Behavior of High Strength Concrete Containing Nano-Metakaolin Exposure to Fire Flame

Mohammed K. Al-Khafaji
Building and Construction Engineering Department, University of Technology/ Baghdad
Email:Mohammed_k1965@yahoo.com
Dr. Waleed A. Abbas
Building and Construction Engineering Department, University of Technology/ Baghdad
Email:waleedalqaisi@yahoo.com
Dr. Shakir Al-Mishhadani
Building and Construction Engineering Department, University of Technology/ Baghdad

Received on:18/8/2015 & Accepted on:12/11/2015

ABSTRACT

The aim of this experimental study was to evaluate the effect of fire flame exposure with different intensities of firing on the mechanical properties of a high strength concrete (HSC). Many variables were encountered in this study. Two mixes of 80 MPa target compressive strength (1:1.22:2) with 3% Nano-Metakaolin and the other with 5% were used. Two types of coarse aggregate were used (natural crushed gravel and crushed dolomite rock with maximum size of 14mm). The specimens were moist cured for 28 days, air-dried in the laboratory to firing at ages 90 days at three temperature levels (400, 600, 800)^{o}C and for three exposure periods (1, 1.5 and 2 hours). Different methods were used to cool specimens. The reduction values of compressive strength for all mixes ranged between (2-69.5)% at 400^{o}C, (8-72)% at 600^{o}C and (10-85)% at 800^{o}C , the reduction values of splitting tensile strength were (9-43.2)%, (17-50)% and (39-76)%, and the reduction values of flexural strength were (51.7-84.8)%, (52.8-87) %, (53.6-87.8)%, respectively.

Keywords: Fire flame, exposure temperature, Nano-Metakaolin, compressive strength, splitting tensile strength, flexural strength.

INTRODUCTION

The ability of concrete to withstand the damaging effects of the environment and of its service condition without deterioration for a long period of time is referred to as its "durability". Clearly the durability of concrete is of prime importance in engineering applications. (Phan and Carino, 1998). Fire is the remainder one of the serious potential risks to most buildings and structures. Since concrete is extensively used in construction, concrete structure behavior in fire conditions is governed by the properties of the constituent materials, concrete and steel at high temperatures. Both concrete and steel endure considerable change in physical properties; strength and stuffiness by the influence of heating, and some of these changes are not recoverable after subsequent cooling. (Ilker and Cenk, 2008).Thermal damage level depends on the spatial, the size of the structural member and temporal fire conditions such as maximum temperature, exposure time, heating rate and cooling type. (Lee et al., 2008). Concrete is well known for its capability to endure high temperatures owing to its high specific heat and low thermal conductivity. However, it does not mean that high temperature or fire, do not influence concrete at all. High temperature may cause changes of color along with significantly affecting the compressive strength of concrete, concrete density, modulus of elasticity and its appearance. Physical deterioration processes is one of the most important effects on the concrete durability structures by high temperatures. **(Morsye et al., 2012)**.**Neville,**

https://doi.org/10.30684/etj.34.5A.5
2412-0758/University of Technology-Iraq, Baghdad, Iraq

(2010) indicates that higher strength of concrete in fires tends to show greater strength loss earlier than other concrete.

Material and Experimental Work

Two mixes with 80 MPa target compressive strength (1:1.22:2) with 3% Nano-Metakaolin and the other with 5% were used. Experimental variables were: compressive strength, splitting tensile strength, and flexural strength, before and after exposure to fire flame. In the current research, the exposure time is 1, 1.5 and 2 hours to obtain temperature levels of 400ºC, 600ºC and 800ºC respectively. The cooling technology of concrete samples is very effective on the mechanical properties of tested samples. Three cooling methods have been followed for cooling before any mechanical and physical testing. They are cooled by, water jet, powder spray, air for (15-20) Hours, and other samples were tested while hot.

Materials :

Cement:

Ordinary Portland cement (O.P.C) (Type 1) manufactured by United Cement Company commercially known (Tasluja) was used. The chemical composition and physical properties of this (OPC) are given in Tables (1) and (2) respectively.

Fine Aggregate:

Natural fine aggregate from Al-Akhaidur region was used. The results of grading, physical and chemical properties of the fine aggregate are listed in Tables (3) and (4) respectively.

Coarse Aggregate:

Crushed gravel from Al-Nebai and crushed dolomite rock from Injanah formation between Mosul and Irbil from Qamchuqa with maximum size of 14mm.The coarse aggregate used in this research is complying with **(IQS No.45/1984)**. The grading, physical and chemical properties of coarse aggregate are illustrated in table (5), (6), (7), (8) respectively.

Nano-Metakaolin

The nano-metakaolin used in this investigation supplied by Middle East Mining Investments Company (MEMCO), has approximately Blaine surface area of 48 m^2/g (480000 cm^2/gm) and average dimension (200×100×20nm). Tables (9) and (10) show the oxide composition and grading of (NMK) respectively.

Polypropylene Fibers:

The polypropylene fiber was provided from market. The properties of polypropylene fibers are shown in Table (11).

Concrete Mix Design

Mixes were designed according to ACI Committee 211.4R,2008. Details of the two groups of mixes proportion are summarized in Table (12).

Table (1) Chemical analysis of the cement

Oxide	Percentage by weight	Limits of IQs No.5/1984
Calcium oxide CaO	61.57	
Silicon dioxide SiO_2	21.32	
Aluminum oxide Al_2O_3	5.60	
Ferrite oxide Fe_2O_3	4.11	
Free CaO	0.06	
Magnesium oxide MgO	2.31	≤ 5
Sulphur Trioxide (SO_3)	2.20	≤ 2.8 *if* $C_3A > 5\%$
Loss On Ignition (L.O.I)	1.57	≤ 4
Lime saturation factor (L.S.F)	0.87	0.66-1.02
Insoluble Residue (I.R)	0.64	≤ 1.5
Tricalcium silicate C_3S	38.53	
Dicalcium silicate C_2S	32.13	
Tricalcium aluminates C_3A	7.89	
Teracalcium alumina Ferrite C_4AF	12.49	

* The test is carried out at Technical Institute of Babylon.

Table (2) Physical properties of cement

Physical Properties	Test result	Limits of IQS No.5/1984
Fineness: specific surface, Balaine method (cm^2/gm)	3150	≥ 2300 cm^2/gm
Setting time Initial, min Final, hrs	 92 4.30	 ≥ 45 min ≤ 10 hrs
Compressive strength (MPa) 3 days 7 days	 21.3 27.5	 ≥ 15 Mpa ≥ 23 Mpa

* The test is carried out at Technical Institute of Babylon.

Table (3) Grading of fine aggregate

Sieve size (mm)	Passing %	Limits of IQS No.45/1984 (zone2)
10	100	100
4.75	98.3	90-100
2.36	80.2	75-100
1.18	64.0	55-90
0.60	42.6	35-59
0.30	20.3	8-30
0.15	3.0	0-10
F.M	2.92	

* The test is carried out at Technical Institute of Babylon.

Table (4) Physical and chemical properties of fine aggregate

Properties	Test results	Limits of IQS No.45/1984
Specific gravity	2.63	
Absorption %	1.2	
Fine materials (passing sieve No. 200)%	0.73	≤ 3.0
SO_3 content %	0.17	≤ 0.5

* The test is carried out at Technical Institute of Babylon.

Table (5) Grading of natural coarse aggregate

Sieve size (mm)	Passing %	Limits of IQS No.45/1984 (5-20)mm
20	100	100
14	100	90-100
10	62.7	50-85
5	4	0-10

* The test is carried out at Technical Institute of Babylon.

