ISSN 2347 - 3983
Volume 8. No. 7, July 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter89872020.pdf
https://doi.org/10.30534/ijeter/2020/89872020

Effects of the Exposure to Fire and Fire Extinguishing Agents on the Behavior of Building Materials

Yousef Mubarak[1], Shaden AlBtoosh[2], Zayed Al-Hamamreh[3], Aya Salman[4]
[1,4] Department of Chemical Engineering, American University of Beirut, Lebanon, ym26@aub.edu.lb
[2,3] The University of Jordan, Chemical Engineering Department, Jordan, z.hamamre@ju.edu.jo

ABSTRACT

This study investigates the effect of elevated temperatures on concrete mixes used in Jordan for building purposes; for its mechanical properties; where compression, tensile and impact tests were conducted for the mentioned materials. Additionally, a thermal conductivity test was carried out for thermal properties at ambient temperatures. Standard methods for the examination of concrete were adopted for all conducted measurements. Moreover, a comparison has been drawn between the behavior of normal strength concrete and the behavior of high strength concrete. This research study also examines the effect of the use of water and dry chemical powder extinguishers on the mechanical properties of concrete at elevated temperatures. Results have shown that a loss of concrete compressive, tensile, and impact strengthsare noticed with increasing temperatures and heating duration. The presence of additives in concrete mixtures increases the strength of both high strength concrete and normal strength concrete. Furthermore, the results have shown that the use of water and dry chemical powder as extinguishing agents and did not deteriorate further the compressive strength of the high strength concrete and normal strength concrete.

Key words: Concrete, Compressive Strength, Impact Strength, Tensile Strength, Dry Powder Chemical

1. INTRODUCTION

One of the main concerns and priorities of the construction industry is the sustainability of the buildings. The exposure to elevated temperature or fire for construction building is considered a dangerous condition that resulted in changes in the construction building materials properties; consequently, change in the behavior of buildings structure [1].Therefore, it is important to understand the responses and the behavior of structural materials that are subject to fire events in terms of materials' heat transfer characteristics and mechanical response.

The wide use of concrete as building materials has led to the need to fully understand the effect of fire on concrete structures. The concrete shows excellent fire resistance properties and sustains its integrity and strength at high temperatures events but the thermal properties of concrete rely on the types of used aggregate, due to the chemical changes in the aggregate mixtures which occur at elevated temperature [2].

Ramakrishna et al. [3] found that upto 20% of fly ash and upto 10% of recycled coarse aggregate can be used for better workability. Latha et al. [4] reported that including Bagasse ash and slag in concrete increases the compressive strength up to a percentage concentration of 8% Bagasse ash and 15% slag sand, any further increase in the concentration of Bagasse ash and slag sand would decrease the overall strength of concrete. Thermophysical, mechanical, and deformation properties of concrete affected at elevated temperatures. These properties change as a function of temperature and depend on the concrete composition of the building. Consequently, high strength concrete properties changed as a result of high temperatures more than those properties of normal strength concrete. This difference is more distinct for mechanical properties that are affected by strength, density, moisture content, heating rate, amount of silica fume, and porosity [5].

As a result of increased incidents of burning buildings, the need for assessment, repair, and rehabilitation of fire-damaged structures' research became more and more important around the world. The safety procedures on buildings during the event of fire prevents the losses in lives and assets and giving importance to fire extinguishing agents which help in controlling the spreading of fire. The available literature suggests that the cooling type, dry cooling (by air or dry chemical powder) and wet cooling (by water) affect the compressive strength which causes different stresses in reinforced concrete members at high temperature that leads to losing load-bearing ability [6]. Balendran, et al. [7]focused on the effect of the slow and quick cooling method on residual compressive strengths of HSC subjected to elevated temperature exposure. The results indicated that cooling had a significant effect on the residual values and quick cooling caused a greater loss in the split cylinder strength than slow cooling at elevated temperatures. The quick cooling was noted to produce maximum loss over slow cooling at temperatures around 400°C.

Although Ahmad[8] investigated the strength of normal concrete and reported that cooling at temperatures below 200 ^{o}C has no effect, but Khoury[9] observed that large damage and reduction in residual compressive strength appear on concrete as a result of aquenching process by cold water.Sarshar and Khoury[10]explained that cooling leads to a mechanical effect on the concrete and reduce residual strengths. The basic loss in the strength takes place due to the changes in the chemical composition/gel structure and micro-cracking due to shrinkage/drying as a result of exposure to elevated temperature. The cooling causes the thermal shock of concrete, which depends on the cooling rate.

