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EFFECTS OF CONCRETE TYPES, ELEVATED TEMPERATURES, AND DIFFERENT COOLING TECHNIQUE ON CONCRETE COMPRESSIVE STRENGTH

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Abstract

The characteristics of concrete subject to high temperature are fundamental to improve the endurance of the fire of constructions and to come up with detailed statistics for fire design. Throughout and subsequent a fire, various components of a concrete structure experience contrasting heating and cooling situations. Consequently, the residual strength and stiffness characteristics in the concrete composition necessitate being estimated previously, a conclusion can be performed as to whether the structure must be rebuilt or can be repaired. Comparisons between the residual compressive strengths of four different concrete type (normal concrete (N1), high strength concrete (H), ultra-high-strength concrete (UH), and steel fiber concrete (N2)) exhibited to different temperatures (25, 100, 200, 400, 600, 800 and 1000°C) cured for 28 days are examined with the impact of three cooling methods to determine their effects on the compressive strength (cooling in the air (gradually), water cooling, and cooling by extinguisher). It was observed that the loss in strength in compression was higher within water cooling than gradually and extinguisher cooling by (59.14% for N1, 58.97% for N2, 57.7% for H, and 56.41% for UH) under (1000°C) compared to (25°C); this is related to the extreme thermal shock causing higher micro cracks leading the concrete to lose more strength. Steel fiber has the ability to resist the rising in temperature caused an enhancement in the compressive strength and less reduction in residual compressive strength after heating. The maximum improvement in residual compressive strength for steel fiber concrete (N2) under (1000°C) were (14.89%) for gradually cooling compared to normal concrete (N1).

Keywords: Compressive strength, Cooling method, Cooling by extinguisher, Ordinary concrete, Steel fiber, Ultra- and high strength concrete.

1. Introduction

Regarding high-temperature resistance, concrete has excellent strength properties as it covers and protects steel during fire exposure compared to other materials. When concrete is exposed to fire, concrete will suffer from many changes in the physical characteristics and chemical composition. These changes to concrete in mechanical and physical properties are related to increased temperature [1, 2]. At raised temperatures, the behaviour of structures and response to specific accidents or conditions of service are of major significance in anticipating the integrity of the structures. After the fire, knowledge of the remaining mechanical properties of the concrete is necessary to assess the element residual load capacity [3, 4]. A specific degree of residual strength can remain in concrete structures exposed to fire after suffering from damage. The compressive strength of concrete achieved from the international investigation has revealed that reduction was produced not only by the temperature however further by the types of cooling conditions after the fire.

Based on investigations by other authors a thermal shock originates by fast cooling concerning the loss during heating and results in a 30% further strength decline. Further intensity declines of about 20-30% are observed when keeping the mixture after the fire in the air [5, 6]. The main parameters that could affect the concrete residual mechanical strength have been identified by several research studies, like the following: w/c ratio, loading level, cooling process, type and size of aggregates, and type of cement [7-10]. Primarily, fire protection of concrete is controlled by circumstances such as fire conditions, temperature, and period. The cooling type, in the opposite direction, affects the compressive strength [11, 12]. To resist fire and heat in the concrete, proper evaluation needs further experimental research obtained in different cooling systems during high temperatures as they cause different stresses in the concrete. As in the case of accidental fires, exposure to high temperatures is known to lead to the deterioration of concrete properties by initiating thermal cracks and the spread of these cracks and cracks formerly present in the mixture constituents, which manages to a reduction in the strength of the concrete and generates additional deterioration in concrete segments.

Bingöl and Gul [3] investigated the effect of cooling regimes (water rapidly and gradually) at raised temperatures following to 700°C. Abd-EL-Aziz et al. [4] considered the different impacts on mortar properties (cement, sand, and brick) for 3h up to 700°C elevated temperatures and the influence of cooling conditions (furnace, water, and air). Results revealed that compressive strength losses in all mixtures subjected to fire whatever the cooling type and higher reduction in compressive strength in air cooling mode. Annerel and Taerwe [5] considered the high-performance mixture with the effect of cooling (post-cooling slow, fast cooling, and cooling in the air) and storage methods. The temperature is chosen between 350-550°C. Results revealed that when exposed to 350°C there is no strength loss and in water cooling, there is a reduction of about 35%. 40% and 30% of reductions to 550°C with 28% strength losses for cooled slowly (in the air). Ramanjaneyulu and Yaragal [6] examined the influence of polypropylene fibers on the mixture mechanical properties and cooling mode (air cooling, furnace cooling, and sudden cooling) under elevated temperature (200-800°C). Results showed that strength reduces with elevated temperature.