Table (6) Physical and chemical properties of natural coarse aggregate

Properties	Test results	Limits of IQS No.45/1984
Specific gravity	2.64	
SO_3 content %	0.02	≤ 0.1 %
Absorption %	0.43	

* The test is carried out at Technical Institute of Babylon.

Table (7) Grading of crushed dolomite rock

Sieve size (mm)	Passing %	Limits of IQS No.45/1984 (5-20)mm
20	100	100
14	100	90-100
10	65.2	50-85
5	6	0-10

* The test is carried out at Technical Institute of Babylon.

Table (8) Physical and chemical analysis crushed dolomite rock

Properties	Test results	Limits of IQS No.45/1984
Specific gravity	2.85	
Absorption %	0.26	
Color	Typical yellow	
Fine materials (passing sieve No. 200)%	0.17	≤ 1 %
CaO%	33.61	
Al_2O_3%	0.071	
F_2O_3%	0.035	
MgO%	12.83	
L.O.I%	48.16	
I.R%	0.10	
Total	94.806	

* The test is carried out at Geological Survey and Mining.

Table (9) chemical composition of NMC

Oxide	%
CaO	0.21
SiO_2	60.37
Al_2O_3	21.62
Fe_2O_3	6.51
MgO	0.28
SO_3	0.17
$K_2O + Na_2O$	2.34
TiO_2	0.82
P_2O_5	0.15

* Chemical test are made by Middle East Mining Investment Company (MEMCO)

Table (10) Grading of NMC

Sieve size (mm)	Passing %
<10mm	100
<4mm	93
<2mm	88

* Grading test are made by Middle East Mining Investment Company (MEMCO)

Table (11) typical properties of polypropylene

Property	Values
Water absorption for 24 Hrs.	< 0.01%
Melting point	164°C
Thermal conductivity ($x10^{-4}$cal/cm-sec-°C)	2.6 – 2.8
Color	White
Specific gravity	0.91 g/cm^3
Fiber length	6 mm
Fiber diameter	18 micron

* According to Manufactures.

Table (12) mix properties of concrete

Mix notation	SP%	Cement materials		Water kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	w/c ratio	Target strength MPa	Mix Proportion	Slump mm
		Cement kg/m^3	NMC kg/m^3							
C80.3	1.4	525	3%(15.75)	165	640	1050	0.30	80	1:1.22:2	100±10
C80.5	1.5	525	5%(26.25)	165	640	1050	0.30	80	1:1.22:2	100±10

Results and Discussion

This section includes the results and discussion of the hardened properties of HSC specimens before and after exposure to fire flame at 400, 600 and 800°C, which include the values of compressive, flexural and splitting tensile strength.

Compressive Strength:

Compressive strength was prepared according to BS1881: part 108: 1983 and tested according to BS 1881: part 116: 1989. Standard cubs of (100)mm and (150)mm were used in this work. The variation in the residual compressive strength values for different mixes before and after exposed to fire flame temperature (400, 600 and 800)°C of cubes and cylinders specimens with different cooling are summarized in Table (13).From table (13) and Figs. (1 to 6) it can be noticed that:

1- The residual compressive strength of all concrete gravel and dolomite specimens cooled by (extinguisher powder, hot tested, air and water) for (1, 1.5 and 2) hours durations were [(59.7-94.2), (52.6-95)]%, [(54.2-91.2), (49-92)]%, [(46.6-87), (44.7-88.3)]% and [(32.2-81), (26-80.8)]% respectively.

2- The reduction of concrete specimens after exposed to fire flame for 2 hours was higher than that of (1, 1.5) hours by (25, 14)% respectively at all fire flame temperatures, the cause of that can be attributed to the higher rate of heating and intensity of firing, which formed relatively week hydration products.

3- The reduction values of dolomite specimens was less than that of gravel concrete specimens at (400 to 600)°C, but these behaviors reflected at (600 to 800)°C. The reason for this behavior can be respected to fire flame in excess (660)°C, calcium and magnesium carbonate begin to break down to Cao, Mgo and CO2. This result in compatible with the study carried out by ***(John and Ban, 2003.)***

4- The percentage residual in compressive strength of G5NMC80 mixes after exposure to fire flame at all temperatures (400, 600 and 800)°C and for all periods of burning (1, 1.5, 2) hours duration, is higher than those of other concrete mixes. The results stated that the nano-metakaolin improved the compressive strength under fire flame temperatures, because they are more dense and there is a decrease in the amount and extent of micro cracking in the transition zone.

5- The decrease in compressive strength of concrete is attributed to the break-down of interfacial bond due to incompatible volume change between cement paste and aggregate during heating and cooling and dehydration of the calcium-silica hydrate in cement paste. This behavior was also confirmed by other ***(Moreley and Royels, 1983; Hinrichsmeyer, 1987; Umran, 2002; Awad, 2008)***

Splitting Tensile Strength:

Splitting tensile strength was determined according to the procedure of **(ASTM C496-2004)**, by two cylinders with dimensions of (100×200)mm. The residual values of splitting tensile strength of all concrete specimens before and after exposure to fire flame are abstracted in Table (14) and Fig. (7 to 12).

1- The residual splitting tensile strength of all gravel and dolomite concrete specimens cooled by (extinguish powder, hot tested, air and water) for (1, 1.5 and 2) hours duration were in order of [(58-91), (56.8-91.4)]%, [(10.9-32), (10.6-31.8)]%, [(65.7-87), (65.9-87.7)]%, and [(58-82), (65-8-82.1)]% at (400)^{o}C fire flame temperature exposure respectively.

2- At 600^{o}C there will be a further decrease in splitting tensile strength for all gravel concrete mixes. The residual strength ranged between (66.2-83)%, (61.6-81)%, (58.7-79.2)% and (50-70)% for gravel concrete specimens cooled by extinguish powder, hot, air and water for 1, 1.50 and 2 hours duration respectively. While, the percentage of residual strength for all dolomite concrete specimens ranged between (65.1-83.5)%, (63.2-81.4), (59-79.9)% and (50-70)% after cooled by extinguish powder, hot, air and water respectively for 1, 1.50 and 2 hours duration respectively.

3- Fire flame caused an extra reduction at 800oC of splitting tensile strength. The percentage of retaining strength were (47-61)%, (44-59.2)%, (42-57)% and (32.5-50)% for gravel concrete specimens cooled by extinguish powder, hot, air and water for 1, 1.50 and 2 hours duration respectively while, the residual strength for all dolomite concrete specimens ranged between (43.1-59)%, (41-56.6)%, (37.6-52.2)% and (24-42.5)% cooled by extinguish powder, hot, air and water respectively for 1, 1.50 and 2 hours duration.

4- The reduction in the splitting tensile strength can be attributed to the contraction of the hardened cement paste upon cooling, which caused an increase in the amount and rate of crack formation.

5- This trend is similar to that obtained by **Habbeb, (2000); Umran, (2002); Obeed, (2007); Al-Jubory, (2010).**

Flexural Strength:

Flexural strength test (modulus of rupture) (MOR) was conducted according to (ASTM C-78-2002) by using concrete prisms of dimensions (100×100×500)mm. Modulus of rupture was conducted by using (100×100×500)mm prisms, each test was calculated by two prisms. It can be noticed from table (15) and Figs. (13 to 18) the effect of fire flame of different temperature and duration exposure on the values of modulus of rupture at 90 days age.

1- At (400, 600, 800)^{o}C of fire flame exposure and for all mixes of gravel concrete specimens, the percentage of the residual flexural strength were (15.2-59.3)%, (13-57.2)%, (12.2-56.4)% and (5.2-50)%, cooled by extinguisher powder, air, water and hot tested respectively. While the retaining flexural strength of dolomite concrete specimens were (12-62.2)%, (7.8-58.7)%, (2.9-51.2)% and (10-60)% cooled by extinguisher powder, hot tested, air and water respectively.

