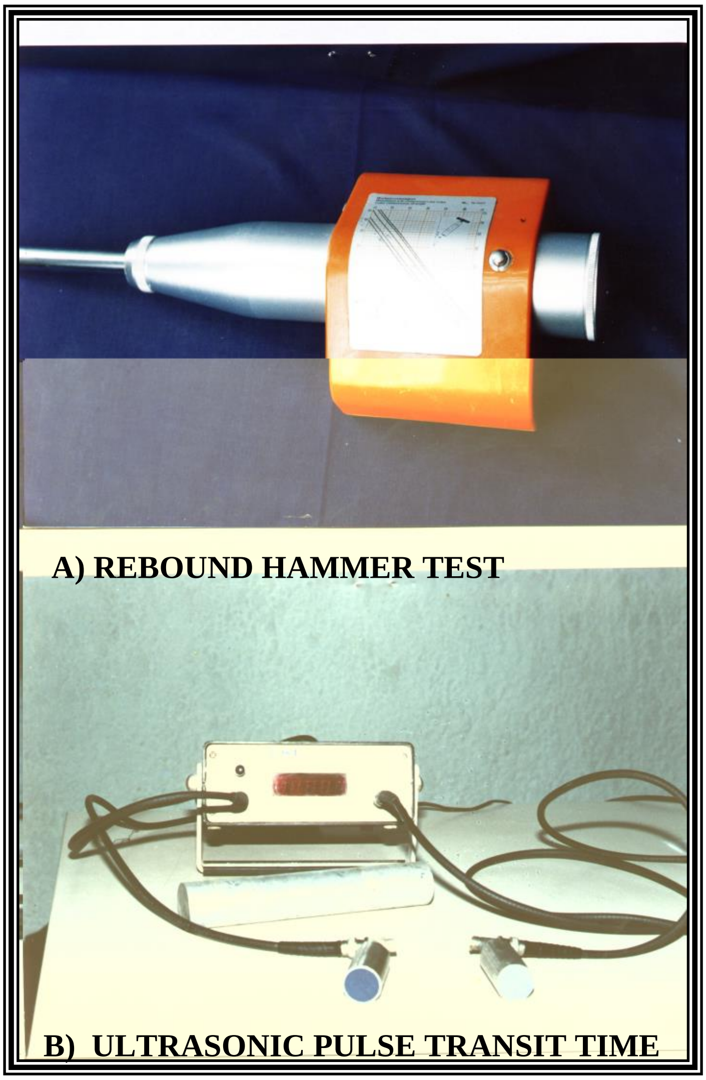
Density kg/m3	Tensile strength (MPa)	Length (mm)	Diameter (mm)	Aspect ratio
7850	1100	25	0.3	75

3-3 Heating and Cooling

The concrete specimens were burnt by direct fire flame from a net of methane burners inside a brick stove with dimensions of 800x800x1000mm. The bare flame was intended to simulate the heating conditions in an actual fire. When the target temperature was reached, two digital thermometers continuously recoded the temperature, one of them was positioned in flame contact with the bottom surface while the other was at the top surface of the specimen. After burning, the concrete specimens were allowed to cool inside the stove for 4 hours and stored in the laboratory environment about 20 hours.

3-4 Non Destructive Tests

The ultrasonic pulse velocity and rebound hammer test were used to monitor the variation in compressive strength, quality and intensity of micro cracking of concrete and estimate the surface hardness of concrete by recording the rebound number. The measurement devices used were as shown in plate (3-1).



Plate(3-1) : The measurement devices.

4- Results and Discussion

4-1 The Density

Table (4-1) shows the effect of the exposure to fire flame on the density of plain and steel fiber reinforced concrete, while figures (4-1) to (4-3) show the relations between fire flame temperature and density of steel fiber reinforced concrete. It can be seen from these Table and Figures that the density behaved as the following:

1- At 300^{o}C fire flame temperature and for all ages and all periods of exposure, the reduction in density was ranged between (2.8-5.7%) and (1.1-2.4%) for plain and steel fiber reinforced concrete if compared with initial density before exposure to fire flame.

2- Further reduction was (6-8.4%) and (4.8-6.7) for plain and steel fiber reinforced concrete respectively took place at 500 ºC fire flame temperature.

3- More reduction in density took place when the fire flame temperature increased. At 700oC, the reduction in density was (8.4-9.9%) and (8.0-9.6%) for plain and steel fiber reinforced concrete respectively. The loss in density of plain concrete was 2% more than that in density of steel fiber reinforced concrete at 300 ºC but this difference decreased when the temperature increased until it becomes 0.3% at 700ºC. These results confirmed that of Purkiss (2), Owen and Thellwell (16).

