Effect of Fire Flame Exposure on Flexural Behavior and Shear Strength of Reinforced NSC and HPC Beams

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ABSTRACT:

In this study flexural behavior and shear strength of reinforced concrete beams made of normal strength concrete (NSC) and high performance concrete (HPC) with compressive strength (30,78) MPa respectively at (28) days age, and assessing the residual flexural and shear strengths after exposure to fire flame.

The concrete specimens were subjected to fire flame at temperature levels of (400 $^{\circ}$**C**) and (700 $^{\circ}$**C**) at two periods of exposure (1, 1.5) hour then cooled either by air and water. Firing and testing the beam specimens were conducted at age of (60) days.

Results indicate remarkable reduction in flexural and shear strengths after exposure to fire flame. The residual flexural strength is (84- 88%), (70- 72%) for HPC, and (86- 91%), (84- 88%) for NSC with (1.0) and (1.5) hour exposure periods respectively at fire temperature (400 $^{\circ}$**C**), while the residual at fire temperature (700 $^{\circ}$**C**) is (50-58%), (37-38%) for HPC, and (53-60%), (26-41%) for NSC with (1.0) and (1.5) hour exposure periods 93%), (75- 77%) for NSC with (1.0) and (1.5) hour exposure periods respectively at fire temperature (400 $^{\circ}$**C**), while the residual at fire temperature (700 $^{\circ}$**C**) is (50-55%), (40-45%) for HPC, and (54-57%), (38-46%) for NSC with (1.0) and (1.5) hour exposure periods respectively.

تأثير التعرض إلى لهب النار على سلوك الانحناء ومقاومة القص لعتبات خرسا نية مسلحة اعتيادية المقاومة وعالية الأداء

الخلاصة :

تناولت هذه الدراسة سلوك الانحناء ومقاومة القص لعتبات خرسانية مسلحة: اعتيادية المقاومة (NSC) وخرسانة عالية الأداء(HPC) وبمقاومة انضغاط (٣٠، ٧٨) ميكا باسكال بعمر (٢٨) يوم، مع تقييم مقاومة عزم الانحناء والقص المتبقية بعد التعرض إلى لهب النار. عرضت النماذج الخرسانية إلى لهب النار في مستويات حرارة (٤٠٠ ، ٧٠٠) درجة مئوية في فترتين من التعرض (١، ١,٥) ساعة، ثم بردت بواسطة الهواء و الماء. وجرى حرق و فحص نماذج العتبات في عمر (٦٠) يوم.

لقد بينت النتائج انخفاض ملحوظ في مقاومات القص و عزم الانحناء بعد التعرض إلى لهب النار، حيث كانت مقاومة عزم الانحناء المتبقية للخرسانة العالية المقاومة هي (٨٤-٨٨%) و (٧٠-٧٢%) و للخرسانة الاعتيادية المقاومة هي (٨٦-٩١%) و (٨٤-٨٨%) بفترات تعرض (١، ١,٥) ساعة على التوالي بعد التعرض إلى درجة حرارة (٤٠٠) درجة مئوية، بينما للخرسانة العالية المقاومة وبعد الحرق إلى (٧٠٠) درجة مئوية مقاومة عزم الانحناء المتبقية هي (٥٠-٥٨%) (٣٨-٣٧%) و للخرسانة الاعتيادية المقاومة هي (٥٣-٦٠%)، (٢٦-٤١) بفترات تعرض (١، ١,٥) ساعة على التوالي.

اما مقاومات القص المتبقية للخرسانة العالية المقاومة هي (٩٠– ٩٨%) و (٧٨– ٩٣%) و للخرسانة الاعتيادية المقاومة هي (٧٨– ٩٣%) و (٧٥- ٧٧%) بفترات تعرض (١، ١,٥) ساعة على التوالي بعد التعرض إلى درجة حرارة (٤٠٠) درجة مئوية، بينما للخرسانة العالية المقاومة وبعد الحرق إلى (٧٠٠) درجة مئوية مقاومة القص المتبقية هي (٥٠-٥٥%) و (٤٥-٤٥%) و للخرسانة الاعتيادية المقاومة هي (٥٤-٥٧%) و (٨٣-٤٦%) بفترات تعرض (١، ١,٥) ساعة على التوالي.

Introduction

In buildings, HPC structural members are designed to satisfy the requirements of serviceability and safety limit states. One of the major safety requirements in building design is the provision of appropriate fire safety measures for structural members **(National Building Code of Canada, 1995).**

With development and application of high-performance concrete (HPC), understanding of its behavior when subjected to fire is needed to insure its safe application **(Lin et- al, 1996).** The fire safety of RC structures largely depends on their fire resistance, which in turn depends on the combustibility and fire resistance of their main structural elements,i.e., beams and columns. As structure elements, beams are subject to flexural and shearing loads. The residual bending moment and shear force of fire-damaged concrete beams are important factors in determining the safety of the structure.

Research Significance

There are indeed little research about temperature gradient and exposure of concrete in direct content with fire flames.

The present work is an attempt to investigate the effect of exposure on NSC and HPC to fire flame on its flexural behavior and shear strength.

Two concrete mixes and (40) reinforced concrete beams were investigated at different temperature levels, different exposure periods and different shear span ratio (a/d).

Many variables are encountered in this investigation, which cover the following aspects:

1- Studying the fire flame effect on flexural behavior and shear strength of reinforced NSC and HPC beams with different steel ratio.

2- Studying the fire flame effect on the immediate deflection of the reinforced NSC and HPC beams and comparing the results with control beams.

3- Studying the fire effect on the mechanical properties of NSC and HPC, such as compressive strength, splitting tensile strength when cooled in air and water, modulus of rupture, modulus of elasticity.