The current research aims to investigate the performance of Jordanian normal strength concrete (NSC) and the high strength concrete (HSC) as construction building materials at elevated temperatures in the range of 200 and 800 °C for a duration of time between 60-240 min. The variation in mechanical properties of construction building materials at elevated temperature by conducting compression, tensile and impact tests; verifying if using of extinguishing agents and water effects mechanical properties of concrete at elevated temperature; and providing guidance describing how concrete structure should be designed to achieve an appropriate fire resistance according to occupancy type of buildings will all be determined and evaluated.

The importance of performing such research can be summarized as follows: 1- Categorization of the building materials according to their resistance during high temperatures helps the design engineers in determining the occupational type and providing guidance about the construction building materials that need to be selected. 2- Construction building materials that have high resistance to high temperatures conditions helps in reducing the expansion of increasing temperature and consequently reducing the likelihood of human assets and financial losses. This can be reached by performing several types of experimental tests, to understand and illustrate the changes in mechanical and thermal properties.

2. MATERIALS AND METHODS

2.1 Materials

Two grades of concrete were used in the current study. Compositions and specifications of each of these grades are shown in Table 1, Table 2 shows the source of each component; these compositions are used widely in Jordan for construction and building materials [11].

Table 1: Composition of the concrete mix used [12]

Type of	Unit	The University of Jordan		Lafarge Jordan specimen's	
		Components Weights			
		Mix(1) NSC	***Mix(2) HSC***	***Mix(1)N SC***	***Mix(2) HSC***
Cement	(kg/m^3)	100	100	270	480
Sand	(kg/m^3)	188	96	960	810
Gravel	(kg/m^3)	348	192	860	810
Water	(L/m^3)	62	39	157	168
SP70M	(L/m^3)	0	0	7.5	0
PC711	(L/m^3)	0	0	0	4
Water/cement ratio		0.62	0.39	0.58	0.35

2.2. Concrete Specimens Preparation

Concrete specimens were prepared in the civil engineering laboratories at the University of Jordan according to the standards that followed in Jordan. The required quantities of cement, sand, and gravel were weighted and then transferred to the concrete mixer. The sand and gravel were moist in advance before mixing and then mixed for 3 minutes, after that the weighted amount of cement was added as well as the remaining quantity of water. The whole ingredients were mixed further for 3 minutes. The obtained homogeneous concrete mixture is then poured into a suitable mold and a vibrating table is used to ensure good compaction. Three concrete shapes were molded; a cubical (150 mm) was used for compression testing Figure 1.a [13] and three cylindrical shapes: the first (ϕ150×300 mm) was used to conduct the splitting tensile testing Figure 1.b [14], the second (ϕ 150×60 mm) was used to conduct impact testing Figure 1.c [15] and the third one (ϕ25×102 mm) with two holes near the top and the bottom base of the specimens were used to accommodate the electrodes of the device to measure the thermal conductivity of concrete Figure 1.d [16]. The top surface of the specimen is smoothed until the specimens are demolded for 24 hours before being cast. After 28 days of curing in the water bath at a temperature of around 21 ^{o}C, the specimens were removed from the water; all concrete specimens were heated to 105 ^{o}C in an electrical furnace to dry the specimens completely before testing [17].

Table 2: The Specifications of the concrete composition [12]

	Type	Universityof Jordan		Lafarge Company	
		Source	***Producer***	***Source***	***Producer***
Cement	CEM 11/A-P 42.5N	Thabet Cement	Lafarge Company	Thabet Cement	Lafarge Company
Sand	Sand	Mahes	Mahes Crusher	Swieleh	Jordanian Ghor crusher
Gravel	Gravel	Dogara	Dogara Crushers	Dogara	Dogara Crushers

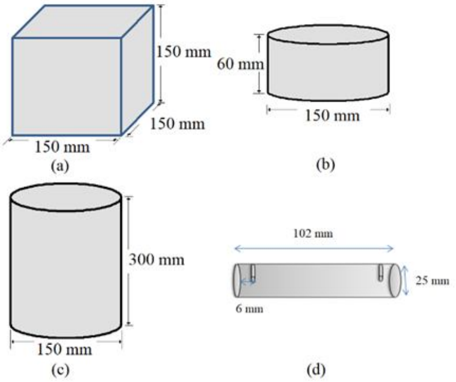

Figure 1: Dimensions of concrete specimens (a, b, c, d)

Samples were left in the electric furnace for at least 24 hours before they removed and their weights, densities, and dimensions were measured and recorded. Another batch of concrete specimens was prepared at Lafarge Company. Superplasticizer (called high range water reducers) is used as an additive to these specimens to increase the strength of concrete. Lafarge Company claims that the addition of the superplasticizer to concrete composites reduces the water content. The amount of the additive added to concrete composite must be optimized to allow for water % reduction and in the meantime to allow the concrete composite for easy flowing [18].