2- Sharply reduced flexural strength for all concrete mixes after exposed to fire flame higher that (600)^{o}C was seen.

3- The residual flexural strength of (G5NMC80) and (D5NMC80) concrete mixes is higher than that of other concrete mixes. Because it drastically transforms the microstructural characteristics of the transition zone between cement paste and aggregates. These transition zones are more compact than the relatively porous one usually obtained when containing non-materials (nano-metakaolin).

Table (13) Compressive Strength (MPa) of Concrete Specimens Before and After Exposure to Fire Flame Temperature With different Cooling At 90 Days Age

Mix Designation	Exposure period (Hours)	Cooling types	Compressive strength (MPa)						
			Temperature (°C)						
			25°C	400°C	Reduction %	600°C	Reduction %	800°C	Reduction %
G3NMC80	1	Powder	94	87.3	7.0	80.2	14.6	76.0	19.0
		Hot		84.0	10.6	77.3	17.7	73.4	22.0
		Air		77.5	1.8	72.8	22.5	66.0	29.7
		Water		64.3	31.6	59.0	37.2	55.0	14.5
	1. 5	Powder		81.0	13.8	70.5	25.0	70.0	25.5
		Hot		77.4	17.6	67.0	28.7	58.0	27.6
		Air		68.0	27.6	62.4	33.6	57.0	39.3
		Water		54.0	42.5	50.0	46.8	42.0	55.3
	2	Powder		68.4	27.2	60.2	36.0	60.0	36.0
		Hot		64.7	31.0	57.0	39.3	54.5	42.0
		Air		58.0	38.3	53.7	42.8	47.0	50.0
		Water		44.0	53.2	37.5	60.0	31.0	67.0
GF3NMC80	1	Powder	85	78.0	8.0	73.0	14.0	69.5	18.2
		Hot		75.0	11.7	70.0	17.6	66.4	21.8
		Air		69.6	18.0	65.7	22.7	57.0	33.0
		Water		54.8	35.5	51.0	31.7	46.0	45.8
	1. 5	Powder		73.0	14.0	61.3	36.2	61.0	28.2
		Hot		70.5	17.0	58.0	53.0	58.3	31.4
		Air		62.0	27.0	54.2	37.4	51.5	39.4
		Water		50.8	40.0	40.0	40.0	37.0	56.4
	2	Powder		62.7	26.2	53.2	44.3	52.0	39.8
		Hot		59.0	30.5	51.0	63.0	49.5	41.7
		Air		50.0	44.0	47.3	13.2	42.0	50.5
		Water		39.6	53.4	31.4	17.0	28.0	67.0
G5NMC80	1	Powder	106	98.0	7.5	92.0	21.4	90.0	15.0
		Hot		94.2	11.0	88.0	40.7	87.5	17.4
		Air		85.0	19.8	83.3	21.7	80.6	24.0
		Water		71.0	33.0	62.8	23.8	63.0	40.5
	1. 5	Powder		88.3	16.7	83.0	29.2	81.5	23.0
		Hot		85.0	19.8	80.7	47.8	78.0	26.4
		Air		81.0	23.6	75.0	30.6	66.4	37.3
		Water		62.0	41.5	55.3	34.7	47.0	55.6
	2	Powder		78.0	26.4	73.5	30.6	71.0	33.0
		Hot		75.3	29.0	69.2	57.2	67.5	36.3
		Air		70.5	33.5	65.7	50.0	58.0	45.2
		Water		52.8	50.0	45.3	26.0	39.0	63.2
GF5NMC80	1	Powder	95	86.0	9.4	82.0	13.6	78.0	17.9
		Hot		83.5	12.0	79.5	16.3	75.7	20.3
		Air		76.0	20.0	71.0	25.2	67.0	29.4
		Water		64.3	32.3	60.5	36.3	53.5	43.7
	1. 5	Powder		79.0	16.8	75.0	21.0	70.0	26.3
		Hot		76.0	20.0	72.7	23.7	67.5	29.0
		Air		71.5	24.7	66.5	30.0	61.8	35.0
		Water		58.0	39.0	53.0	44.2	43.0	54.7
	2	Powder		68.0	28.4	64.7	31.9	58.0	39.0
		Hot		66.7	29.7	62.0	34.7	56.7	40.3
		Air		60.5	36.3	56.5	40.5	50.0	47.3
		Water		51.0	46.3	45.5	52.0	37.0	61.0
D3NMC80	1	Powder	82	76.8	6.3	70.6	14.0	62.0	24.4
		Hot		73.5	10.3	67.0	18.3	59.5	27.4

Mix Designation	Exposure period (Hours)	Cooling types	Compressive strength (MPa)						
			Temperature (°C)						
			25°C	400°C	Reduction %	600°C	Reduction %	800°C	Reduction %
		Air		72.0	12.2	66.0	19.5	57.0	30.4
		Water		57.0	30.5	52.6	35.8	41.0	50.0
	1. 5	Powder		68.5	16.4	62.7	23.5	54.5	33.5
		Hot		66.2	19.2	60.0	26.8	52.0	36.5
		Air		62.0	24.4	57.0	30.4	50.0	39.0
		Water		48.0	41.4	44.6	45.6	36.8	55.0
	2	Powder		61.0	25.6	54.0	34.0	45.5	44.5
		Hot		58.5	28.6	51.0	37.8	43.0	47.5
		Air		56.0	31.7	50.0	39.0	41.0	50.0
		Water		39.0	52.4	32.8	60.0	28.0	65.8
DF3NMC80	1	Powder	78	72.0	7.7	67.0	14.1	60.0	23.0
		Hot		69.5	11.0	64.0	18.0	57.0	27.0
		Air		68.0	12.8	63.0	19.2	54.3	30.3
		Water		51.3	19.2	47.0	39.7	31.0	60.0
	1. 5	Powder		68.0	12.8	57.0	27.0	50.5	35.2
		Hot		65.7	15.7	55.2	29.2	47.0	39.7
		Air		62.0	20.5	54.0	30.7	44.5	43.0
		Water		47.5	398.0	37.0	52.0	28.0	64.0
	2	Powder		58.3	25.2	50.0	35.9	43.0	44.8
		Hot		54.6	30.0	47.5	39.0	40.5	48.0
		Air		53.0	32.0	46.3	40.6	38.0	51.2
		Water		37.8	51.5	30.0	61.5	25.0	68.0
D5NMC80	1	Powder	98	91.0	7.1	86.0	12.2	78.0	20.4
		Hot		88.0	10.2	83.0	15.3	75.0	23.4
		Air		85.4	12.8	82.0	16.3	73.5	25.0
		Water		67.0	31.6	60.0	38.7	50.0	49.0
	1. 5	Powder		83.0	15.3	78.5	19.9	72.0	26.5
		Hot		80.0	18.3	77.0	21.4	68.7	29.9
		Air		78.7	19.7	74.0	24.5	64.0	34.7
		Water		59.0	39.8	53.0	46.0	45.0	54.0
	2	Powder		77.0	21.4	72.0	26.5	60.0	38.7
		Hot		74.5	24.0	69.0	29.0	57.5	41.3
		Air		73.0	25.5	66.8	31.0	54.0	44.9
		Water		50.0	49.0	45.0	54.0	36.0	63.2
DF5NMC80	1	Powder	93	87.5	6.0	84.0	9.6	75.0	19.3
		Hot		85.0	8.6	83.4	10.3	72.0	22.2
		Air		82.0	11.8	80.0	14.0	69.5	25.2
		Water		65.7	29.3	60.0	35.4	50.0	46.2
	1. 5	Powder		81.0	13.0	77.5	16.6	67.0	28.0
		Hot		78.0	16.0	75.0	19.3	64.3	30.8
		Air		76.3	18.0	71.0	23.6	60.5	35.0
		Water		60.0	35.4	55.0	40.8	40.0	57.0
	2	Powder		69.5	25.2	66.8	28.0	52.0	44.0
		Hot		64.0	31.0	62.0	33.3	50.7	45.4
		Air		61.0	34.4	57.0	38.7	48.0	48.3
		Water		52.7	43.0	46.5	50.0	35.0	62.3