Literature Review

The old name of high performance concrete is " high strength concrete" which the compressive strength is forming main demanding of the concrete production. Another properties are added to the high strength of the structure such as durability, early strength, impermeability and modulus of elasticity of the concrete **(Neville, 1995)**. High-Performance concrete is defined as concrete that meets special performance and uniformity requirements that can not always be achieved routinely by using conventional materials and normal mixing, placing, and curing practices.

The Benefits of HPC

There are a number of potential benefits arising from the use of high performance concrete in structures **(The Benefits of High Performance Concrete, 1998).**

1- More slender elements can be obtained.

2- Lower concrete volumes.
3- Reduced percentage of reinforcement.
4- Smaller and less foundations.
5- More rapid construction.
6- Reduced maintenance improved durability by increased strength, lower permeability, reduced chloride ion penetration, corrosion inhibition, increasing resisitivity up to more than 500%, sulfate resistance.

Reinforced Concrete Simple Deep Beams

Zsutty, 1971 recognized that the shear test data are not homogeneous due to the fact that there are two separate types of beam behavior. Accordingly, he segregated the data and performed separate regression for short beams and long beam. For long beam (i.e., slender beams),the ultimate shear strength prediction was found according to the Eq (1)

$$V_c = 2.2\,(f_c'\rho_w d/a)^{1/3}\, b_w\, d \qquad \text{(1)}$$

Rebeiz, 1999 presents an alternative shear strength prediction equation for RC members. It uses the techniques of dimensional analysis, interpolation function, and multiple regression analysis. The analysis showed that the best model for the ultimate shear strength prediction was found according to the Eq (2).

$$V_c = [0.4+ 1.7(f_c'\rho_w d/a)^{1/2}]\, b_w\, d \qquad \text{(2)}$$

Effect of Fire on Normal Strength Concrete

Essa, 1999 **studied the effect of burning by fire flame on some mechanical properties of concrete. The investigated properties were concrete compressive strength, density, ultrasonic pulse velocity (U.P.V)**

and Schmidt rebound hammer number. The specimens were heated to two temperature levels (500 °C) (achieved by subjecting the cubes to direct fire flame from petroleum gas burner) and (800 °C) (achieved by using an oven). The heating durations were 1 and 2 hrs. for the specimens exposed to (500 °C), while it was 1hr. for the specimens exposed to (800 °C). He found that the reduction in compressive strength is higher in specimens heated to (800 °C) than those heated to (500 °C) (1 and 2hr.).

Umran, 2002 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, 1.5 and 2 hours 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 150 mm cubes and flexural strength of (100x100x400 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 more 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.

Effect of Fire on High Performance Concrete

Chan and Lox, 2000 carried out an experimental program to study the mechanical properties and pore structure of high performance concrete (HPC) and normal – strength concrete after exposure to high temperature. After the concrete specimens were subjected to temperature of 800 °C, their residual compressive strength was measured. The porosity and pore size distribution of the concrete were investigated by using mercury intrusion porosimetry. The test results showed that (HPC) had higher residual strength, although the strength of (HPC) degenerated more sharply than the normal – strength concrete after exposure to high temperature. They found that the changes in pore structure could be used to indicate the degradation of mechanical property of (HPC) subjected to high temperature

Habeeb, **2000** studied the effect of high temperatures on some mechanical properties of high strength concrete (HSC) such as compressive strength, flexural strength and dynamic modulus of elasticity (Ed). Three design strengths were investigated 40, 60 and 80 MPa.. The specimens were heated slowly to five temperature levels (100, 300, 500, 600 and 800 °C), and to three exposure periods 1, 2 and 4 hours .

He found that :

1- (HSC) is more sensitive to high temperatures than (NSC).The residual compressive strength ranged between (90 – 106%) at 100°C, (72-103%) at 300 °C, (55 – 87%) at 500 °C and (22-66%) between (600-800 °C).

2- 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 (92 – 98%), (52-98%) and (29- 47%) at 100°C, 300°C and 500 °C respectively and (2-30%) at 600 –800 °C .

Effect of Fire on Flexural Behavior and Shear Strength

Hsu and Lin, 2006 investigated residual bearing capabilities of five-exposed reinforced concrete beams. The analysis method includes combining thermal and structural analyses for assessing the residual bearing capabilities, flexural and shear capacities of reinforced concrete beams after fire exposure. The thermal analysis uses the finite difference method to model the temperature distribution of a reinforced concrete beam maintained at high temperature. The structural analysis, using the lumped method, is utilized to calculate the residual bearing capabilities, flexure and shear capacities of reinforced concrete beams after fire exposure. This novel scheme for predicting residual bearing capabilities of fire-exposed reinforced concrete beams is very promising in that is eliminates the extensive testing otherwise required when determining fire ratings for structural assemblies.

Lin et al, 1999 fabricated 35 full-scale RC beams with various dimensions and parameters. All beams were cured under the same conditions in a laboratory. After curing for 28 days, the beams were placed in a gas furnace. The beams were heated according to the ASTM E- 119 standard temperature-rise curve (ASTM E05.11, 1982) through three surfaces; the beam tops were insulated. After natural cooling the beams were loaded using the two-point load method and tested to failure. The calculated values are typically less than experimental values, indicating that modeling results are conservative. The results shown residual of shear strength with duration of fire. The modeling results revealed that the shear reinforcement provided the main shear strength in common states but decreased quickly when yielding strength has influenced by high temperature. The covered concrete could delay the influence of high temperature on shear reinforcement. Increasing the thickness of covered concrete is helpful to protect the damage of fire on shear strength.

Experimental Work

Introduction

The aim of this research work is to study the effect of fire flame exposure on flexural behaviour and shear strength of reinforced high performance concrete beams.

In this chapter, the details of the experimental program of the present work are presented. It includes details of materials used, specimen preparation and tests procedure. Two mixes with design compressive strength of 30 and 78 MPa were used.