2.3 Methods and Characterization

The temperature of the prepared specimens NSC and HSC was raised to the specified temperature (200, 400, 600, and 800 °C) and maintained at this temperature in the electric furnace fora duration of time of (30, 60, 120, and 240 minutes). Upon removal of each set of specimens from the electric furnace, each set was cooled down to room temperature by three modes of cooling. For each set, some of the samples were left to cool naturally through the air; some of the samples were cooled down using water with a pressure of 300 kPa and a temperature of 25 °C while some of the samples were cooled down to the ambient temperature by the aid of a dry chemical powder extinguisher (ABC).

Compressive, tensile, impact, and thermal tests were carried out for concrete specimens when they get cooled down to room temperature following the standard procedures and equipment [14].

2.4 Mechanical Testing

Compressive and splitting tensile strength tests were performed according to the general technical specifications for building in Jordan [13,14]. These tests were conducted using a compressive machine of model number C058PD111 which has a 2000 KN in capacity with dimensions of 870 x 600 x 1400 mm and a power supply (motorized models): 230 V 1ph 50 Hz 750 W and compression platens 510 x 320 x 55 mm. Drop hummer equipment was used for concrete impact testing according to ACI-544 [15]. A drop hummer equipment [model number: HM-551 ASTM which has a 10 lb. (4.5kg) mass and 18 in (457mm) drop was used in the present work to perform the impact tests. The force at which the specimen is failed under compressive, tensile or impact is used to calculate the strength of the concrete specimen.

2.5 Thermal Testing

Cusson's thermal conductivity apparatus- p5687 was used to measure the value of the thermal conductivity of concrete specimens according to a standard procedure mentioned by Yan et al. [16].

3.RESULTS AND DISCUSSIONS

3.1 Compressive Strength Tests

3.1.1Influence of Temperature and Heating Duration on Compressive Strength

The compressive strength values for NSC and HSC concrete specimens that were heated for temperatures (200, 400, 600, and 800°C) for different heating durations (30, 60, 120, and 240 min) are tabulated in Table 3. As clearly seen, the compressive strength decreases as both the temperature and the heating duration increase starting from 200°C considering that the reference specimens were tested at 100°C to ensure that the concrete was completely dried. The results presented in Figures 2 and 3 show a little increase in concrete compressive strength for NSC and HSC when the temperature increases from 100 to 200°C due to the chemical reaction that occurs at low temperatures which increases the concrete strength, while in general the compressive strength of concrete decreases with temperature and heating duration increase. The percentage of the loss in compressive strength after heating relatively to the reference compressive strength of concrete was also studied and shown in Table 4.

Table 3: Compressive strength of heated NSC and HSC in (MPa) at different heating durations

Temp. (° C)	**30 minuets**		**60 minuets**		**120 minuets**		**240 minuets**	
	HSC	***NSC***	***HSC***	***NSC***	***HSC***	***NSC***	***HSC***	***NSC***
100	62.7	39.6	62.7	39.6	62.7	39.6	62.7	39.6
200	63.1	39.8	63.6	40.8	46.3	20.0	44.5	19.6
400	59.5	37.0	54.6	34.1	40.6	16.7	39.6	13.7
600	53.7	31.8	51.4	29.2	35.9	11.9	31.4	11.4
800	48.4	29.2	42.0	24.5	31.2	11.1	26.2	10.3

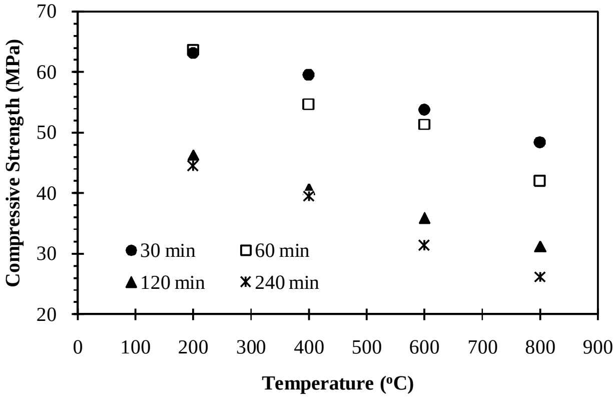

Figure 2: Compressive strength of heated HSC samples at different heating durations