Raheem et al. [7] introduced different concrete mixtures with the effect of cooling by water and different temperature (400,600,900°C). Abdelraheem et al.

[8] utilized the ultra-high-performance mixture (UHPC) mechanical properties including cooling operations (water quenching plus air cooling) under elevated temperature (1, 2hr, 4hr) exposure times and (room temperature, 100, 200, 600, and 1000°C). Abdulhussei et al. [9] studied the mechanical properties of cement mortar under elevated temperature (exposed for two hrs.) (100, 200, 400, and 700°C) with two cooling modes with 1/2 hr (air and water). Compared to the original mix examined through 20°C in 28 ages, concrete strength decreased by 65.3% when subjected to 700°C water cooling. Al-Rjoub and Tamimi. [10] analyzed the construction features of mixtures with recycled glass with the cooling mode of (immersion in water, spraying water, natural cooling, and Co_2 fire extinguishers) under the thermal shock of temperatures between (150-600°C). Severe damage in concrete has been producing by fast cooling.

Ma et al. [11] examined various cooling modes on recycled aggregate concrete and plain concrete with elevated temperatures. Wang et al. [12] studied the effects of two cooling modes (water and natural cooling) under elevated temperatures between (20-800°C) on the compressive strength of recycled fine and coarse aggregates concrete. Carvalho et al. [13] presented the effect of cooling mode and elevated temperatures (400, 500, 600, 700, and 800°C) on concrete compressive intensity. They measure the compressive intensity in three conditions (the furnaces temperature level, after the process of natural cooling, and at ambient temperature water aspersion). Zhang et al. [14] examined various temperatures (20, 400, 500, 600, 700, and 850°C) and cooling mode (water and air cooling) on concrete with different ratio replacement of desert sand. They concluded that water cooling produces more reduction in compressive strength.

In this research a comparison between four different concrete type (ultra and high strength concrete, steel fiber concrete, and normal concrete) subjected to different temperature degrees (25, 100, 200, 400, 600, 800 and 1000°C) examined with three cooling methods effects (cooling in the air (gradually), water cooling, and cooling by extinguisher).

2. Material and Methods

Ordinary Portland cement conformed to the IQ, No.5, 1984 standard [15] was used with normal aggregates having a gradation compatible with the standard IQ, No.45, 1980 [16] and coarse aggregate having an extreme aggregate size of (10mm). Table 1 displays the considerable characteristics of cement. Tables 2 and 3 show fine aggregate category and mechanical properties. Tables 4 and 5 show coarse aggregate category and physical properties. Figures 1 and 2 show fine and coarse aggregate category curves. Grey-colored silica fume generates by (Materials Company with the sign of Basif) [17] was used in concrete with ultra and high-strength with 10% and 25% of the cement weight to enhance the volume unite mass and the compressive toughness. To enhance the mixture tensile strength, increase the concrete ductility, bond strength, and to minimize the crack propagation, stainless steel fiber from (Hebei Yusen, China Company of Metal Wire Mesh) [18] with high tensile stress (2600 MPa) and modulus of elasticity of (210000 MPa) from the manufactured sheet, according to the ASTM A820/A 820M-16 [19] with the content of 1% by concrete volume (to avoid the accumulation of steel fiber) with (L=13 mm and D=0.2 mm and an aspect ratio of 65) was used in the laboratory investigation. A high-performance (PC20-SikaViscoCrete) [20] concrete superplasticizer manufactured by the SIKA Company, was used to rely on the advantage of its water-reducing properties to increases compressive strength.

Table 1. Mechanical characteristics of cement.