Materials

Al_Sharqiya Ordinary Portland Cement (OPC) (ASTM TYPE1) manufactured in Kingdom of Saudi Arabia (KSA) was used throughout this research. The compliance of the cement is examined according to Iraqi specification **(IQS No.5:1984)**. Natural Sand from AL-Najaf sea region was used. Its grading conformed to the Iraqi specification **(IQS, No.45:1984).** Crushed gravel with maximum size of 19_{mm} and 14_{mm} was used as coarse aggregate in normal and high performance concrete. The ideal coarse aggregate used should be clean, generally cubical, or angular, 100% crushed aggregate with a minimum of flat and elongated particles **(ACI Committee 363, 1997)**, it was obtained from AL-Nibaii source. The grading of coarse aggregate for NSC and HPC which conforms to the Iraqi specification **(IQS, No.45:1984).**

Admixtures

For HPC production, the water content of the mix is needed to be reduced and at the same time maintaining suitable workability, which can be achieved by using superplasticizer **(ACI Committee 363, 1997) and (Neville, 1995)** and to compensate for the associated reduction in water content and workability of the concrete mix.

A superplasticizer (SP) of sulphonated melamine and naphthalene formaldehyde condensates, known as (GLENIUM-51) is used in this investigation as high range water reducing superplasticizer.

The description is according to information supplied by manufacturing company. Laboratory test results indicate that the admixture is high range water reducing admixture, conforming to the **(ASTMC494, 1999) Type F** specification. The dosage used in this investigation was 1.15% by weight of cement.

Silica Fume

Silica fume, also known as microsilica, is a byproduct of the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of very fine vitreous particles with a surface area in the order of (20,000 m^2/kg) when measured by nitrogen absorption techniques. Silica fume is used in concrete to improve its properties. It has been found that silica fume improves.

1-Compressive strength of concrete.

2-Bond strength between concrete ingredients and between concrete and steel reinforcement

3-Abrasion resistance.

4-Reduces permeability; and therefore helps in protecting reinforcing steel from corrosion.

Silica fume is available as a densified powder or in a water-slurry form. It is generally used at 5 to 12% by mass of cementitious materials as a partial replacement for concrete structures that need high strength or significantly reduced permeability to water

(National Ready Mixed Concrete Association, 2000)

Concrete Mixture

Two mixes of concrete were investigated in this work, namely 30 and, 78 MPa at age (28) days.

The normal concrete was designed according to British mix design method (**BS 5328 part2**: **1991)** specifications.

The details of the two groups of mix proportion are shown in Table (1).

Table(5) Mix proportion of concrete

Group	Super-Plasticizer%	Cement materials		Water kg/m^3	Fine Agg kg/m^3	Coarse Agg kg/m^3	W/C or W/C$^+$ SF	Target Strength MPa	Slump mm
		Cement kg/m^3	SF kg/m^3						
NSC	-	٣٥٠	-	١٨٩	٨٣٤	١١٨١	٠,٥٤	٣٠	80
HPC	%١,١٥	525	٢٦	165	٦٤٠	١٠٥٠	٠,٣	٧٨	٢٠٠

Testing of Hardened Concrete

Compressive Strength Test

The compressive strength test was performed according to (BS. 1881, part 116, 1989).100 mm cubes were tested using standard testing machine with a capacity of 3000 kN.

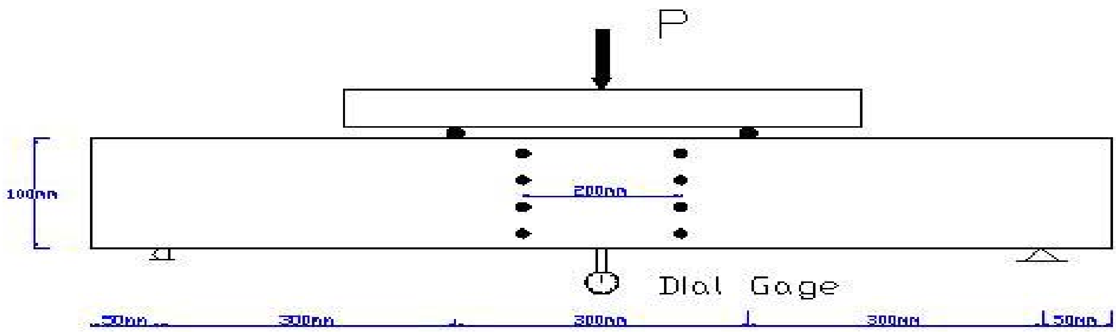
Splitting Tensile Strength Test

The splitting tensile strength was conducted on cylinders of 100mm diameter×200mm height. The average of three test specimens was taken.

The test was carried out in accordance with **(ASTMC496-86 ,1989)**

Flexural Strength Test

Concrete prisms of dimensions (100*100*400)mm were cast according to BS 5328:4:1990 procedure. The prisms were cast, demolded and cured in a similar manner as the compressive strength cubes according to BS 1881 was performed using two point load .

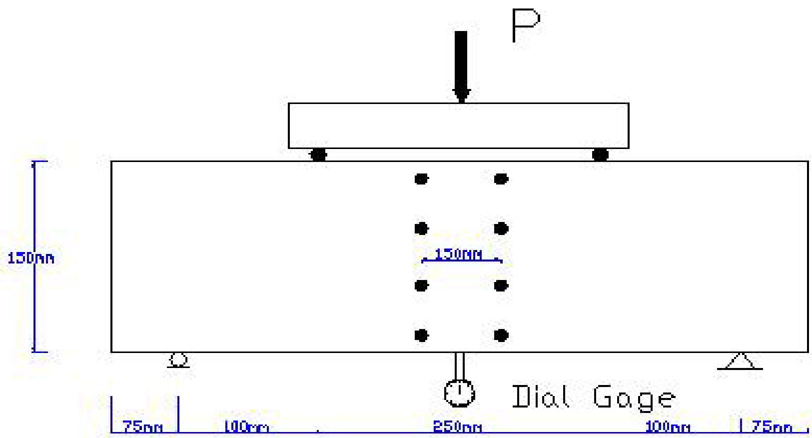


Static Modulus of Elasticity

The static modulus of elasticity was determined according to **(ASTM C-469, 1984)** specifications. A total number of 42 cylinders (150* 300)mm were tested.