Table (4-1): ***Test values of the density of plain and steel fiber reinforced concrete specimens before and after exposure to fire flame.***

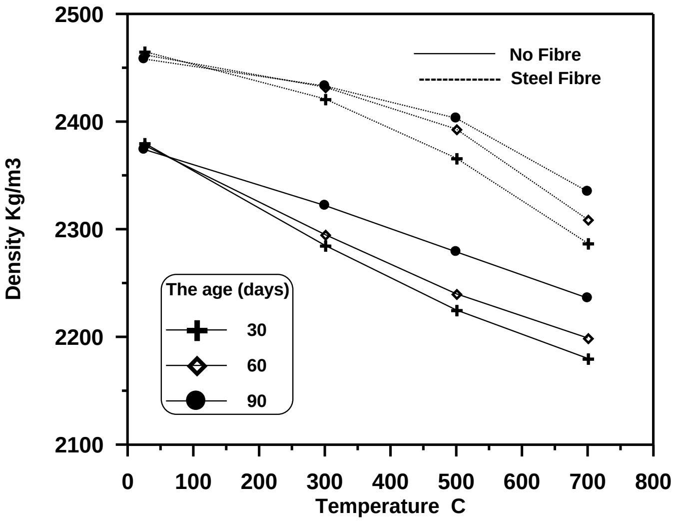
Age at exposure (days)	***Period of Exposure (hours)***	***Density (kg/m3) Temperature ^{o}C***				***Ratios (pa/pb)***			***Fiber content***
		25 (a)	***300 (b)***	***500 (c)***	***700 (d)***	***b/a***	***c/a***	***d/a***	
	0.5		2285	2225	2180	0.960	0.935	0.916	No Fiber
			2421	2366	2287	0.982	0.960	0.928	Steel Fiber
	1.0	**2380***	2261	2213	2177	0.950	0.930	0.915	No Fiber
			2379	2346	2267	0.965	0.952	0.920	Steel Fiber
30	***2.0***	**2465***	22449	2189	2142	0.945	0.920	0.900	No Fiber
		*	2342	2287	2230	0.950	0.928	0.905	Steel Fiber
	0.5		2295	2240	2199	0.965	0.942	0.925	No Fiber
60			2432	2393	2309	0.988	0.972	0.938	Steel Fiber
	1.0	**2378***	2283	2225	2171	0.960	0.936	0.913	No Fiber
			2412	2383	2277	0.980	0.968	0.925	Steel Fiber
	2.0	**2462***	2259	2199	2163	0.950	0.925	0.910	No Fiber
		*	2383	2289	2245	0.968	0.930	0.912	Steel Fiber
90	***0.5***		2322	2279	2236	0.978	0.960	0.942	No Fiber
			2433	2403	2335	0.990	0.978	0.950	Steel Fiber
	1.0	**2374***	2303	2267	2198	0.970	0.955	0.926	No Fiber
			2414	2384	2305	0.982	0.970	0.938	Steel Fiber
	2.0	**2458***	2283	2255	2184	0.962	0.950	0.920	No Fiber
		*	2385	2347	2261	0.970	0.955	0.920	Steel Fiber

***ρ*a**=The density of plain and fiber reinforced concrete after exposure to fire flame .

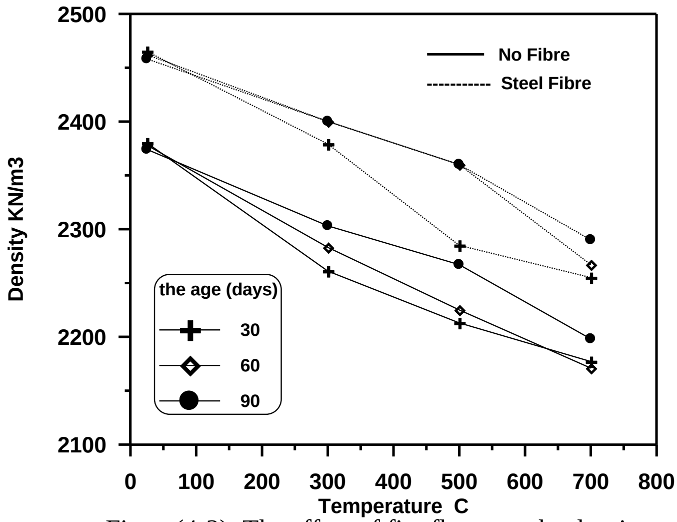
ρb= The density of plain and fiber reinforced concrete before exposure to fire flame .