Table (14) Splitting Tensile Strength Of Concrete Specimens Before and After Exposure To Fire Flame Temperature with Different Cooling At 90 Days Age

Mix Designation	Exposure period (Hours)	Cooling types	Splitting Tensile Strength (MPa)						
			Temperature (°C)						
			25°C	400°C	Reduction %	600 °C	Reduction %	800 °C	Reduction %
G3NMC80	1	Powder	8.57	7.75	9.50	7.11	17.00	5.10	40.50
		Hot		7.45	13.00	6.95	19.00	4.88	43.00
		Air		7.21	15.80	6.75	21.20	4.68	45.40
		Water		6.45	24.70	5.60	34.60	4.04	52.00
	1. 5	Powder		7.26	15.90	6.68	22.00	4.69	45.20
		Hot		7.02	18.00	6.53	23.80	4.45	48.00
		Air		6.78	20.80	6.34	26.00	4.24	50.50
		Water		5.50	35.80	4.66	34.00	3.72	56.60
	2	Powder		6.85	20.00	6.34	26.00	4.29	50.00
		Hot		6.64	22.50	6.15	28.20	4.13	51.80

Mix Designation	Exposure period (Hours)	Cooling types	Splitting Tensile Strength (MPa) Temperature (ºC) 25ºC	400ºC	Reduction %	600 ºC	Reduction %	800 ºC	Reduction %
		Air		6.43	25.00	5.91	31.00	3.95	54.00
		Water		5.76	32.80	5.14	40.00	3.18	62.90
GF3NMC80	1	Powder	8.83	7.81	11.50	7.06	20.00	5.22	40.80
		Hot		7.55	14.50	6.87	22.20	5.04	43.00
		Air		7.32	17.10	6.62	25.00	4.78	45.80
		Water		6.51	26.30	5.96	32.50	3.80	57.00
	1. 5	Powder		6.94	21.40	6.29	28.70	4.78	45.80
		Hot		6.72	24.00	6.09	31.00	4.60	48.00
		Air		6.54	26.00	5.87	33.50	4.53	48.70
		Water		6.04	31.50	5.06	42.70	3.32	62.40
	2	Powder		6.49	26.50	5.84	33.80	4.34	50.80
		Hot		6.29	28.70	5.65	36.00	4.19	52.50
		Air		6.00	32.00	5.49	37.80	3.80	57.00
		Water		5.22	40.80	4.76	46.00	3.09	65.00
G5NMC80	1	Powder	9.18	8.35	9.00	7.57	17.50	5.60	39.00
		Hot		8.18	10.90	7.34	20.00	5.43	40.80
		Air		7.99	13.00	7.27	20.80	5.23	43.00
		Water		7.52	18.00	6.42	30.00	4.59	50.00
	1. 5	Powder		7.87	14.20	7.08	22.80	5.16	43.80
		Hot		7.73	15.80	6.89	25.00	4.95	46.00
		Air		7.55	17.70	6.61	28.00	4.75	48.20
		Water		7.08	22.80	5.90	35.70	4.05	55.80
	2	Powder		7.38	19.60	6.71	27.00	4.70	48.80
		Hot		7.17	21.90	6.47	29.50	4.50	51.00
		Air		6.97	24.00	6.22	32.20	4.29	53.20
		Water		6.44	30.00	5.32	42.00	3.48	62.10
GF5NMC80	1	Powder	9.47	8.52	10.00	7.76	18.00	5.68	40.00
		Hot		8.30	12.30	7.50	20.80	5.47	42.20
		Air		8.08	14.60	7.27	23.20	5.22	44.80
		Water		7.38	22.00	6.39	32.50	4.19	55.70
	1. 5	Powder		7.57	20.00	6.64	30.00	5.40	43.00
		Hot		7.30	22.90	6.44	32.00	4.94	47.80
		Air		7.03	25.70	6.22	34.30	4.74	50.00
		Water		6.34	33.00	5.39	43.00	3.99	57.80
	2	Powder		7.08	25.20	6.44	32.00	4.79	49.40
		Hot		6.84	27.70	6.20	34.50	4.56	51.80
		Air		6.63	30.00	5.94	37.20	4.35	54.00
		Water		6.08	36.00	5.17	45.40	3.45	63.50
D3NMC80	1	Powder	7.43	6.78	8.00	6.20	16.50	4.38	41.00
		Hot		6.48	12.80	6.05	18.50	4.20	43.40
		Air		6.27	15.60	5.87	21.00	3.88	47.80
		Water		5.70	23.20	4.85	34.70	2.94	60.40
	1. 5	Powder		6.36	14.40	5.85	21.20	4.01	46.00
		Hot		6.14	17.30	5.69	23.40	3.83	48.50
		Air		5.90	20.60	5.52	25.70	3.65	50.80
		Water		4.86	34.60	4.66	33.20	2.41	67.30
	2	Powder		6.01	19.10	5.51	25.80	3.67	50.60
		Hot		5.78	22.20	5.35	28.00	3.56	52.00
		Air		5.59	24.70	5.16	30.50	3.38	54.50
		Water		5.00	32.70	4.46	40.00	2.21	70.20
DF3NMC80	1	Powder	8.15	7.26	10.90	6.56	19.50	4.41	45.80
		Hot		7.10	12.80	6.37	21.80	4.23	48.00
		Air		6.78	16.80	6.24	23.40	3.99	51.00
		Water		6.02	26.10	5.61	31.10	2.80	65.60
	1. 5	Powder		6.45	20.80	5.86	28.00	4.01	50.80
		Hot		6.22	23.60	5.64	30.80	3.84	52.80
		Air		6.05	25.70	5.43	33.40	3.76	53.90
		Water		5.40	33.70	4.77	41.40	3.04	62.70
	2	Powder		6.04	25.80	5.46	33.00	3.97	51.20
		Hot		5.83	28.40	5.24	35.70	3.84	52.80
		Air		5.56	31.80	5.09	37.50	3.49	57.20
		Water		4.90	39.80	4.40	46.00	2.30	71.80
D5NMC80	1	Powder	8.10	7.40	8.60	6.74	16.80	4.54	43.90