Mechanical characteristics	**values**	**1984 No.5 IQS Limits**
Blain method, m^2/kg (surface area)	372	≥230
Setting in the initial time	02:05	Not less than 45 min
Setting in the final time	03:60	Not more than 10 hrs
Durability	0.30%	≤0.8%
Strength of compression of mortar MPa:		
7 -day	28	≥23
3- day	16	≥15

Table 2. Fine aggregate **range.**

Size of Sieve mm	**Passing (%)**	**IQS No.45/1984 Limits**
4.75	100	90-100
2.36	90	85-100
1.18	87	75-100
0.6	67	60-79
0.3	21	12-40
0.15	9	0-10

Table 3. Fine aggregate physical properties.

properties	**Result %**	**1984 No.45 IQS Limits**
absorption	0.7	---
content of sulphate	0.068	≤0.5%
Specific gravity	2.2	---

Table 4. Coarse aggregate **range.**

Sieve Size mm	**Passing (%)**	**IQS No.45/1984 Limits**
12.5	100	100
9.5	60	40-80
4.75	5	0-20
2.36	0	0-10

Table 5. Coarse **aggregate physical properties.**

Properties	**Results**	**IQS No.45/1984 Limits**
Specific apparent gravity	2.3	---
Sulfate (SO_3)	0.05 %	≤ 0.1%
Absorption	0.48%	---

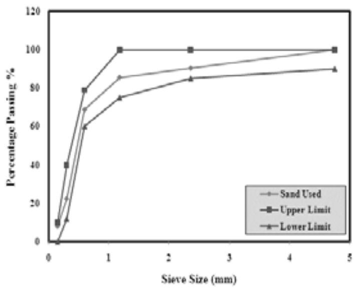

Fig. 1. Illustration of sand sieving.

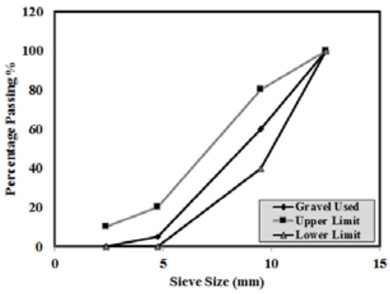

Fig. 2. Illustration of gravel sieving.

The standard concrete cylinder (100×200 mm) is used for compressive tests for all mixture types. An average of three specimens for each test was taken. The experimental program is divided into four groups depending on the concrete type. The current research is to estimate the concrete compressive strength while is exposed to rising temperatures of (25, 100, 200, 400, 600, 800, and 1000°C) under the different method of the cooling process (cooling in the air (gradually), water cooling and by extinguisher), to examine the consequence of these methods on the strength in compression of the mixtures.

For normal mixtures, the mixtures were planned as stated by the ACI 211.1 [21] to give the specified strength in compression within the duration of 28 days equal to 35 MPa. The slump is equal to (80 mm) carried out according to ASTM C143/C143M [22]. For high strength concrete, the slump is equal to (100 mm) [22-26]. For Ultra-High-Strength Concrete (UHSC) several tests have been carried out to choose the appropriate dose of superplasticizer [27]. Figure 3 shows the water reduction effect of using different dosages percentages of superplasticizer. With w/c ratio equal (0.2) the maximum possible reduction in the water was (56%) compared to non-superplasticizer mix.

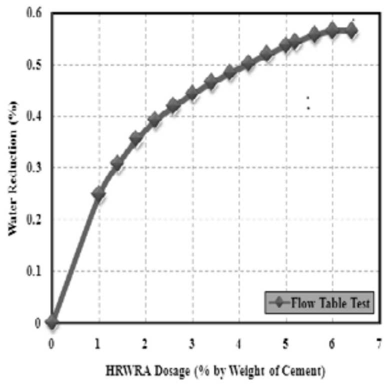

Fig. 3. Relationship between HRWRA dosage and water reduction (%).

Table 6 explains the mix planning about the test program utilized in this examination of different types. The fresh concrete was produced by mixing 1) For normal concrete the dry materials sand, cement, and the aggregate were mixed with the specified quantity of water and for (steel fiber normal concrete) after mixing, the steel fiber introduced finally to the concrete and mixed to ensure homogeneity of the mixture. 2) For concrete with ultra and high strength the dry materials sand, cement, silica fume, and the aggregate were mixed with the specified quantity of water with superplasticizer and mixed to ensure homogeneity of the mixture [27]. Finally, with three-layers, the molds are cast with concrete and the outside surface at the top of the molds is modified, and after 24 hours the concrete molds were demoulded. The cylinders were left in this condition for 28 days. An electric furnace with 1000°C capacity was used to heat the forms. Figure 4 shows the mixing and casting of molds. Figure 5 shows an illustration of the most important details of the research labour.

Fig. 4. Pictures describing the organizations **of the work.**

Table 6. Details of the proportions of concrete mixes prepared for research.