***=**The density of concrete at 25 ^{o}C .

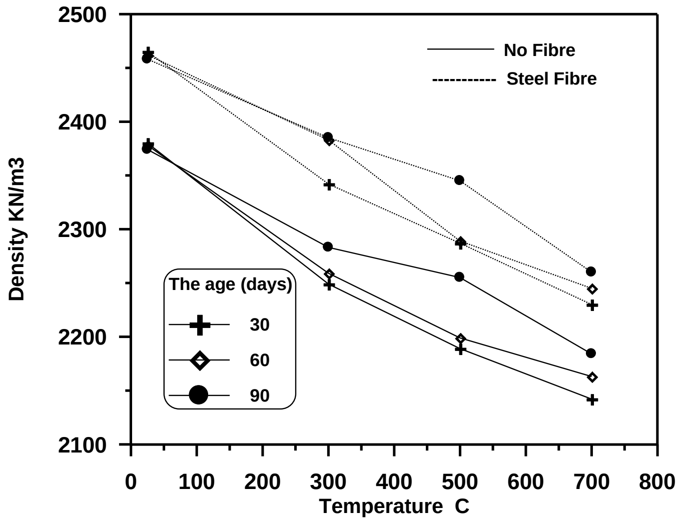
****=**The density of steel fibre reinforced concrete at 25 ^{o}C .



Figure(4-1): The effect of fire flame on the density of plain and steel fibre reinforced concrete at 0.5 hours period of exposure.



Figure(4-2): The effect of fire flame on the density of plain and steel fibre reinforced concrete at 1.0 hours period of exposure.



Figure(4-3): The effect of fire flame on the density of plain and steel fibre reinforced concrete at 2.0 hours period of exposure.

4-2 Compressive Strength

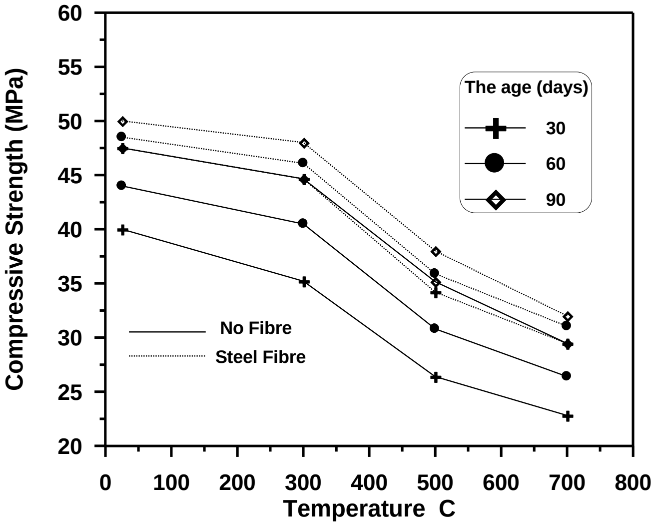
Concrete cubes (150x150x150 mm) were tested at ages 30, 60 and 90 days. The compressive strength results are summarized in Table (4-2), while figures (4-4) to (4-6) show the relation between compressive strengths and fire flame temperatures for both plain and steel fiber reinforced concrete. The percentage of residual compressive strengths were (41 -94 %) for plain concrete and (42 - 96 %) for steel fiber reinforced concrete for all periods of exposure. Surface cracks of about (1 mm) width took place on the concrete specimens. These results agreed with that obtained by other investigators, Purkiss (2), Collet et al (17), Logothetis and Economou (18). It is observed that the color of the concrete specimens changed to pink and increased in intensity. This may be due to hydration conditions of iron oxide component and other mineral constituents of the fine and coarse aggregates (3, 19). The surface cracks increased in number, length and depth due to temperature rise.

From above figures it can be seen that large proportion of the decrease in compressive strength occurs at the first 0.5 hour period of exposure. It can be seen that the adverse effect of fire is pronounced. Also on plain concrete more than on steel fiber reinforced concrete, while the effect is equal when the period of fire exposure reaches two hours or increase higher temperature exposure. This effect is still noticeable at 300^{o}C but above 500^{o}C all the specimens behave similarly. It is to be noted that below about 300^{o}C the mechanical properties of steel are little affected by temperature (2).