Mix Designation	Exposure period (Hours)	Cooling types	Splitting Tensile Strength (MPa)						
			Temperature (ºC)						
			25ºC	400ºC	Reduction %	600 ºC	Reduction %	800 ºC	Reduction %
		Hot		7.24	10.60	6.51	19.60	4.47	44.80
		Air		7.10	12.30	6.47	20.10	4.21	48.00
		Water		6.65	17.90	5.67	30.00	3.40	58.00
	1. 5	Powder		7.00	13.50	6.28	22.40	4.15	48.70
		Hot		6.85	15.40	6.11	24.50	4.04	50.00
		Air		6.69	17.40	5.85	27.70	3.84	52.60
		Water		6.26	22.70	5.30	34.50	2.97	63.30
	2	Powder		6.56	19.00	5.96	26.40	3.79	53.20
		Hot		6.36	21.50	5.72	29.30	3.68	54.50
		Air		6.21	23.30	5.49	32.20	3.38	58.30
		Water		5.70	29.60	4.70	42.00	2.39	70.50
DF5NMC80	1	Powder	8.83	7.99	9.50	7.27	17.60	5.09	42.30
		Hot		7.76	12.10	7.04	20.30	4.85	45.00
		Air		7.58	14.10	6.80	23.00	4.55	48.40
		Water		6.91	21.70	5.98	32.20	3.15	64.30
	1. 5	Powder		7.08	19.80	6.23	29.40	4.63	47.50
		Hot		6.84	22.50	6.02	31.80	4.39	50.20
		Air		6.58	25.50	5.83	33.90	4.20	52.40
		Water		5.93	32.80	5.14	41.70	3.07	65.20
	2	Powder		6.60	25.20	6.30	28.60	4.26	51.70
		Hot		6.40	27.50	5.81	34.20	3.85	56.40
		Air		6.21	29.60	5.54	37.20	3.70	58.10
		Water		5.70	35.40	4.84	45.10	2.37	73.10

Table (15) Flexural Strength of Concrete Specimens Before And After Exposure To Fire Flame Temperature With Different Cooling At 90 Days Age

Mix Designation	Exposure period (Hours)	Cooling types	Flexural strength (MPa)						
			Temperature (ºC)						
			25ºC	400ºC	Reduction %	600 ºC	Reduction %	800 ºC	Reduction %
G3NMC80	1	Powder	9.63	5.54	42.40	4.62	52.00	2.81	70.80
		Hot		5.32	44.70	4.44	53.90	2.60	73.00
		Air		5.24	45.50	4.35	54.80	2.52	73.80
		Water		4.63	51.90	3.73	61.20	2.12	78.00
	1. 5	Powder		4.89	49.20	4.25	55.80	2.36	75.50
		Hot		4.68	51.40	4.05	57.90	2.19	77.20
		Air		4.62	52.00	3.96	58.80	2.08	78.40
		Water		3.99	58.50	3.38	64.90	1.53	84.10
	2	Powder		4.31	55.20	3.75	61.00	1.68	82.50
		Hot		4.12	57.20	3.56	63.00	1.54	84.00
		Air		3.99	58.50	3.44	64.20	1.34	86.00
		Water		3.48	63.80	2.80	70.90	0.87	91.00
GF3NMC80	1	Powder	11.52	6.59	42.80	5.66	50.80	3.45	70.00
		Hot		6.38	44.60	5.42	52.90	3.11	73.00
		Air		6.24	45.80	5.32	53.80	3.01	73.80
		Water		5.54	51.90	4.43	61.50	2.40	7931.00
	1. 5	Powder		5.89	48.80	5.08	55.90	2.89	74.90
		Hot		5.66	50.80	4.85	57.90	2.70	76.50
		Air		5.53	52.00	4.74	58.80	2.58	77.60
		Water		4.78	58.50	4.08	64.50	1.85	83.90
	2	Powder		5.21	54.70	4.56	60.40	1.91	83.40
		Hot		5.01	56.50	4.29	62.70	1.63	85.80
		Air		4.90	57.40	4.14	64.00	1.57	86.30
		Water		4.17	63.80	3.38	70.60	0.89	92.20
G5NMC80	1	Powder	10.43	6.23	40.20	5.24	49.70	3.32	68.10
		Hot		5.95	42.90	5.00	52.00	3.07	70.50
		Air		5.84	44.00	4.91	52.90	3.92	62.40
		Water		5.21	50.00	4.18	59.90	2.25	78.40

Mix Designation	Exposure period (Hours)	Cooling types	Flexural strength (MPa)						
			Temperature (°C)						
			25°C	400°C	Reduction %	600 °C	Reduction %	800 °C	Reduction %
	1. 5	Powder		5.50	47.20	4.77	54.20	2.81	73.00
		Hot		5.21	50.00	4.50	56.80	2.57	75.30
		Air		5.13	50.80	4.39	57.90	2.48	76.20
		Water		4.39	57.90	3.86	62.90	1.83	82.40
	2	Powder		4.91	52.90	4.32	58.50	1.85	82.20
		Hot		4.69	55.00	4.08	60.80	1.56	85.00
		Air		4.58	56.00	3.97	61.90	1.47	85.90
		Water		3.95	62.10	3.21	69.20	0.92	90.50
GF5NMC80	1	Powder	13.06	7.71	40.90	6.53	50.00	4.07	68.80
		Hot		7.47	42.80	6.24	52.20	3.78	71.00
		Air		7.36	43.60	6.08	53.40	3.65	72.00
		Water		6.42	50.80	5.10	60.90	2.75	78.90
	1. 5	Powder		6.81	47.80	5.90	54.80	3.44	73.60
		Hot		6.58	49.60	5.61	57.00	3.18	75.60
		Air		6.42	50.80	5.51	57.80	3.00	77.00
		Water		5.46	58.10	4.77	63.40	2.23	82.90
	2	Powder		6.11	53.20	5.35	59.00	2.28	82.50
		Hot		5.82	55.40	5.06	61.20	1.89	85.50
		Air		5.69	56.40	4.86	62.80	1.71	86.90
		Water		4.84	62.90	3.93	69.90	1.07	91.80
D3NMC80	1	Powder	8.35	4.90	41.30	4.09	51.00	2.29	72.50
		Hot		4.66	44.20	3.90	53.30	2.09	74.90
		Air		4.51	46.00	3.88	53.50	2.00	76.00
		Water		4.15	50.30	3.31	60.30	1.63	80.40
	1. 5	Powder		4.35	47.90	3.84	54.00	1.92	77.00
		Hot		4.17	50.00	3.65	56.20	1.90	77.20
		Air		4.07	51.20	3.56	57.30	1.80	78.40
		Water		3.60	56.80	3.09	63.00	1.26	84.90
	2	Powder		3.84	54.00	3.38	59.50	1.34	83.90
		Hot		3.65	56.30	3.17	62.00	1.15	86.20
		Air		3.54	57.60	3.08	63.10	1.06	87.30
		Water		3.12	62.60	2.53	69.70	0.56	93.30
DF3NMC80	1	Powder	10.20	6.02	41.00	5.21	48.90	2.93	71.20
		Hot		5.80	43.10	5.05	50.50	2.66	73.90
		Air		5.71	44.00	4.96	51.40	2.55	75.00
		Water		5.01	50.80	4.18	59.00	1.85	81.80
	1. 5	Powder		5.38	47.20	4.70	53.90	2.36	76.80
		Hot		5.11	49.90	4.48	56.00	2.15	78.90
		Air		4.97	51.20	4.36	57.20	2.06	79.50
		Water		4.35	57.30	3.72	63.50	1.48	85.50
	2	Powder		4.77	53.20	4.19	58.90	1.54	84.90
		Hot		4.54	55.50	3.95	61.20	1.33	86.90
		Air		4.38	57.00	3.82	62.50	1.24	87.80
		Water		3.85	62.20	3.07	69.90	0.55	94.60
D5NMC80	1	Powder	9.70	6.03	37.80	5.05	47.90	2.62	73.00
		Hot		5.82	40.00	4.85	50.00	2.43	74.90
		Air		5.69	41.30	4.75	51.00	2.30	76.30
		Water		4.96	48.80	4.08	57.90	1.68	82.60
	1. 5	Powder		5.24	56.00	4.56	53.00	2.35	75.70
		Hot		5.04	48.00	4.34	55.20	2.13	78.00
		Air		4.91	49.30	3.72	61.60	2.00	79.30
		Water		4.29	55.70	3.17	673.00	1.37	85.80
	2	Powder		4.73	51.20	3.95	59.20	1.47	84.80
		Hot		4.46	54.00	3.69	62.00	1.27	86.90
		Air		4.33	55.60	3.58	63.10	1.14	88.20
		Water		3.79	61.00	3.02	68.80	0.50	94.80
DF5NMC80	1	Powder	11.53	6.88	40.30	5.89	48.90	3.02	73.80