Details	Sand	Gravel	Cement	w/c	SP% by weight of cement	SF% by weight of cement	Sf % by volume	Concrete type	f'_c (MPa)
	kg/m^3								
N1	680	1000	450	0.45	0	0	0	Normal	35
N2	680	1000	450	0.45	0	0	1	Normal with fiber	39
H	800	900	550	0.38	0.5	10	0	High strength	52
UH	950	0	900	0.2	6	25	0	Ultra-high strength	78

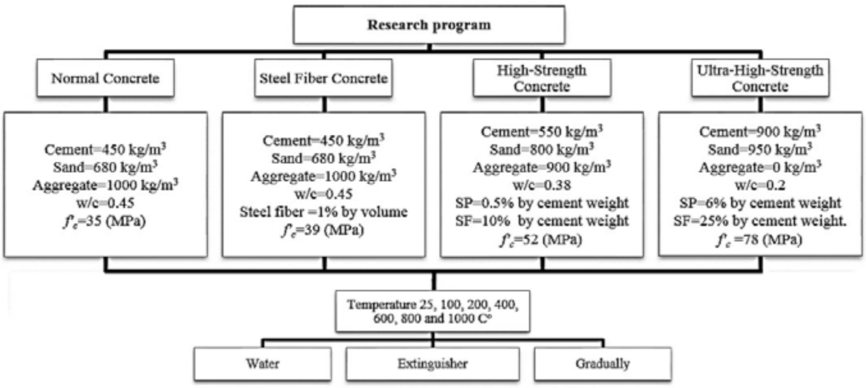

Fig. 5. Flowchart concerning research program.

3. Heating Condition and Compressive Strength

After the curing stage, the specimens were taken out and heated to the appropriate temperatures in an automatic furnace. The heating frequency is retained at 5°C/min continuously the destination temperature attained and the length of the sampling stays inside the furnace for 2 hours after the exposure to guarantee that the sample centres area approached the objective temperature. The designated temperatures were (25, 100, 200, 400, 600, 800, and 1000°C). The results of the tests carried out on test specimens cured at 28-day were used for control purposes. After heating, the specimens were cooled by three cooling methods. 1) gradually cooling the molds were kept in the laboratory room temperature in the air after it removed from the furnace (gradually) and left for one day before tested, 2) water cooling the specimen was cooled down by placing them in water with an initial temperature of 25°C immediately after heating, and 3) extinguisher cooling, the specimen was cooled down by Co_2 fire extinguisher for laboratory purposes. For all cooling methods, the process is continued until the temperatures outside the concrete drop below 200°C. Figures 6 to 8 show the types of cooling methods. Tables 7 to 10 show the compressive strength of several concrete types with various heating degrees.

Fig. 6. Extinguisher-cooling method.

Fig. 7. Water-cooling method.

Fig. 8. Gradually-cooling method.

Table 7. Strength in compression of normal concrete (N1) accompanied by seven heating degree.

Heating degree (°C)	Normal strength Concrete N1					
	f'_c (MPa)			(%)		
	Water	Extinguisher	Gradually	Water	Extinguisher	Gradually
25	35	35	35	0	0	0
100	35.2	35.2	35.4	0.57	0.57	1.14
200	34.7	34.9	35.1	-0.86	-0.29	0.29
400	30	32	34	-14.29	-8.57	-2.86
600	21.8	27	29	-37.71	-22.86	-17.14
800	18.6	22.52	25.2	-46.86	-35.66	-28.00
1000	14.3	18.65	23.5	-59.14	-46.71	-32.86

Table 8. Compressive strength of steel fiber-normal concrete (N2) with seven heating degrees.

Heating degree (°C)	Steel Fiber-Normal strength Concrete N2					
	f'_c (MPa)			(%)		
	Water	Extinguisher	Gradually	Water	Extinguisher	Gradually
25	39	39	39	0	0	0
100	39.3	39.4	39.5	0.77	1.03	1.28
200	39.1	39.1	39.2	0.26	0.26	0.51
400	34	36	38	-12.82	-7.69	-2.56
600	25	30	34	-35.90	-23.08	-12.82
800	21	25	28	-46.15	-35.90	-28.21
1000	16	21	27	-58.97	-46.15	-30.77

Table 9. Strength in compression of high strength concrete (H) accompanied by seven heating degree.