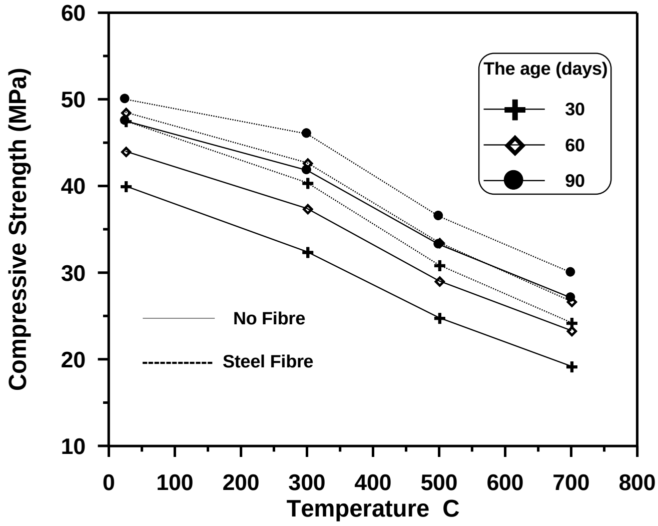
Table (4-2): ***Test values of compressive strength of plain and fiber reinforced concrete specimens before and after exposure to fire flame.***

Age at exposure (days)	***Period of Exposure (hours)***	***Compressive Strength (MPa) Temperature ^{o}C***				***Ratios (f_{ca}/ f_{cb})***			***Fiber content***
		25 (a)	***300 (b)***	***500 (c)***	***700 (d)***	***b/a***	***c/a***	***d/a***	
30	***0.5***	**40*** / **47.5****	35.2	26.40	22.80	0.88	0.66	0.57	No Fiber
			44.65	34.20	29.45	0.94	0.72	0.62	Steel Fiber
	1.0		32.40	24.80	19.20	0.81	0.62	0.48	No Fiber
			40.38	30.88	24.23	0.85	0.65	0.51	Steel Fiber
	2.0		28.80	23.60	16.40	0.72	0.59	0.41	No Fiber
			35.63	29.45	20.43	0.75	0.62	0.43	Steel Fiber
60	***0.5***	**44*** / **40****	40.48	30.80	26.40	0.92	0.70	0.60	No Fiber
			46.08	35.89	31.04	0.95	0.74	0.64	Steel Fiber
	1.0		37.40	29.04	23.32	0.85	0.66	0.53	No Fiber
			42.68	33.47	26.68	0.88	0.69	0.55	Steel Fiber
	2.0		32.56	25.08	19.36	0.74	0.57	0.44	No Fiber
			37.35	29.10	21.83	0.77	0.60	0.45	Steel Fiber
90	***0.5***	**47.5*** / **50****	44.65	35.15	29.45	0.94	0.74	0.62	No Fiber
			48.00	38.00	32.00	0.96	0.76	0.64	Steel Fiber
	1.0		41.80	33.25	27.08	0.88	0.70	0.57	No Fiber
			46.00	36.50	30.00	0.92	0.73	0.60	Steel Fiber
	2.0		36.10	29.93	22.33	0.76	0.63	0.47	No Fiber
			39.00	32.50	24.00	0.78	0.65	0.48	Steel Fiber

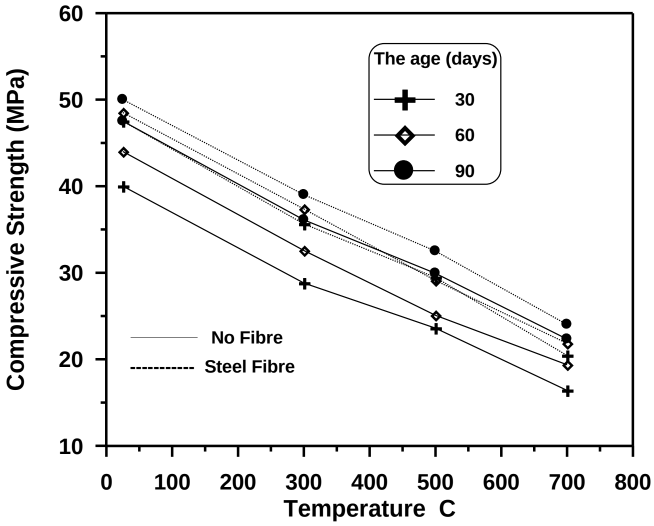
***fca*=** Compressive strength after exposure to fire flame.
fcb= Compressive strength before exposure to fire flame.
*****: No fibre.
****** : With steel fibre.



Figure(4-6): The effect of fire flame on the compressive strength of plain and steel fibre reinforced concrete at 0.5 hour period of exposure.



Figure(4-6): The effect of fire flame on the compressive strength of plain and steel fibre reinforced concrete at 1.0 hour period of exposure.



Figure(4-6): The effect of fire flame on the compressive strength of plain and steel fibre reinforced concrete at 2.0 hours period of exposure.

4-3 The Effect of the Age after Exposure to Fire Flame

The test results show that the residual compressive strength after exposure to fire decreases at 30 days age more than the reduction at 60 and 90 days. This may be attributed to the fact that hydration of cement paste is more complete at later ages.