Testing Procedure

The beams are tested by using universal testing machines. The load was applied using steel beam that divided the load to two equal point loads. Before loading, initial reading of deflection dial gage and mechanical strain gage were obtained. Deflection was measured at mid span by using one dial gauge as shown in Figures (1), (2). Demec strains gauges were usually distributed along the depth of one side at the middle of the beam at each load increment, observations of crack development on the concrete beams were marked with a heavy felt pen and the mechanically measured demec strains reading were taken. the load was continued until ultimate load (defined as the highest capacity beyond which loading dropped).



Heating and Cooling

The reinforced concrete beams and control specimens were burnt with direct fire flame from a net of methane burners inside a brick stove with dimensions of (2000*1600*800)mm(length*width*height).
When the target temperature was reached, the temperatures were continuously recorded by two digital thermometers, one of them was positioned in flame contact with the bottom, while the other was at the top of the specimen. For the cooling regime , the fire flame was switched off at the end of the exposure time.

The specimens were removed immediately after being extinguished and picked by steel frame. Apart of them allowed to be cool outside the stove for 2 hours.

Usually at the day before the testing day the beam to be tested was cleaned, painted and subdivided into lines acts as support points and strain points to clarify the propagation of cracks and the crack viewing would become easier.

The other specimens were sprinked with water immediately for

Testing Reinforced Concrete

Beam Specimens Preparation

Forty simply supported reinforced concrete beam specimens were cast and cured under laboratory conditions at the construction materials laboratory of the civil engineering department of Babylon University. The reinforcing bars were cut to the desired length, and 90-degree hooks were formed at the ends of each bar. Stirrups made from 6mm diameter plain bars were provided to prevent the shear failure. Eight beams were retained as reference beams for 60 days , thirty-two beams were exposed to fire flame with different periods of exposure and different temperature levels of exposure. The control specimens including cubes, cylinders and prisms were cast from each batch of concrete in addition to the beam specimens as mentioned before.

Beam Specimens Details

The beams were simply supported . the beams were 1000mm length , 100mm height and 100mm width in the case of flexural failure, other beams were 600mm length, 150mm height and 100mm width in the case shear .As shown in Figure (3) and(4).