Heating degree (°C)	High Strength Concrete H					
	f'_c (MPa)			(%)		
	Water	Extinguisher	Gradually	Water	Extinguis her	Gradually
25	52	52	52	0	0	0
100	52.4	52.5	52.7	0.769	0.962	1.346
200	51.8	52	52.2	-0.38	0	0.385
400	45.2	47.6	50.6	-13.1	-8.46	-2.69
600	33.3	41	45.22	-36	-21.2	-13
800	28.4	34.2	38.3	-45.4	-34.2	-26.3
1000	22	28.5	35.6	-57.7	-45.2	-31.5

Table 10. Strength in compression of ultra-high strength (UH) with seven heating degrees.

Heating degree (°C)	Ultra-High Strength Concrete UH					
	f'_c (MPa)			(%)		
	Water	Extinguisher	Gradually	Water	Extingui sher	Gradually
25	78.0	78.0	78.0	0	0	0
100	78.7	78.8	79.1	0.90	1.03	1.41
200	78.2	77.8	79.2	0.26	-0.26	1.54
400	68.0	72.0	77.0	-12.82	-7.69	-1.28
600	50.0	63.0	68.0	-35.90	-19.23	-12.82
800	43.0	52.0	58.0	-44.87	-33.33	-25.64
1000	34.0	44.0	54.0	-56.41	-43.59	-30.77

4. Results and Discussion of the Influence of Cooling Techniques

Exposure of concrete to high temperatures is the dependent factor in the severity and appearance of fractures, as it is noticed that above 400°C, the effect of the cooling system becomes clear. Regardless of the cooling method, it is observed at less than 200°C, the heating effect is very low, but there is an increase when the temperature is increased until it reaches a maximum of 600°C, where the effect of the thermal shock becomes clear and a decrease in strength is noticed. In this research, it can be concluded with regard to the effect of cooling processes and its methods, and in comparison with gradually cooling, that cooling the extinguisher and cooling by the water may cause a significant and clear effect and more severe fracture, which causes a clear development in the appearance, development and, increase of fractures. In concrete mixture, more impact and damage were observed in concrete due to rapid cooling compared to the slow cooling method. The decrease in compressive strength as a maximum, as indicated by the results, is due to the water-cooling mode, although there was a decrease in the extinguisher's cooling mode and the gradual cooling mode. Water cooling mode produces a higher thermal shock and reduces the concrete strength by increasing the micro-cracks.

Till 200°C the water inside the concrete movies up towards the outside the specimens leading and fasting the hydration process which increases the strength of concrete and also this might be due to the less sensitivity of compressive strength to minor microcracks yields higher recovery. After the heating process, cracking began to appear, causing a loss in strength combined with the hydrated cement paste dehydration and the drying advance at a more accelerated degree including water remaining discharged out of mixtures close by the exterior creating pores that leads to strength reduction. [3, 7-8]

There are three stages within elevated temperatures due to the complex physicochemical transformations related to the micro-structural changes, these are: The first peak is correlating including the dissipation of available water and the (C-S-H) dehydration at 200°C. The second peak is related to the both (CH and C-S-H) decomposition at 550°C. The calcium carbonate decomposition at the third peak at 850°C. [3, 7-8]

Concrete matrix is formed of paste and dispersed discrete aggregate as it is recognized, the bond between cement and aggregate is weak at the contact surfaces and it will be estimated as a critical zone or zone of transition connecting the aggregate plus cement paste matrix. The decrease of compressive strength is due to the changes occurring in this zone, which is noticed it takes the responsibility, through the difference in the roughness of the surfaces of both the aggregate and cement paste composition, and as a consequence of non-thermo correlation including the cement paste and the aggregate which accordingly produces a bond failure including the aggregate surface and the cement paste. Besides other changes in physical and chemical such as aggregate expansion or mortar and cement paste shrinkage which leads to the concrete micro-cracks appearance. The higher the temperature the higher is the porosity will be produced [3, 7-8]. The changes in the porosity are accompanied by the generation of microcracks as a result of changes in the chemical constitution of the hydrated paste gel (related to the loss of adsorbed water) or building up of pore pressure or thermal incompatibility of the cement paste and the aggregate. The cooling method may affect mechanically and enhances the degree of microcracking and this results in further degradation of the compressive strength than that in concrete under heating.