Mix Designation	Exposure period (Hours)	Cooling types	Flexural strength (MPa)						
			Temperature (°C)						
			25°C	400°C	Reduction %	600 °C	Reduction %	800 °C	Reduction %
		Hot		6.58	42.90	5.70	50.50	2.77	76.00
		Air		6.46	44.00	5.54	51.90	2.61	77.30
		Water		5.76	50.00	4.72	59.00	1.90	83.50
	1. 5	Powder		6.08	47.30	5.32	53.80	2.70	76.60
		Hot		5.78	49.80	5.07	56.00	2.42	79.00
		Air		5.65	51.00	4.91	57.40	2.28	80.20
		Water		4.86	57.80	4.28	62.80	1.39	87.90
	2	Powder		5.44	52.80	4.86	57.80	1.61	86.00
		Hot		5.18	55.00	4.57	60.40	1.33	88.40
		Air		5.07	36.00	4.42	61.60	1.17	89.80
		Water		4.44	61.50	3.59	68.80	0.37	96.80

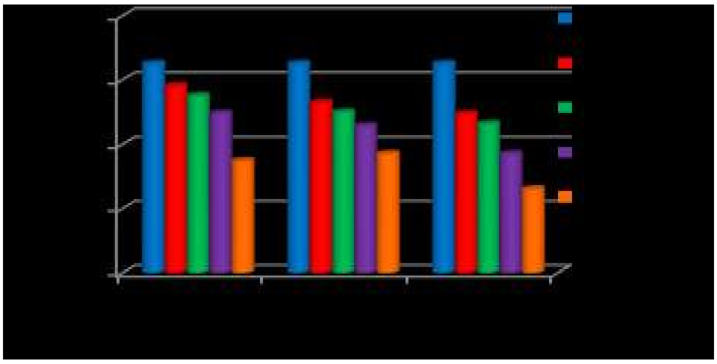


Figure (1) Compressive Strength of (GF3NMC80$_1$) before and after exposure to fire flame temperature with different cooling for (1)Hour

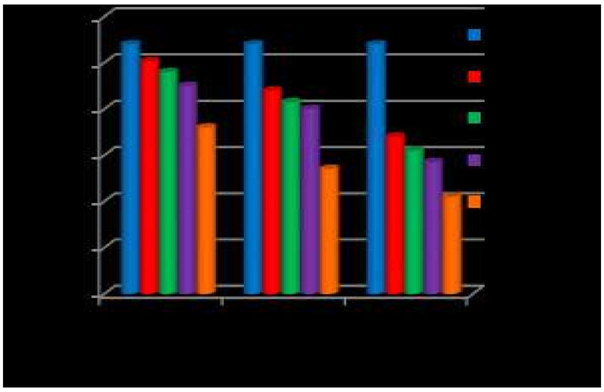


Figure (2) Compressive Strength of (D5NMC802) before and after exposure to fire flame temperature with different cooling for (1)Hour

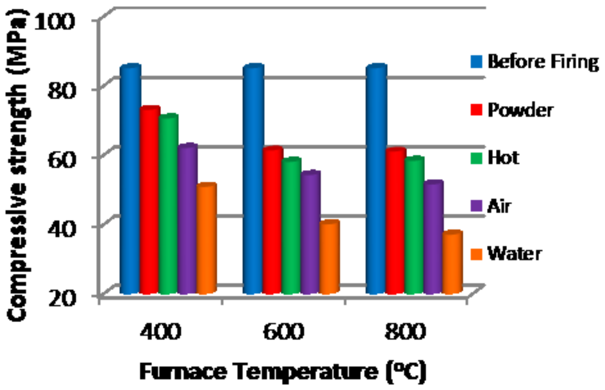


Figure (3) Compressive Strength of (GF3NMC801) before and after exposure to fire flame temperature with different cooling for (1.5)Hour

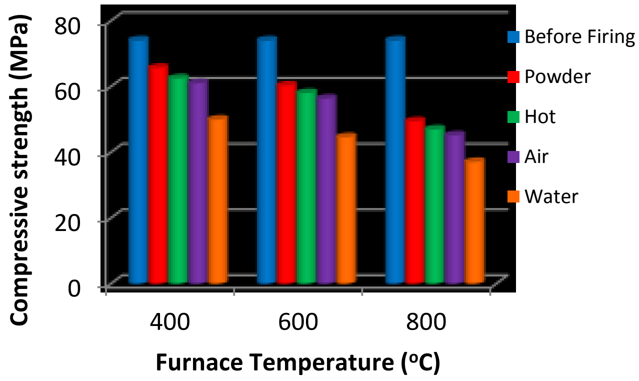


Figure (4) Compressive Strength of (D5NMC80$_2$) before and after exposure to fire flame temperature with different cooling for (1.5)Hour

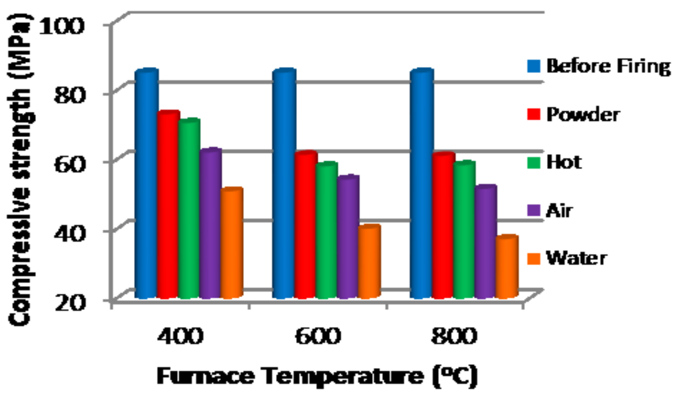


Figure (5) Compressive Strength of (GF3NMC80$_1$) before and after exposure to fire flame temperature with different cooling for (2)Hour

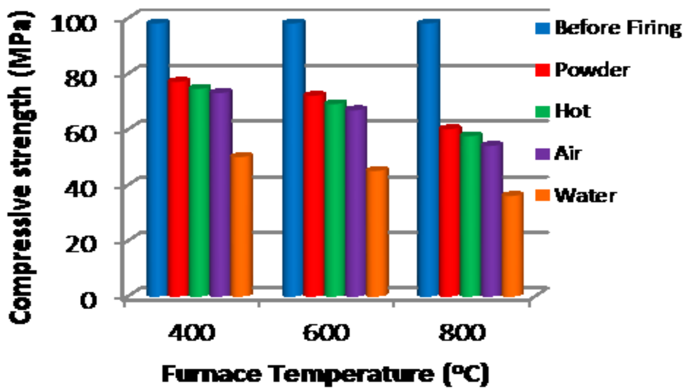


Figure (6) Compressive Strength of (D5NMC80$_2$) before and after exposure to fire flame temperature with different cooling for (2)Hour