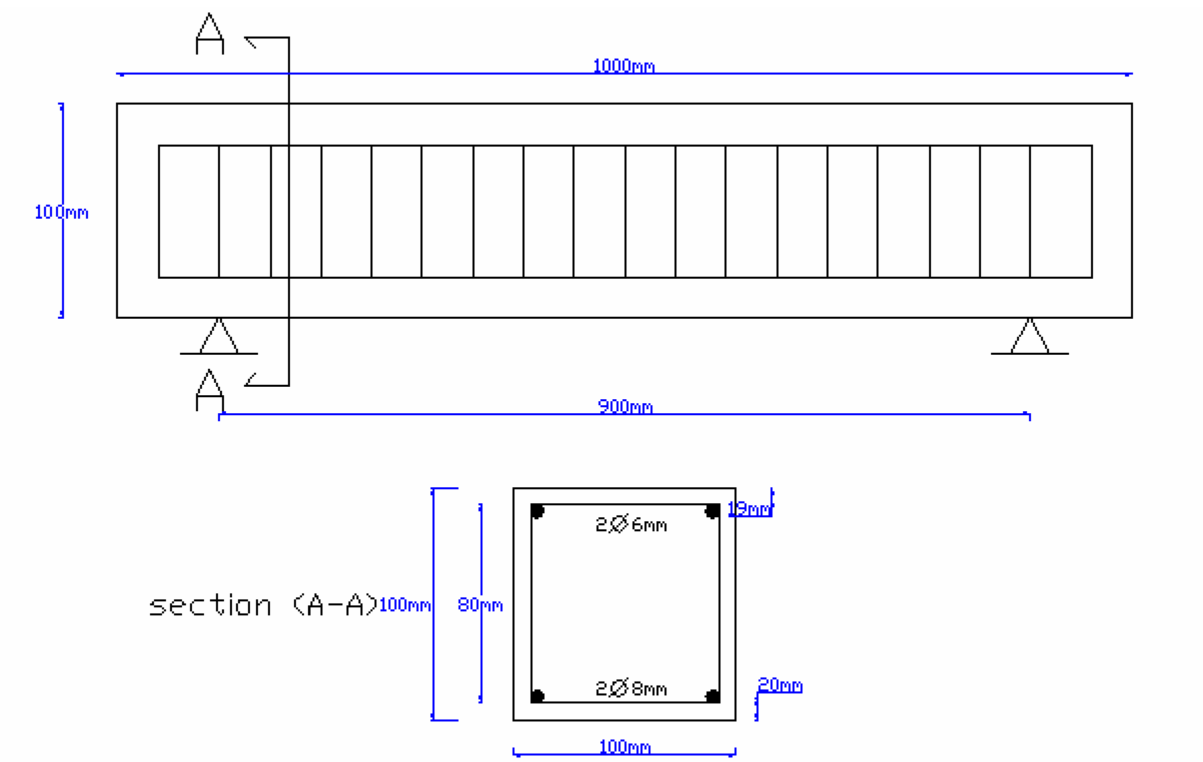


Figure (3) Reinforcement details of normal reinforced concrete beam

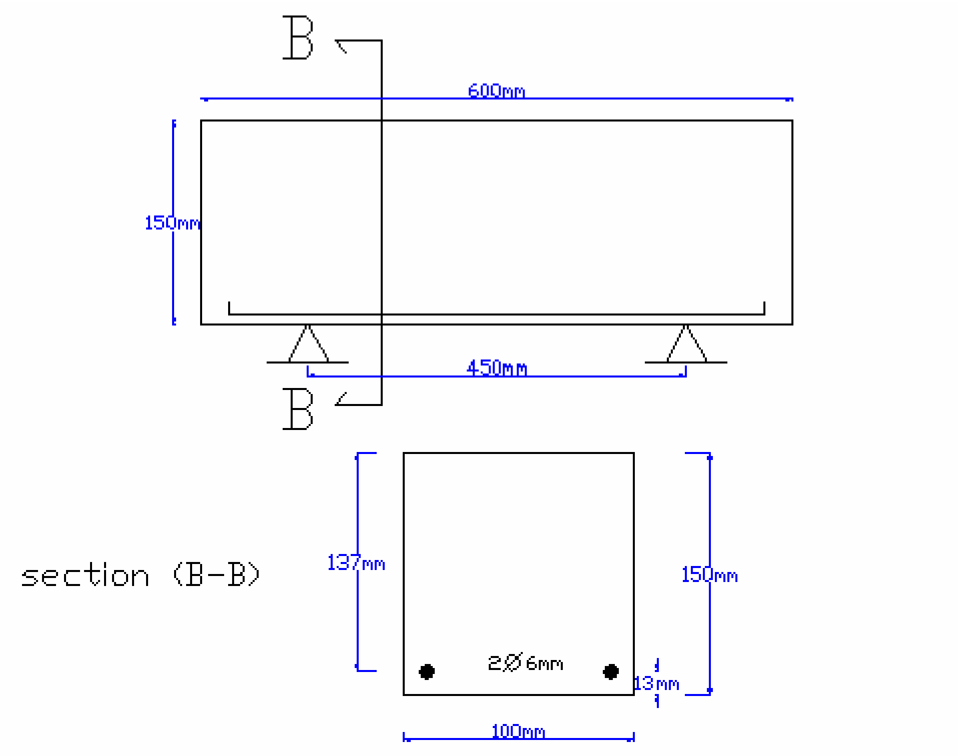


Figure (4) Reinforcement details of deep reinforced concrete

Test Results and Discussion

Effect of High Temperatures on Compressive Strength of Concrete.

In order to obtain a better understanding of the behavior of reinforced concrete beams in flexure and shear after exposure to fire flame, it is important to study the properties of concrete subjected to fire flame firstly.

In the current study, three cubes of concrete with dimensions of (100mm) for HPC and NSC were fired at each level of heating for each type of concrete to obtain the compressive strength of concrete after heating and to detect the effect of fire flame on the compressive strength of NSC and HPC. Table (6) shows the test results for NSC and HPC, while Figures (5) to (8) show the relationship between compressive strength and fire temperature for NSC and HPC. It is obvious from the results that the compressive strength decreases with exposure to high temperatures.

Table (6) Measured values of cube compressive strength before and after fire flame exposure

Type of concrete	Age at exposure (days)	Period of exposure (hour)	Cube Compressive strength (MPa) Temperature °C ٢٥ (١)	٤٠٠ (٢)	٧٠٠ (٣)	fcua/fcub* Ratio ٢/١	٣/١	Type of cooling
NSC	٦٠	١	٤٢	٣٥,٥	٢٧	٠,٨٤	٠,٦٥	Air
				٣٣,٥	١٩	٠,٨٢	٠,٤٦	Water
		١,٥		٣٥	٢٢	٠,٨٣	٠,٥٤	Air
				٣١,٥	12	0.77	0.29	Water
HPC	٦٠	١	٨٩	٦٥	٤٥	٠,٧٣	٠,٥٠	Air
				٥٢,٥	٣٨	٠,٥٩	٠,٤٣	Water
		١,٥		٥٢	٤٢,٥	٠,٥٨	٠,٤٨	Air
				٤٥,٥	٣٥,٥	٠,٥١	٠,٤٠	Water

* **fcua**: cube compressive strength after burning

fcub: cube compressive strength before burning

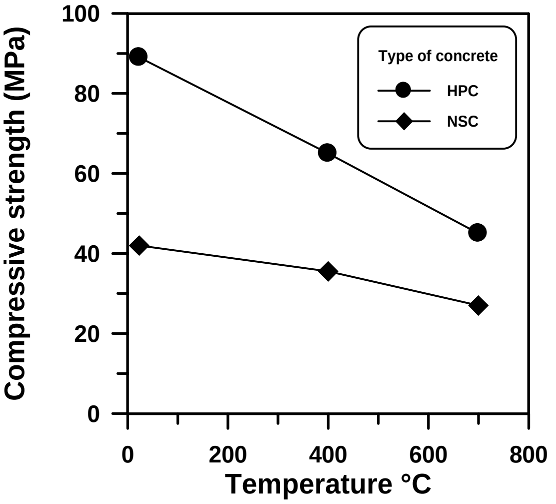


Fig (5): Relationship between compressive strength and fire temperature for (1) hour period of exposure and air cooling.

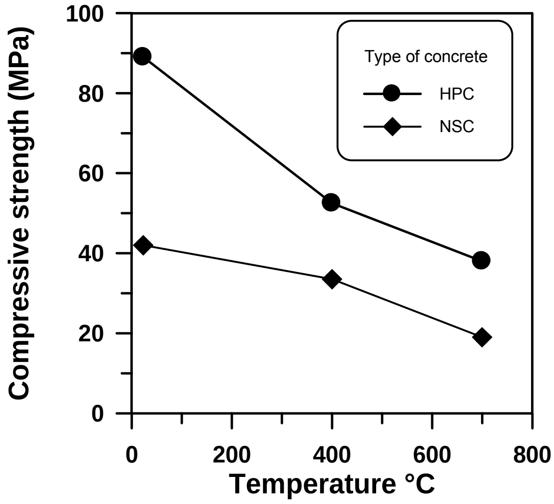


Fig (6): Relationship between compressive strength and fire temperature for (1) hour period of exposure and water cooling.