Adding steel fiber generate a slight improvement in concrete characteristics. The compressive strength of fibrous concrete exhibit higher strength associated with non-fibrous concrete both before and following exposure to upraised temperatures and develops the form of failure for every heat degree examination, from immediate brittle failure to more ductile failure. Fibers control the width of the crack and connect the cracks, consequently, enhance the capacity of carrying load, strength and at high temperature develop resistance to concrete spalling [1, 2]. The increasing in residual compressive strength for steel fiber concrete (N2) compared to normal concrete (N1) are (11.43, 11.65, 12.68, 13.33, 14.68, 12.90 and 11.89% for water cooling), (11.43, 11.93, 12.03, 12.50, 11.11, 11.01 and 12.60% for extinguisher cooling) and (11.43, 11.58, 11.68, 11.76, 17.24, 11.11 and 14.89% for gradually cooling) under (25, 100, 200, 400, 600, 800 and 1000°C) respectively.

4.1. Cooling by extinguishing

Figure 9 reveals the strength in compression of several concrete types including various heating degree and extinguisher cooling method.

- For normal strength concrete (N1): There is A very slight intensification in compressive strength for 100°C around (0.57%) and compressive strength decrease of about (0.29, 8.57, 22.86, 35.66 and 46.71%) for 200, 400, 600, 800 and 1000°C, respectively.
- For steel fiber-normal strength concrete (N2): There is an advance in compressive strength for 100 and 200°C of about (1.03 and 0.26%) respectively, and compressive strength reduction of about (7.69, 23.08, 35.9 and 46.15%) for 400, 600, 800 and 1000°C, respectively.
- For high strength concrete (H): There is an addition in compressive strength for 100 and 200°C of about (0.96 and 0.0%) respectively, and compressive strength reduction of about (8.46, 21.2, 34.2 and 45.2%) for 400, 600, 800 and 1000°C, respectively.
- For ultra-high-strength concrete (UH): There is an advance in compressive strength for 100°C around (1.03%) and compressive strength reduction of about (0.26, 7.69, 19.23, 33.33 and 43.59%) for 200, 400, 600, 800 and 1000°C, respectively.

The highest rates of decrease in strength in compression are for normal mixtures, as normal concrete is the weakest type of concrete compared to other types in terms of compressive strength. As for steel fiber normal concrete, the presence of fiber has reduced the appearance of cracks, so the concrete did not weaken under the influence of high temperatures. While for the high and strength of ultra-high, the properties of the mixture lead to the increase in density and the decrease in the spaces between the concrete components, which helped reduce the temperature effect and the resistance of this type of concrete to heat. Where the maximum reduction in strength for (1000°C) compared to (25°C) are (46.71% for N1, 46.15% for N2, 45.2% for H, and 43.59% for UH).

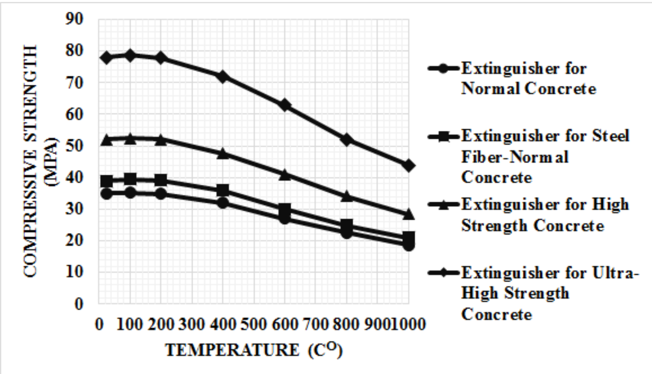

Fig. 9. Compressive strength of different concrete types with different heating degree and extinguisher cooling method.

4.2. Cooling by water

Water has been used as conventional means of extinguishing the fire for long, as it is inexpensive, freely available, removes the heat, and is non-toxic, but it may conduct electricity. Concrete is brittle and heterogeneous materials it may be considered to react adversely to the sudden shock exerted by the instant cooling so leads to loss its strength.

The strength loss pattern under rapid cooling is almost identical for all the concrete grades. This explains that higher temperature facilitates steep thermal gradient upon immediate cooling and hence is the reason for more drop in the strength. Figure 10 presents the compressive strength of different concrete types with various heating degree and water-cooling methods.