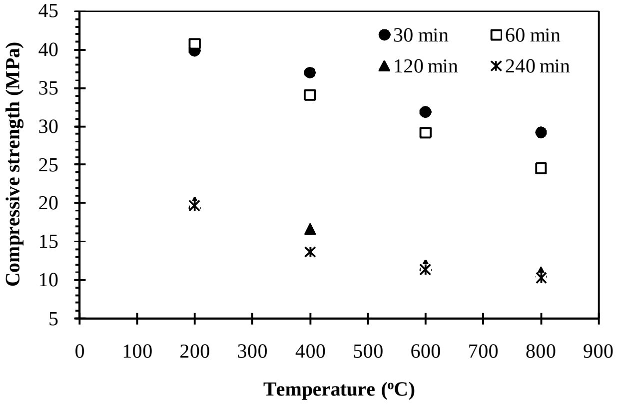

Figure 3: Compressive strength of heated NSC samples at different heating durations

The results in Figure 4 show that the relative compressive strength loss of HSC concrete is gradually increased on 30min from 5% at 400°C to 23% at 800 °C for and from 6% at 400 °C to 26% at 800 °C for NSC as in shown in Figure 5. At 120 minutes heating duration, the loss in compressive strength is about 36-50 % for HCS and 57-72% for NCS at 400-800°C respectively, while, at 240 minutes the loss in HSC compressive strength is 37% to 58% and from 65% to 74% for NSC at 400-800°C respectively as presented in Table 4. These results are compatible with Toumi, et al. results [19], who explained that concrete compressive strength decreases as the heating duration increases for both NSC and HSC at different temperatures; in addition to that, the authors reported that HSC has more strength compared to NSC at the same conditions.

Table 4: Compressive strength loss values for heated NSC and HSC at different heating durations.

Temp. (° C)	**30 minutes**		**60 minutes**	
	HSC	***NSC***	***HSC***	***NSC***
200	-0.0065	-0.0054	-0.0148	-0.030
400	+0.052	+0.06	+0.128	+0.13
600	+0.14	+0.19	+0.179	+0.26
800	+0.23	+0.26	+0.32	+0.38
Temp. (° C)	**120 minutes**		**240 minutes**	
	HSC	***NSC***	***HSC***	***NSC***
200	+0.26	+0.49	+0.29	+0.50
400	+0.35	+0.57	+0.34	+0.65
600	+0.43	+0.69	+0.49	+0.71
800	+0.50	+0.72	+0.58	+0.74
+ Loss of strength, - Gain of strength				

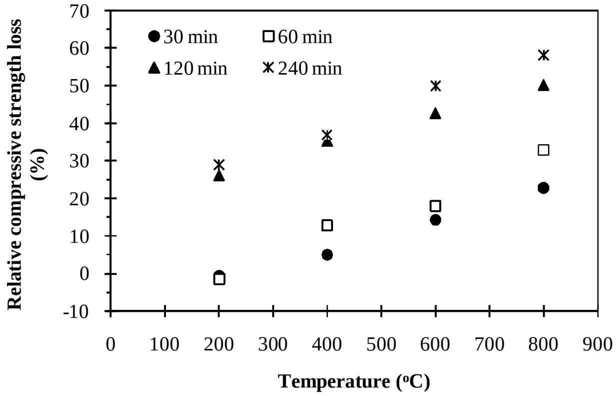

Figure 4: Relative compressive strength loss of heated HSC samples at different heating durations

Figure 6 shows the concrete compressive strength for the current research compared to Toumi's results after a 1-hour heating duration at different temperatures. On the other hand, Toumi, et al. [19] reported that all their tested concretes have revealed a compressive strength loss. Concrete compressive strength after 3 hours of heating duration at 700 °C experienced a high reduction in concrete compressive strength of around 61% for NSC and 71% for HSC. An acceptable explanation for the reduction in concrete compressive strength as a result of exposing to high temperature can be attributed to the changes occurred in the concrete microstructure as a result of some complicated processes occurred such as shrinkage, decomposition, volume expansion and crystal destruction [20].

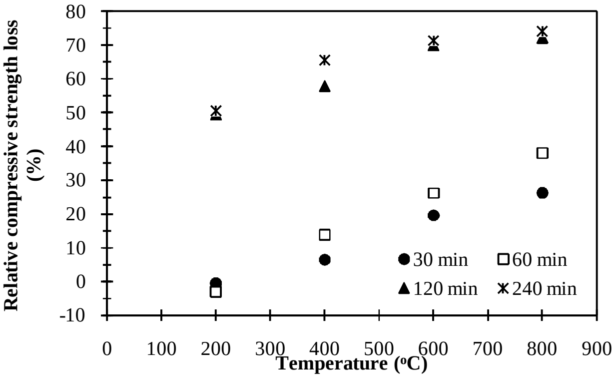

Figure 5: Relative compressive strength loss of heated NSC samples at different heating durations