Flexural Analysis of NSC and HPC Beam Specimens.

The ultimate design flexural loads of the test specimens were calculated according to **(ACI-318/2005)** code. The beams were loaded as simply supported beams with symmetrical two point loads. The design of beams considers that the beam will fail in flexure (yielding of steel reinforcement) before shear failure, therefore vertical stirrups were included.

Ultimate moment capacity-Mu-can be found according to the following ACI-318/2005 code formula .

$$Mn = Asfyd \ (1 - 0.59\,\rho \frac{fy}{fc}). \quad \textbf{\textit{(1)}}$$

where $f_c = 0.85 f_{cu}$ ***for NSC***

$f_c = 0.9 f_{cu}$ for HPC

Analysis of Deep Beam Specimens

These beams were designed to reveal shear failure, this failure happens in deep beams, which have a shear span to depth ratio (a/d) less that 2 (**ACI 318M- 2005**). In the current research shear span to depth ratio (a/d) was (0.73), the span length is (600mm), the type of loading used in the test is two point symmetrical load. The failure line is outside middle third span just to present actual shear failure. Inclined cracks occur after applying the load near the reaction support at an angle of approximately 45°.

Shear Analysis for NSC and HPC Deep Beam Specimens

The ultimate design shear capacity for deep beam test specimens is calculated according to **(ACI-318/2005)** code. The design of beams considers that the beams will fail in shear before flexure failure by yielding of steel reinforcement, therefore the specimens were cast without web reinforcement.

Design of cross-sections subjected to shear failure shall be based on:

$$ØV_n \geq V_u \quad (2)$$

Where Ø strength reduction factor equal to 0.85

Where Vu is factored shear force at the section considered and Vn is nominal shear strength computed by :

$$V_n = V_c + V_s \quad (3)$$

Where V_c is nominal shear strength provided by concrete.

Shear strength Vc shall be computed by:

$$Vc = 0.17\sqrt{fc^{-}}\,bwd \quad (4)$$

Residual Load Bearing Capabilities of Fire-Exposed Reinforced Concrete Beams:

Flexural Capacity of RC Beams Exposed Fire.

The beam specimens reinforced with steel ratio of (0.0126) are designed to fail in flexure (yielding of steel reinforcement) for the two types of concrete (NSC and HPC).

From the test results shown in Table (6) and (7), it is clear that the values of bending moment capacity decrease when the beams were exposed to fire flame for the two fire temperatures 400 °**C** and 700 °**C** .

For NSC specimens at burning temperature (400 °**C**), the residual bending moment capacity was (86-91%), (84-88%), as for HPC specimens the residual bending moment capacity was (84-88%), (70-72%) for 1.0 and 1.5 hour exposure periods respectively.

For NSC specimens at burning temperature (700 °**C**), the residual bending moment capacity was (53-60%), (26-41%), as for HPC specimens the residual bending moment capacity was (50-58%), (37-38%) for 1.0 and 1.5 hour exposure periods respectively.

From these results, it is clear that the bending moment capacity for HPC is more sensitive to fire flame temperature than NSC. This is attributed to the higher density and lesser voids, most of the water is adsorbed causing a higher loss in bending moment for HPC as follow. This finding must be taken into account when HPC structure is exposed to fire.

Shear Capacity of RC Beams Exposed to Fire.

The beam specimens reinforced with steel ratio of (0.004) are designed to fail in shear for the two types of concrete (NSC and HPC).

The shear capacity test results are given in Tables (8) and (9).

At burning temperature (400 °**C**), for NSC specimens the residual shear capacity was (78-93%), (75-77%) for 1.0 and 1.5 hour periods respectively.

For HPC beam specimens the residual shear capacity was (90-98%), (89-92%) for 1.0 and 1.5 hour exposure periods respectively.

It can be indicated that HPC shear strength has an obvious resistance to high fire temperatures more than of NSC.

At burning temperature (700 °**C**), for NSC specimens the residual shear capacity was (54-57%), (38-46%) for 1.0 and 1.5 hour exposure periods respectively. For HPC specimens the residual shear capacity was (50-55%), (40-45%) for 1.0 and 1.5 hour exposure periods respectively.

From the test results it can be indicated that the residual shear capacity for HPC and NSC beam specimens become closer at fire temperature 700 °**C.**

Verification of ACI Building Code Provisions.

The test results were used to verify the recommendations and design simplifications of the ACI Building Code Pertaining to flexural strength design and shear strength design, specifically, comments are made on accuracy of strength Predictions.

These results were summarized in Tables (7) to (10).

Table (7): Comparison of the flexural test results with that obtained from ACI 318 code fo NSC flexure beam specimens

Specimen Identi-fication	Compressive Strength of cube (MPa)	Steel Yield Stress (MPa)	Ultimate Load (kN)	Mu(test) (kN.m)	Percentage Residual Moment (%)	Mu(ACI) (kN.m)	~~Mu (test)~~ Mu (ACI)
NFB	42	540	29.100	4.37	100	3.86	١,١٣
NF4-1A	35.5	540	26.5	3.98	91	3.78	١,٠٥
NF4-1W	33.5	540	25.8	3.78	86	٣,٧٤	١,٠١
Nf4-1.5A	35	540	25.6	3.84	88	٣,٧٦	١,٠٢
NF4-1.5W	31.5	540	24.5	3.675	84	٣,٧	٠,٩٩
NF7-1A	27	432	17.6	2.64	60	٢,٩٩	٠,٨٨
NF7-1W	19	432	15.4	2.31	53	٢,٧٩	٠,٨٣
NF7-1.5A	22	432	12.2	1.8	41	٢,٨٨	٠,٦٣
NF7-1.5W	12	432	7.6	1.14	26	٢,٣٨	٠,٤٨

Table (8): Comparison of the flexural test results with that obtained from ACI 318 code for HPC flexure beam specimens.