- For normal strength concrete (N1): There is an advance in compressive strength for 100°C around (0.57%) and a compressive strength reduction around (0.86, 14.29, 37.71, 46.86 and 59.14%) for 200, 400, 600, 800 and 1000°C, respectively.
- For steel fiber-normal strength concrete (N2): There is an improvement in compressive strength for 100 and 200°C of about (0.77 and 0.26%) respectively, and compressive strength reduction of about (12.82, 35.9, 46.15 and 58.97%) for 400, 600, 800 and 1000°C, respectively.
- For high strength concrete (H): There is an advance in compressive strength for 100°C around (0.77%) and compressive strength reduction of about (0.38, 13.1, 36.0, 45.4 and 57.7%) for 200, 400, 600, 800 and 1000°C, respectively.
- For ultra-high-strength mixture (UH): There is an improvement in compressive strength for 100 and 200°C of about (0.90 and 0.26%) and compressive strength reduction of about (12.82, 35.9, 44.87 and 56.41%) for 400, 600, 800 and 1000°C, respectively.

For the water-cooling method, the heated concrete subjected to a severe thermal shock that causes an increase in micro-cracking both in magnitude and amount and hence causes a severe drop in the compressive strength and it caused larger concrete damage higher than that caused by other cooling.

Here is also the normal concrete are the weakest followed by steel fiber mixture, high and concrete of ultra-high. Where the maximum reduction in strength for (1000°C) compared to (25°C) are (59.14% for N1, 58.97% for N2, 57.7% for H and 56.41% for UH).

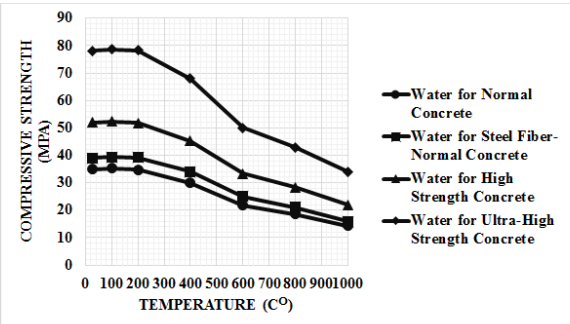

Fig. 10. Compressive strength of different concrete types with different heating degree and water-cooling method.

4.3. Gradual cooling by air

Figure 11 presents the compressive strength of different concrete types with a various heating degrees and gradually cooling methods. Figure 12 presents the compressive strength test for different heating degrees and cooling methods.

- For normal strength concrete (N1): There is an improvement in compressive strength for 100 and 200°C of about (1.14 and 0.29%) respectively, and compressive strength reduction of about (2.86, 17.14, 28.0 and 32.86%) for 400, 600, 800 and 1000°C, respectively.
- For steel fiber-normal strength concrete (N2): There is an improvement in compressive strength for 100 and 200°C of about (1.28 and 0.51%) respectively, and compressive strength reduction of about (2.56, 12.82, 28.21 and 30.77%) for 400, 600, 800 and 1000°C, respectively.
- For high strength concrete (H): There is an advance in compressive strength for 100 and 200°C of about (1.34 and 0.38%) respectively, and compressive strength reduction of about (2.69, 13.04, 26.3 and 31.5%) for 400, 600, 800 and 1000°C, respectively.
- For ultra-high-strength concrete (UH): There is an addition in compressive strength for 100 and 200°C of about (1.41 and 1.54%) respectively, and strength in compression reduction of about (1.28, 12.82, 25.64 and 30.77%) for 400, 600, 800 and 1000°C, respectively.

The decrease percentage here is less compared to the previous two cooling methods, because this method does not cause a high damage on the concrete or cause a shock to the concrete leading to the emergence of cracks. Where the maximum reduction in strength for (1000°C) compared to (25°C) are (32.86% for N1, 30.77% for N2, 31.5% for H and 30.77% for UH).

Regarding the three cooling methods and their impact on concrete, the best behaviour of concrete in terms of compressive strength is ultra-high strength concrete due to the stiffness and strength of the mixtures and also the type of materials used followed by high, steel fiber normal and normal concrete, that means the normal concrete is the weakest compared to other types of concrete.