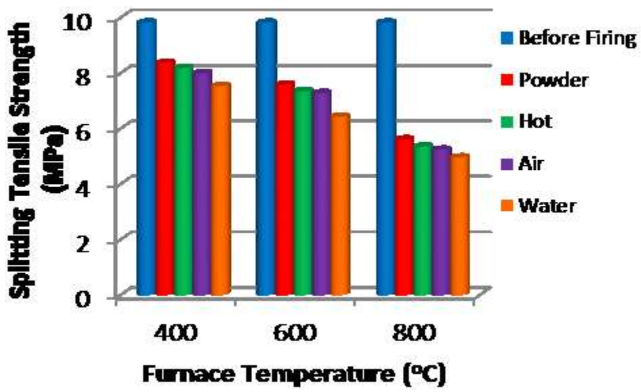


Figure (7) Splitting Tensile Strength for (G5NMC80$_2$) before and after exposure to fire flame temperature with different cooling for (1)Hour

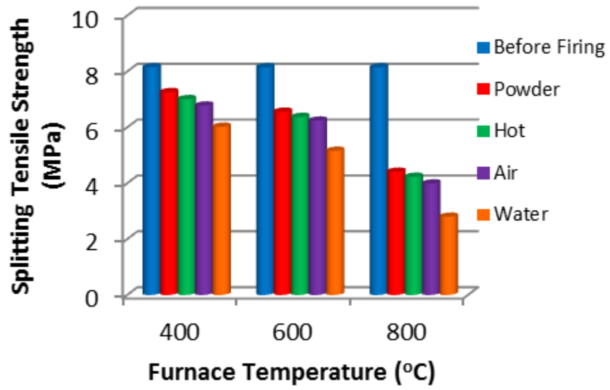


Figure (8) Splitting Tensile Strength for (DF3NMC80$_2$) before and after exposure to fire flame temperature with different cooling for (1)Hour

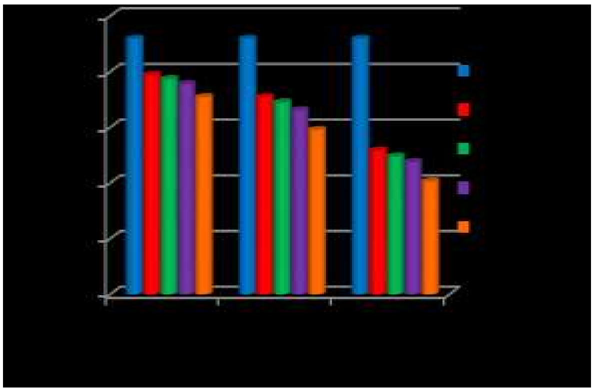


Figure (9) Splitting Tensile Strength for ($G5NMC80_2$) before and after exposure to fire flame temperature with different cooling for (1.5)Hour

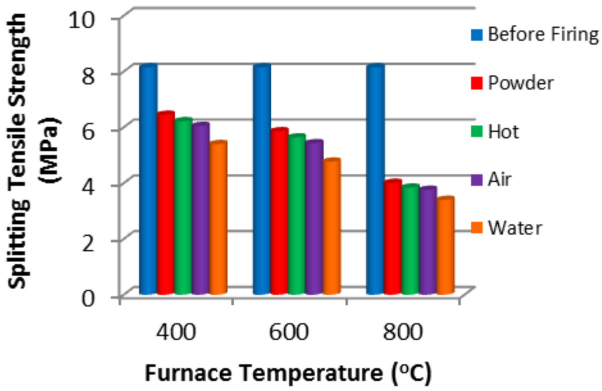


Figure (10) Splitting Tensile Strength for ($DF3NMC80_1$) before and after exposure to fire flame temperature with different cooling for (1.5)Hour

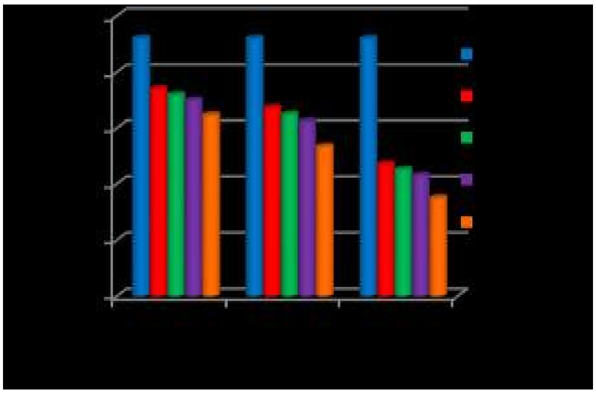


Figure (11) Splitting Tensile Strength for (G5NMC80) before and after exposure to fire flame temperature with different cooling for (2)Hour

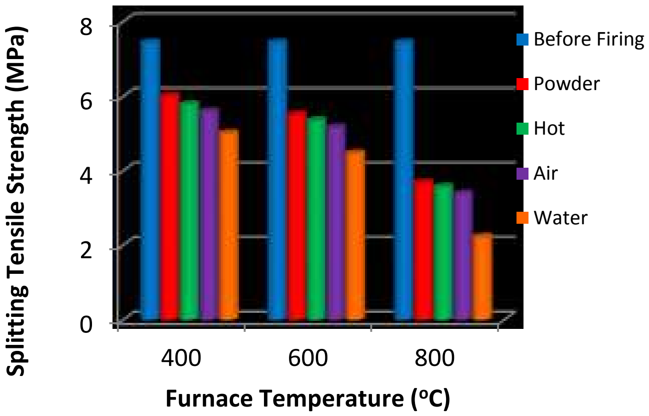


Figure (12) Splitting Tensile Strength for (DF3NMC80$_1$) before and after exposure to fire flame temperature with different cooling for (2)Hour

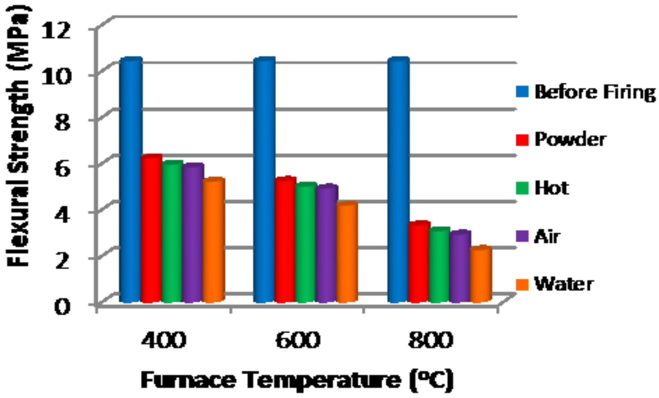


Figure (13) Flexural Strength of (G5NMC80$_2$) before and after exposure to fire flame temperature with different cooling for (1)Hour

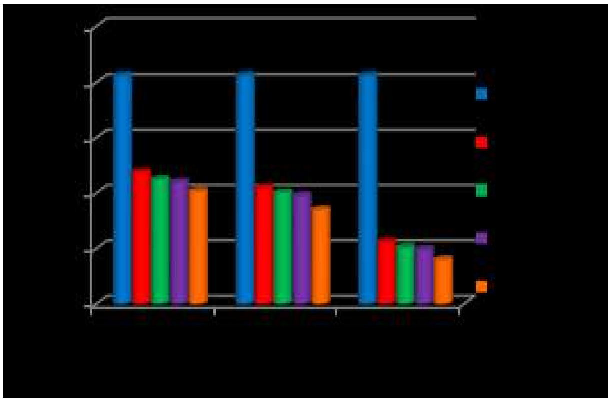
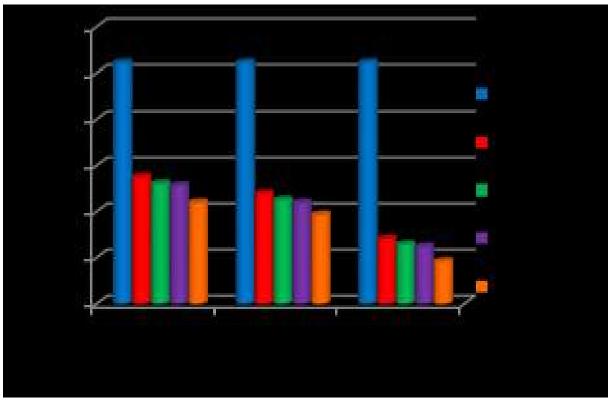
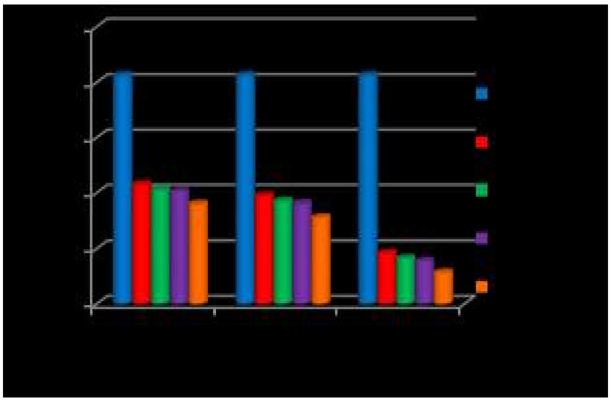