Specimen Identi-fication	Compressive Strength of cube (MPa)	Steel Yield Stress (MPa)	Ultimate Load (kN)	Mu(test) (kN.m)	Percentage Residual Moment (%)	Mu(ACI) (kN.m)	~~Mu (test)~~ Mu (ACI)
HPFB	89	540	38.100	5.72	100	4.14	١,٣٨
HPF4-1A	65	540	33.50	5.03	88	4.06	١,٢٤
HPF4-1W	52.5	540	32.20	4.83	84	٣,٩٨	١,٢١
HPF4-1.5A	52.5	540	27.50	4.13	72	٣,٩٧	١,٠٤
HPF4-1.5W	45.5	540	26.80	4.02	70	٣,٩٣	١,٠٢
HPF7-1A	45	432	22.20	3.33	58	٣,٢١	١,٠٤
HPF7-1W	38	432	19.00	2.85	50	٣,١٦	٠,٩

HPF7-1.5A	42.5	432	14.600	2.19	38	٣,١٩	٠,٦٧
HPF71.5W	35.5	432	14.300	2.15	37.5	٣,١٣	٠,٦٧

Table (9): Comparison of the shear test results with that obtained from ACI 318 code for NSC deep beam specimens

Specimen Identification	Compressive Strength of cube (MPa)	Compressive Strength of cylinder (MPa)	υ_u (test) (MPa)	Percentage Residual shear strength	υ_u (ACI) (MPa)	$\frac{\upsilon_c \text{ (test)}}{\upsilon_c \text{ (ACI)}}$
NSB	42	٣٥,٧	1.18	100	١,٠٢	١,١٧
NS4-1A	٣٥,٥	٣٠,١٨	١,١٠	٩٣	٠,٩٣	١,١٨
NS4-1W	٣٣,٥	٢٨,٤٨	٠,٩٢	٧٨	٠,٩١	١,٠١
NS4-1.5A	٣٥	٢٩,٧٥	٠,٨٩	٧٥	٠,٩٣	٠,٩٦
NS4-1.5W	٣١,٥	٢٦,٧٨	٠,٩٢	٧٧	٠,٨٨	١,٠٤
NS7-1A	٢٧	٢٢,٩٥	٠,٦٨	٥٧	٠,٨١	٠,٨٣
NS7-1W	١٩	١٦,١٥	٠,٦٤	٥٤	٠,٦٨	٠,٩٣
NS7-1.5A	٢٢	١٨,٧	٠,٥٥	٤٦	٠,٧٤	٠,٧٥
NS7-1.5W	١٢	١٠,٢	٠,٤٥	٣٨	٠,٥٤	٠,٨٣

Table (10): Comparison of the shear test results with that obtained from ACI 318 code for HPC deep beam specimens

Specimen Identification	Compressive Strength of cube (MPa)	Compressive Strength of cylinder (MPa)	υ_u (test) (MPa)	Percentage Residual Shear strength	υ_u (ACI) (MPa)	$\frac{\upsilon_c \text{ (test)}}{\upsilon_c \text{ (ACI)}}$
HPSB	٨٩	٨٠,١	2.28	100	١,٥٢	١,٤٩
HPS4-1A	٦٥	٥٨,٥	٢,٢٣	٩٨	١,٣	١,٧٢
HPS4-1W	٥٢,٥	٤٧,٢٥	٢,٠٥	٩٠	١,١٧	١,٧٥

HPS4-1.5A	٥٢	٤٦	٢,٠٩	٩٢	١,١٥	١,٨١
HPS4-1.5W	٤٥,٥	٤٠,٩٥	٢,٠٣	٨٩	١,٠٩	١,٥٥
HPS7-1A	٤٥	٤٠,٥	١,٢٦	٥٥	١,٠٨	١,١٦
HPS7-1W	٣٨	٣٤,٢	١,١٥	٥٠	٠,٩٩	١,١٥٦
HPS7-1.5A	٤٢,٥	٣٨,٢٥	١,٠٣	٤٥	١,٠٥	.٠,٩٨
HPS7-1.5W	٣٥,٥	٣١,٩٥	٠,٩٢	٤٠	٠,٩٦	٠,٩٦

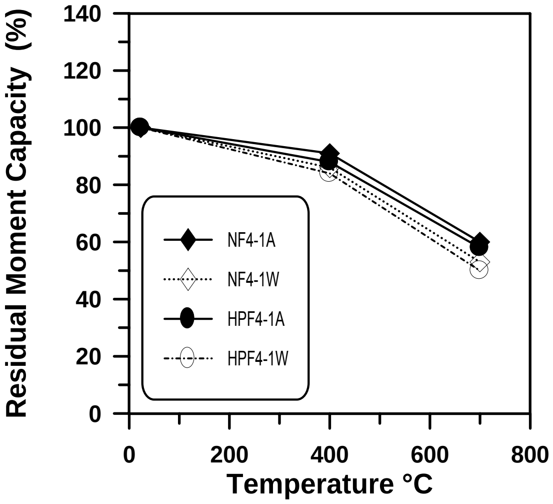


Figure (9): Effect of fire temperature on the residual moment capacity of flexure beam specimens for (1) hour period of exposure.

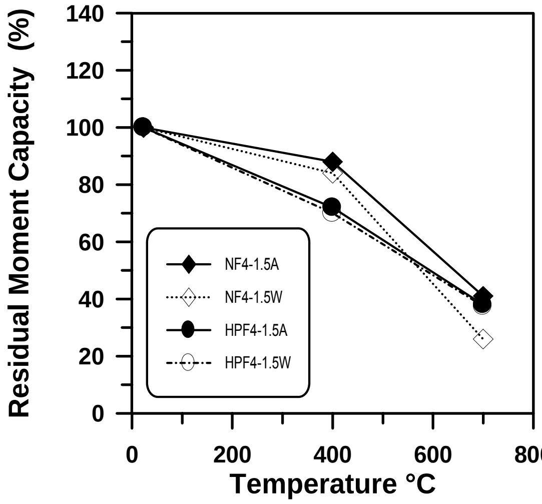


Figure (10): Effect of fire temperature on the residual moment capacity of flexure beam specimens for (1.5) hour period of exposure.