4-4 Effect of the age at heating

As in compressive strength the effect of the fire flame at 30 days age was more than at 60 and 90 days ages. This is also due to the complete hydration of the cement at later age.

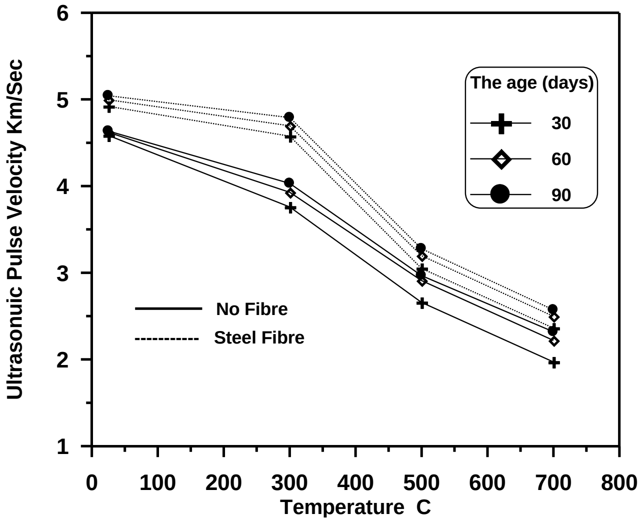
4-5 Residual Ultrasonic Pulse Velocity

The U.P.V test results are presented in Table (4-3) for plain and steel fibre reinforced concrete. The changes in U.P.V after heating is expressed as a ratio of the initial U.P.V for unheated samples, have been plotted against temperatures, figures (4-7) to (4-9). As can be seen from these figures, there is a sharp reduction I the U.P.V values for plain and fiber reinforced concrete. It is obvious from the results that U.P.V tests are more sensitive than any other tests.

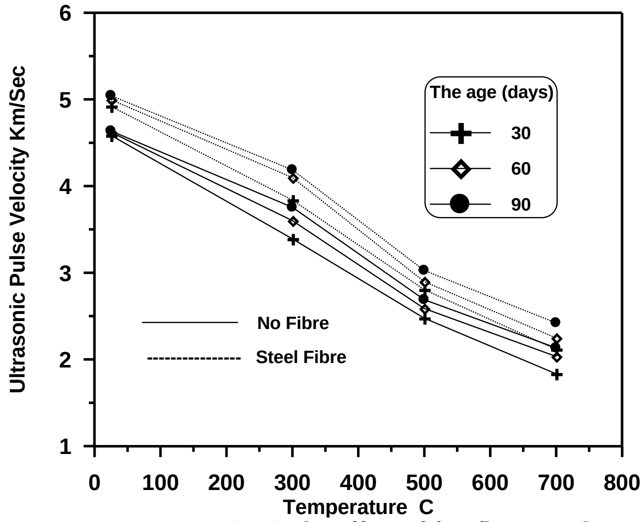
Table (4-3): ***Test values of the ultrasonic pulse velocity of plain and steel fibre reinforced concrete specimens before and after exposure to fire flame temperatures.***

Age at exposure (days)	*Period of Exposure (hours)*	*U.P.V (km /sec)*				*Ratios* $(U.P.V)_a/(U.P.V)_b$			*Fiber content*
		Temperature ^{o}C							
		25 (a)	*300 (b)*	*500 (c)*	*700 (d)*	*b/a*	*c/a*	*d/a*	
	0.5		3.758	2.658	1.970	0.82	0.58	0.43	No Fiber
30		4.583*	4.575	3.050	2.361	0.93	0.62	0.48	Steel Fiber
	1.0		3.390	2.4758	1.833	0.74	0.54	0.40	No Fiber
		4.920**	3.837	2.804	2.115	0.78	0.57	0.43	Steel Fiber
	2.0		3.163	2.154	1.420	0.69	0.47	0.31	No Fiber
			3.542	2.410	1.574	0.72	0.49	0.32	Steel Fiber
	0.5		3.927	2.910	2.218	0.85	0.63	0.48	No Fiber
60		4.620*	4.695	3.197	2.497	0.94	0.64	0.50	Steel Fiber
	1.0		3.600	2.587	2.033	0.78	0.56	0.44	No Fiber
		4.995**	4.096	2.897	22.47	0.82	0.58	0.45	Steel Fiber
	2.0		3.373	2.264	1.617	0.73	0.49	0.35	No Fiber
			3.696	2.497	1.798	0.74	0.50	0.36	Steel Fiber
	0.5		4.030	2.966	2.318	0.87	0.64	0.50	No Fiber
90		4.635*	4.789	3.277	2.571	0.95	0.65	0.51	Steel Fiber
	1.0		3.754	2.688	2.132	0.81	0.58	0.46	No Fiber
		5.042**	4.185	3.025	2.420	0.83	0.60	0.48	Steel Fiber
	2.0		3.476	2.318	1.670	0.75	0.50	0.36	No Fiber
			3.832	2.571	1.916	0.76	0.51	0.38	Steel Fiber