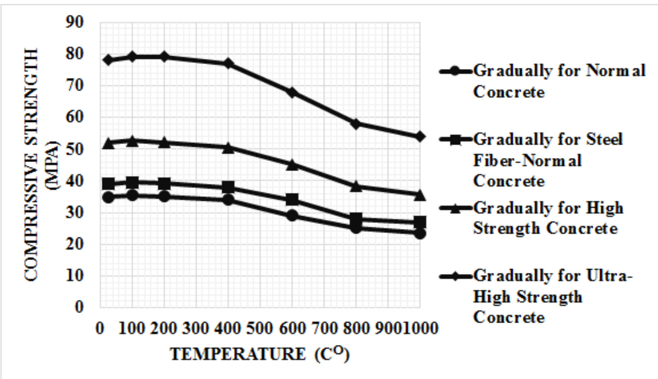

Fig. 11. Various mixture types for strength of compression with different heating degree and gradually cooling methods.

Fig. 12. Strength in compression test for cylinder for several heating degrees and cooling methods.

5. Conclusions

After completing the practical experiments and examinations, the following conclusions were reached, where the following points are the main conclusions of the research:

- There is no significant effect of heating up to 200°C on the strength in compression of mixtures of different types. But finally, the strength in compression declined as the experiment temperature developed. After 600°C, there is a higher contraction in concrete strength in compression, and the highest heat degree results in greater damage. The cooling method is a constituent influencing the mixture intensity. The decline in strength is considered to be related to the increasing of micro-crack whatever the subject elevated temperature.
- The gradually cooling method is the best method followed by the extinguisher cooling method and finally the water cooling method. Where the reduction in temperature is very slow and gradual, resulting in minimal damage compared to other cooling techniques. Fast cooling methods leads to fast volume changes and a severe thermal shock which can results in large internal stresses and leads to micro-cracking and fractures which bring about a drop in strength in compressive.
- The reduction in strength in compression was less under gradually cooling method by (32.86% for N1, 30.77% for N2, 31.54% for H and 30.77% for UH) under (1000°C) compared to (25°C).
- The ultra-high strength concrete represents the best behaviour in terms of strength in compression due to the strength and stiffness followed by high strength concrete, steel fiber concrete and finally normal mixtures.
- The strength in compression reduction for normal mixtures with cooling methods (gradually, extinguisher and water) are (32.86, 46.71 and 59.14%) respectively under (1000°C) compared to (25°C).

- The reduction in compressive strength for steel fiber concrete with cooling methods (gradually, extinguisher and water) are (30.77, 46.15 and 58.97%) respectively under (1000°C) compared to (25°C).
- The compressive strength reduction for high strength concrete with cooling methods (gradually, extinguisher and water) are (31.5, 45.2 and 57.7%) respectively under (1000°C) compared to (25°C).
- The compressive strength reduction for ultra-high-strength concrete with cooling methods (gradually, extinguisher and water) are (30.77, 43.59 and 56.41%) respectively under (1000°C) compared to (25°C).
- Adding (1%) steel fiber generate an improvement in concrete strength. The increasing in residual compressive strength for steel fiber concrete (N2) under (1000°C) were (11.89% for water cooling, 12.60% for extinguisher cooling and 14.89% for gradually cooling) compared to normal concrete (N1).
- Changing the mixtures type by adding additives to get high strength or ultra-high-strength concrete improved the compressive strength and furthermore reduce the loss in compressive strength with heat. The dense microstructure of High-strength concrete (HSC) and UHSC assumes a significant effect of cooling method and this phenomenon makes the concrete more likely to damage when cooled down.
- The increasing in residual compressive strength for high and ultra-high strength concrete (H, UH) under (1000°C) were (53.85 and 137.7% for water cooling), (52.82 and 135.92% for extinguisher cooling) and (51.49 and 129.79% for gradually cooling) compared to normal concrete (N1).

6. Recommendations for Future Works

For future experimental study and to increase the value of science, polypropylene fibers should be used or other types of fibers, to show the difference with steel fibres, firstly by studying the concrete cracks and explosion. Secondly by studying the melting of fiber and pores that will be created in concrete which leads the moisture to escape through the threaded hole.

Nomenclatures

f'_C	Cylinder compressive strength of concrete.
D	Diameter of steel fiber, mm
L	Length of steel fiber, mm
Abbreviations	
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CH	Calcium hydroxide
C-S-H	Calcium-silicate-hydrate
HRWRA	High range water reducing agent
HSC	High-strength concrete
SF	Steel fiber % by volume
SF	Silica fume by weight of cement
SP	Superplasticizer by weight of cement
UHSC	Ultra-High-Strength Concrete

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