Figure (14) Flexural Strength of (D5NMC80$_2$) before and after exposure to fire flame temperature with different cooling for (1)Hour



Figure(15) Flexural Strength of (G5NMC80$_2$) before and after exposure to fire flame temperature with different cooling for (1.5)Hour



Figure(16) Flexural Strength of (D5NMC802) before and after exposure to fire flame temperature with different cooling for (2)Hour

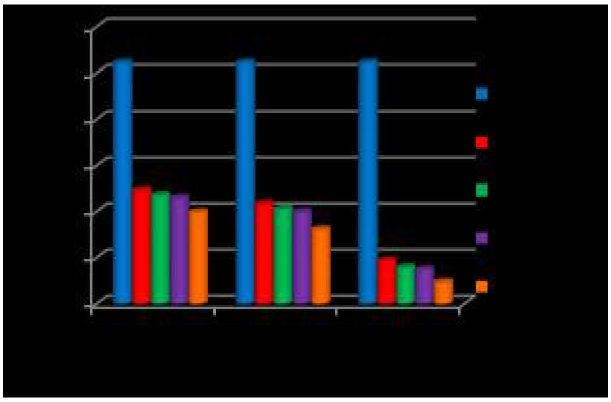


Figure (17) Flexural Strength of (G5NMC802) before and after exposure to fire flame temperature with different cooling for (2)Hour

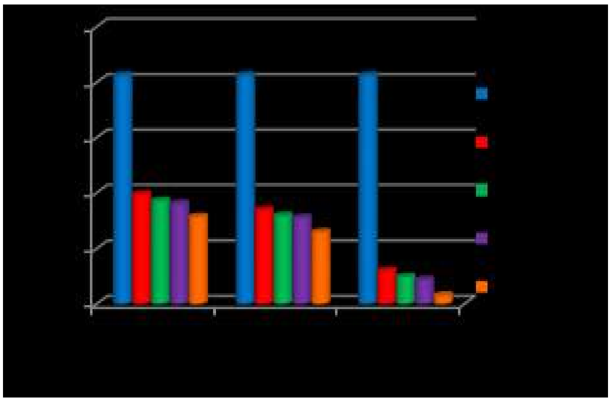


Figure (18) Flexural Strength of (D5NMC802) before and after exposure to fire flame temperature with different cooling for (2)Hour

CONCLUSION

Based on the test results of the present study and after the evaluation on these results, the findings are summarized as follows:

1- The residual compressive strength values for all mixes ranged between (30.5-98)% at 400^{o}C, (28-92)% at 600^{o}C and (15-90)% at 800^{o}C.

2- Extra reduction in splitting tensile strength took place for all concrete specimens of HSC, particularly at 800^{o}C and cooled by water, the percentage of reduction ranged between (9-43.2)%, (17-50)% and (39-76)% for gravel and dolomite mixes at 400, 600 and 800^{o}C.

3- The flexural strength were sensitive to fire flame temperatures and caused extra reduction in MoR for all concrete specimens, than other mechanical properties of HSC, cooled by water and 800^{o}C fire flame exposure temperature caused high rate of decrease in flexural strength.

4- For all periods of exposure at (400 to 600)^{o}C fire flame temperatures, high strength concrete which contains dolomite as a course aggregate gives more residual modulus of rupture than mixes contains gravel as coarse aggregate by about (5-10)%, but the reduction of dolomite concrete specimens are greater than gravel concrete specimens by about (10-20)% after exposure to fire flame temperature at (600 to 800)^{o}C.

5- Failure of concrete specimens during the firing process within the temperature range of 400 to 800^{o}C by addition of (0.5)% polypropylene fibers, splalling of concrete did not occur, however, surface cracking was still observed. While special type of failure occurred, some corners of the cube specimens cracked of after exposed to 800^{o}C fire flame temperature.

6- For all periods of exposure and 400 to 800^{o}C fire flame temperature, cooled by extinguisher powder gives higher residual values of mechanical properties, while using cooled by water causes further reduction of mechanical properties of all concrete mixes.

REFERENCES

[1].Al-Jubory, Atheer Helal Mahdi, (2010), **"Flexed Behavior of Partial Restrain** Beams of Self Compacting Concrete Exposed to Fire Flame", Master A Thesis, College of Engineering, Babylon University.

[2].Habeeb, G. M., 2000, "Residual Mechanical Properties of High Strength Concrete Subjected to Elevated Temperature", Ph.D, Thesis, College of Engineering, Department of Civil Engineering, Al- Mustansiria University, Baghdad, Iraq, 164 pp.

[3].Ilker, B. T., and Cenk, K., (2008), "Properties of Reinforced concrete steel rebars exposed to high temperature", material science, volume 2000, Article ID 814137, 4 pages.

[4].Iraqi Organization of Standards, lQS 45: 1984, for Aggregate.

[5].Iraqi Organization of Standards, lQS 5: 1984 , for Portland Cement.

[6].John Newman, Ban Seng Choo, (2003)[(c)], Book, "Advanced Concrete Technology: Processes".

[7].Lee J., Yunping Xi, and Kaspar Willani , (2008), "Properties of Concrete after high-Temperature Heating anti Cooling", ACT Materials Journal, August.pp.334-340.

[8].Umran, Mirza Karim, (2002), "Fire Flame Exposure Effect on Some Mechanical Properties of Concrete", Master A Thesis, College Engineering, Civil Department, Babylon University.

[9].Morley, P.D and Royels, R., (1983), "Response of the Bond iii Reinforced Concrete to High Temperature", Magazine of Concrete Research,Vol.38, No.123, pp.67-75.

[10].Morsy, M. S., Al-Salloum, Y. A., Abbas, H., Alsayed, S. H. I., (2012), "Behavior of Blended Cement Mortars Containing Nano-Metakaolin at Elevated Temperatures", Construction and Building Materials.

[11].Neville, A.M., (2010), "Properties of concrete", Fourth and final Edition, Wiley, New York and Longman, London.

[12].Obeed, Ahmed T., (2007), "Effect of Exposure to Fire Flame on Some Mechanical Properties of Self-compacting concrete Using Different Types of Filler", M.Sc Thesis , Babylon University.

[13].Phan, L. T., and Carino, N. J., (1998), “Review of Mechanical properties of High-strength concrete at Elevated Temperature” Journal of Materials in Civil Engineering, pp. 58-64.

[14].Saqier, Awad A., (2008), "Effect of Fire Flame Exposure on Flexural Behavior and Shear Strength of Reinforced NSC and HPC Beams", M.Sc Thesis ,Babylon University.