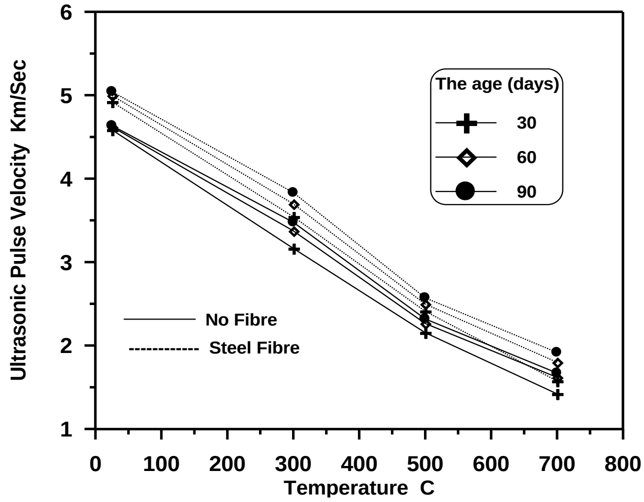
(U.P.V)a= Ultrasonic pulse velocity after exposure to fire flame.
(U.P.V)b= Ultrasonic pulse velocity before exposure to fire flame.



Figure(4-7) The effect of fire flame on the ultrasonic pulse velocity of plain and steel fibre reinforced concrete at 0.5 hour period of exposure.



Figure(4-8) The effect of fire flame on the ultrasonic pulse velocity of plain and steel fibre reinforced concrete at 1.0 hour period of exposure.



Figure(4-9) The effect of fire flame on the ultrasonic pulse velocity of plain and steel fibre reinforced concrete at 2.0 hours period of exposure.

It can be seen from figures that the reduction in the ultrasonic pulse velocity after exposure to fire flame is as follow:

At 300^{o}C, the reduction in (U.P.V) was (13 - 31 %) for plain concrete and (5-28 %) for steel fibre reinforced concrete. Similar results was observed by Purkiss (2) and Logothetis and Economou (18).

At 500^{o}C, the reduction was (36 - 53 %) for plain concrete and (35-51 %) for steel fibre reinforced concrete. These results agreed with the results obtained by Purkiss (2) and Habeeb (19) .

At 700^{o}C the reduction in (U.P.V) were (50 - 69 %) for plain concrete and (49 -68 %) for steel fiber reinforced concrete. Purkiss (2) reported that the reduction in (U.P.V) at this temperature is (70%) for plain concrete and (75%) for steel fiber reinforced concrete.

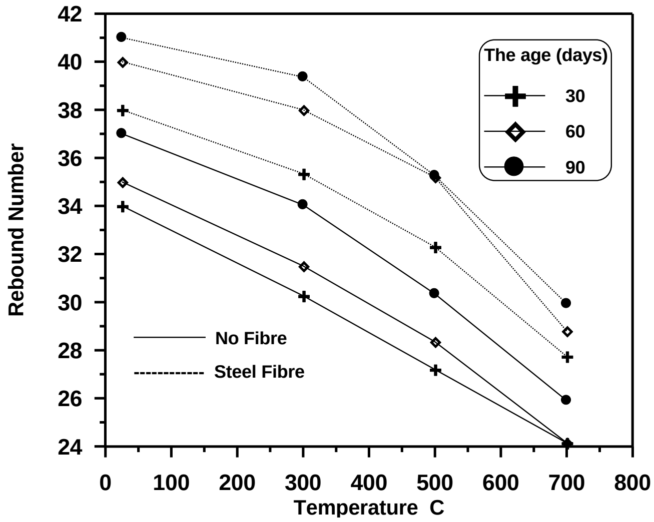
4-6 Surface Hardness Results

Surface hardness of the concrete cubes was assessed by the "Schmidt rebound hammer". Table (4- 4) shows the results of the rebound number for plain and steel fiber reinforced concrete specimens before and after exposure to fire flame.