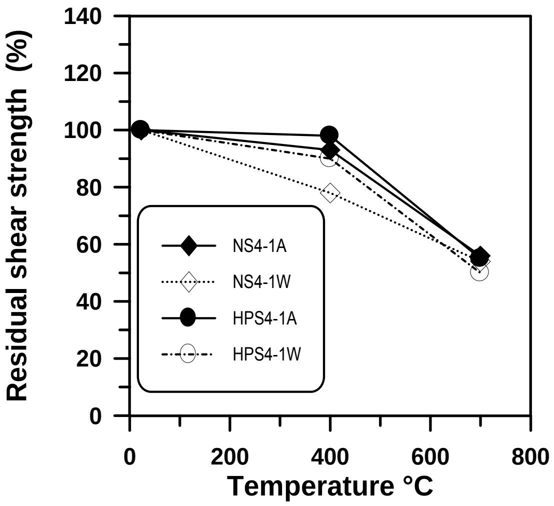


Figure (11): Effect of fire temperature on the residual shear strength of deep beam specimens for (1) hour period of exposure

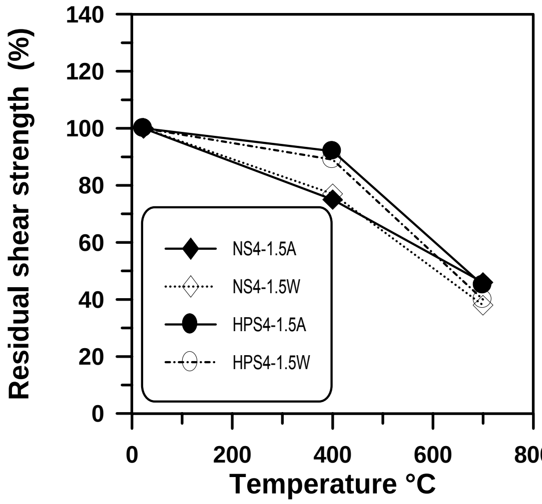


Figure (12): Effect of fire temperature on the residual shear strength of deep beam specimens for (1.5) hour period of exposure

Conclusions

Based on the test results of the present study, the following conclusions can be drawn.

1- The compressive strength of concrete decreases with fire flame

temperature by an amount depending on the exposure temperature.

- The percentage residual in compressive strength for HPC after exposure to (400ºC and 700ºC) is about (51-73%) and (40-50%) respectively.
- The percentage residual in compressive strength for NSC after exposure to (400ºC and 700ºC) is about (77-84%) and (29-65%) respectively.

2- The bending moment capacity in HPC is more sensitive to fire flame exposure than NSC.

- After exposure to fire temperature (400 °**C**), for HPC the residual bending moment capacity is (84-88%), (70-72%), as for NSC (86-91%), (84-88%) for (1.0) and (1.5) hour exposure periods respectively.
- After exposure to fire temperature (700 °**C**), for HPC the residual bending moment capacity is (50-58%), (37-38%), as for NSC (53-60%), (26-41%) for (1.0) and (1.5) hour exposure periods respectively.

3- The shear strength capacity in HPC is lesser negatively affected by fire flame temperature than NSC as follow.

- After exposure to fire temperature (400 °**C**), for HPC the residual shear strength capacity is (90-98%), (78-93%), as for NSC (78-93%), (75-77%) for (1.0) and (1.5) hour exposure periods respectively.
- After exposure to fire temperature (700 °**C**), for HPC the residual shear strength capacity is (50-55%), (40-45%), as for NSC (54-57%), (38-46%) for (1.0) and (1.5) hour exposure periods respectively.

4- Based on the available experimental results in this research work concerning the bending moment capacity and shear strength capacity for shallow and deep beams it can be concluded that:

- After exposure to fire temperature (400 °**C**), for HPC and NSC, the ACI 318/ 2005-code can be safely used to predict the residual bending moment capacity and shear strength capacity from the residual compressive strength after exposure to fire flame.
- After exposure to fire temperature (700 °**C**), for HPC and NSC, the ACI-Code become unable to predict bending moment capacity and shear strength capacity.

5- The ratio between the measured and ACI-predicted values for flexural strength were in the range (0.99-1.05), (1.02-1.21) for NSC and HPC respectively at temperature (400 °**C),** while the values were (0.48-0.88), (0.67-1.04) at temperature (700 °**C).**

6- The ratio between the measured and ACI-predicted values for shear strength were in the range (0.96-1.18), (1.55-1.81) for NSC and HPC respectively at temperature (400 °**C),** while the values were (0.75-0.93), (0.96-1.16) at temperature (700 °**C).**

7- For comparison purposes, the values of shear strength compare with three codes (ACI, Canadian, New Zealand), Zsutty and Rebeiz research, based on RSSV (Relative Shear Strength Value) when the beam specimens are exposed to fire flame as follows.

- At burning temperature (400 °**C**), for HPC beams, the RSSV is greater than (1) for all equations, while for NSC beams the RSSV is less than (1) which were (0.96-1.18), (0.82-1), (0.74-0.91), (0.82-1.01) for (ACI, Canadian, Zsutty, Rebeiz) respectively.
- At burning temperature (700 °**C**), for HPC beams, the RSSV were (0.96-1.16), (0.82-0.99), (0.71-0.94), (0.83-1.05), while for NSC beams were (0.75-0.93), (0.64-0.79), (0.54-0.65), (0.56-0.71) for (ACI, Canadian, Zsutty, Rebeiz) respectively.

8- The New Zealand Code predicts shear strength after exposure to (400°**C** and 700°**C**) fire flame temperature conservatively for HPC and NSC.

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