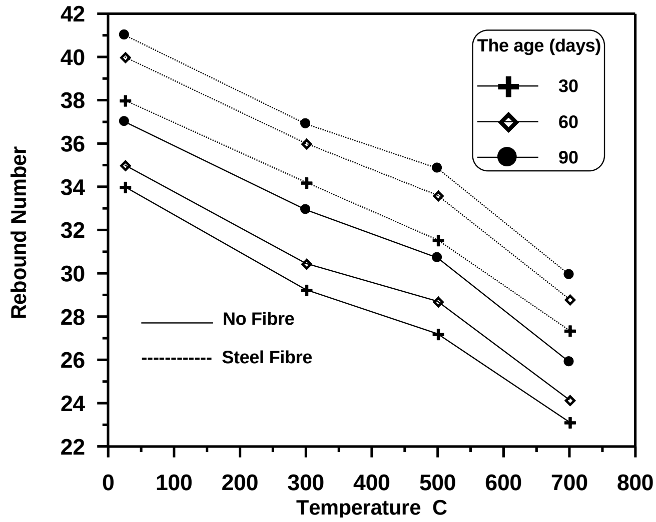
Table (4-4) : ***Test values of the rebound number of concrete specimens of plain and steel fiber reinforced concrete before and after exposure to fire flame.***

Age at exposure (days)	*Period of Exposure (hours)*	*Rebound Number Temperature ^oC*				*Ratios (RN_a/RN_b)*			*Fiber content*
		25 (a)	*300 (b)*	*500 (c)*	*700 (d)*	*b/a*	*c/a*	*d/a*	
30	***0.5***	**34*** **38****	30.26	27.20	24.14	0.89	0.80	0.71	No Fiber
			35.34	32.30	27.74	0.93	0.85	0.73	Steel Fiber
	1.0		29.42	27.20	23.12	0.86	0.80	0.68	No Fiber
			34.20	31.54	27.36	0.90	0.83	0.72	Steel Fiber
	2.0		28.56	26.52	21.42	0.84	0.78	0.63	No Fiber
			33.06	30.40	24.32	0.87	0.80	0.64	Steel Fiber
60	***0.5***	**35*** **40****	31.50	28.35	24.15	0.90	0.81	0.69	No Fiber
			38.00	35.20	28.80	0.95	0.88	0.72	Steel Fiber
	1.0		30.45	28.70	24.15	0.87	0.82	0.69	No Fiber
			36.00	33.60	28.80	0.90	0.84	0.72	Steel Fiber
	2.0		29.75	27.65	22.05	0.85	0.79	0.63	No Fiber
			34.40	32.40	26.00	0.86	0.81	0.65	Steel Fiber
90	***0.5***	**37*** **41****	34.04	30.34	25.90	0.92	0.82	0.70	No Fiber
			39.36	35.62	29.93	0.96	0.86	0.73	Steel Fiber
	1.0		32.93	30.71	25.90	0.89	0.83	0.70	No Fiber
			36.90	34.85	29.93	0.90	0.85	0.73	Steel Fiber
	2.0		31.82	29.97	22.20	0.86	0.81	0.60	No Fiber
			36.08	33.62	25.01	0.88	0.82	0.61	Steel Fiber

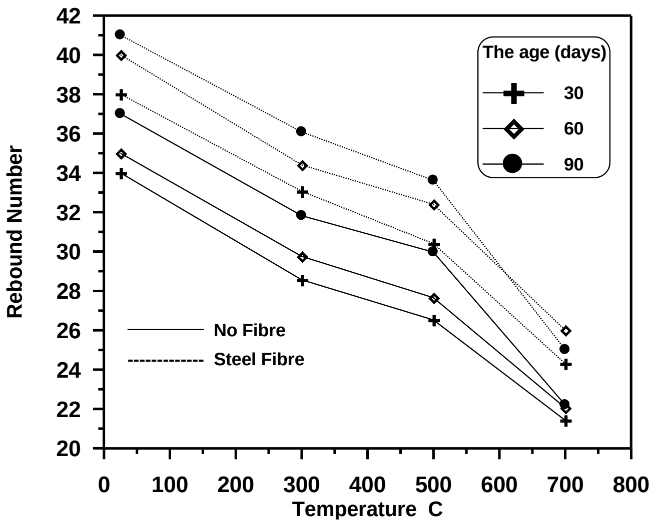
RN_a = Rebound number after exposure to fire flame.
RN_b = Rebound number before exposure to fire flame.



Figure(4-10) The effect of fire flame on the rebound number of plain and steel fibre reinforced concrete at 0.5hour period of exposure.



Figure(4-11) The effect of fire flame on the rebound number of plain and steel fibre reinforced concrete at 1.0 hour period of exposure.



Figure(4-12) The effect of fire flame on the rebound number of plain and steel fibre reinforced concrete at 2.0 hour period of exposure.

The effect of burning by fire flame on rebound number is shown in Figures (4-10) to (4-12). It can be observed that the rebound number decreases when the surface of concrete is subjected to fire flame.

At 300 ^{o}C, 500 ^{o}C and 700 ^{o}C, the reduction in the rebound number was (8-16%), (4-13%), (17-22%) and (14-20%), (29-40%), (27-39%) respectively for plain and steel fiber reinforced concrete. Similar results was found by Purkiss (2), Owen and Thell well (16) and Swamy et al (20). The decrease in the rebound number with increase in temperature can be attributed to the fact that fire causes damage to surface concrete rather than to concrete in core of the member.

4-7 Mathematical Models for Prediction of Compressive strength of concrete

In order to obtain a mathematical model that can accurately predicts the compressive strength of concrete with and without program package called "Statistica 5.0". This program includes extensive statistical operations and regression analysis capacities.

The mechanical properties of concrete might be known such as initial compressive strength, temperature of fire flames ultrasonic pulse velocity, Rebound number, ages, period of exposure and density were used in order to obtain the best regression model that can predict compressive strength of concrete after exposure to fire flame with and without steel fiber which can be written as follows:

$$fca_1 = fcb^{0.8947} * T^{-0.2367} * U^{0.2465} * R^{0.4173} * A^{0.0354} * P^{-0.0966} * D^{-0.0428}$$

$$C.C = 0.995$$

$$fca_2 = fcb^{1.3693} * T^{-0.0994} * U^{0.4529} * R^{0.3583} * A^{0.0172} * P^{-0.0577} * D^{-0.3688}$$

$$C.C = 0.991$$

where:

fca_1 and fca_2 = Compressive strength of the specimens after exposure to fire flame temperature (MPa) with and without steel fiber.

fcb=Compressive strength of the specimens before exposure to fire flame temperature (MPa).

T= Temperature of fire flame (^{o}C)

U=Ultrasonic Pulse velocity (km/sec).

R=Rebound number after exposure to fire flame.

A= The age of the specimens at the time of exposure.

P = The period of exposure to fire flame in (hour).

D=Density of concrete after exposure to fire flame (kg/m^3).

C.C = Coefficient of correlation.

Conclusions:

The density, compressive strength, ultrasonic pulse velocity and rebound number of concrete decreases with increasing fire flame , temperature for plain and steel fiber reinforced concrete.

It was found that the loss in density of plain concrete was 2% more than that in density of steel fiber reinforced concrete at 300oC but this difference decreases when the temperature increases until becoming 0.3% at 700 oC.

Large proportion of drop in the compressive strength occurs at the first 0.5 hour period of exposure.

The ultrasonic pulse velocity test showed a response to the effect of fire flame. It appears that this non-destructive method gives better-predicted values for the residual strength, when it is used in the mathematical model if compared with other destructive tests.

The reduction in rebound number was (8-16%), (4-13%) and (17-22%) for plain concrete and (14-20%), (29-40%) and (27-39%) steel fiber reinforced concrete at 300oC, 500oC and 700oC respectively. The decrease in the rebound hammer with the increasing in fire temperature can be attributed to the fact that fire causes damage to the surface concrete rather than to concrete in the core of the member.

Beyond 500oC the effect of the fire flame on the compressive strength, ultrasonic pulse velocity and rebound number was equal for both plain and steel fiber reinforced concrete when the period of fire exposure reaches two hours.

The inclusion of crimped steel fibers improves the compressive strength of concrete. This improvement is about 9.6 to 19% at 28 days and 6 to 21.5% at 90 days.

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تأثير لهب النار على مقاومة الانضغاط للخرسانة المسلحة بالألياف الحديدية

الخلاصة

تعتبر الخرسانة المسلحة بالألياف الحديدية من المواد الحديثة, والتي تمتاز بخواص جيدة مثل المطولية. يشمل البحث الحالي محاولة لدراسة تأثير لهب النار على مقاومة الانضغاط للخرسانة المسلحة بالألياف الحديدية. عرضت النماذج الخرسانية الى درجات حرارة تتراوح بين (25−700) درجة مئوية وبأعمار مختلفة هي (30,60,90) يوما حيث تم تعريض النماذج الى ثلاثة درجات حرارية هي (300, 500, 700) درجة مئوية لثلاث فترات تعرض هي (0.5 1.0 , 2.0) ساعة. بعد التعرض تركت النماذج في الهواء. تم استخدام موديلات رياضية جديدة لغرض استخراج مقاومة الانضغاط للخرسانة المسلحة بالألياف الحديدية بعد التعرض إلى لهب النار للحصول على قيم تخمينية مع أيجاد معامل ارتباط جيد باستخدام بعض المعلومات عن الخواص الميكانيكية للخرسانة قبل تعرضها إلى لهب النار .