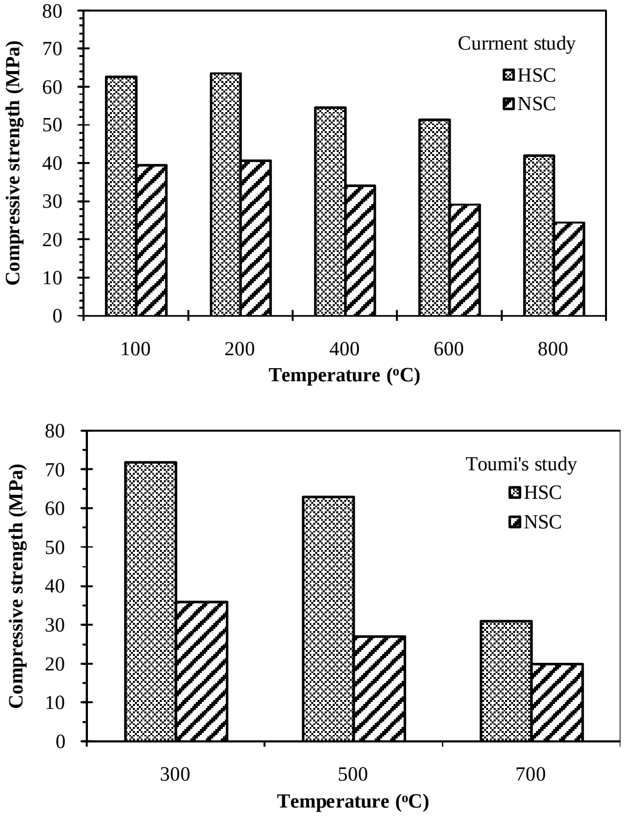

Figure 6: Comparison of heated HSC and NSC compressive strength between the current research results and Toumi's results

3.1.2 Effect of Concrete Grade on the Compressive Strength

As shown above, HSC possesses higher compressive strength values compared to NSC; this can be attributed to the reduced water content that exists in the HSC. Adding more water to the concrete mixture creates a diluted cement paste which will lead and cause a concrete weakness and more liable to cracking and shrinkage possibilities and by the end this will lead to a further reduction in the concrete compressive strength as a result of the increase of water/cement ratio. Also, shrinkage leads to micro-cracks, which represent the zones of weakness in the concrete. When a fresh concrete mix is placed in the mold, excess water is squeezed out of the paste so that the large quantity of the excess water starts to bleed out to the concrete surface. The microchannels and passages which are created inside the concrete will allow water drops to flow, so, weak zones and micro-cracks will be formed internally [21]. Apebo and Shiwua [22] reported that decreasing the water/cement ratio from 0.6 to 0.4 will increase concrete compressive strength by about 30%. In the current study, the obtained compressive strength value of HSC is 48% greater than that of NSC. Moreover, a general relation between the water/cement ratioand concrete compressive strength as shown in Figure 7, the figureshows that increasing the water/cement ratio will decrease the concrete compression strength [23].

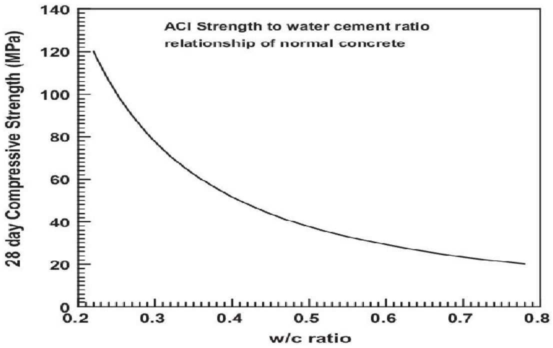

Figure7: The Relation between Water/Cement ratio and the concrete strength

3.1.3 Effect of Additives on Concrete Compressive Strength

Concrete compressive strength was studied experimentally for both concrete specimens', those with and without additives. The additives were added to the concrete mix for Lafarge company specimens, while the university's specimens were free of any additives. Figure 8 reveals that there is a noticeable difference between the compressive strength values for both HSC and NSC with and without the additives. It has been found that the presence of the additives increased the compressive strength by 28% for HSC and by about 90% for NSC.

The study results are in good agreement with Ahmad's results [24], who studied the effects of using additives on concrete compressive strength and reported that the addition of these additives to the concrete mix increases their compressive strength. It has also been reported that the addition of these additives to the concrete mix has many benefits not only increasing the compressive strength but also reducing the water content required to prepare the homogenous and flowable concrete mix [18].

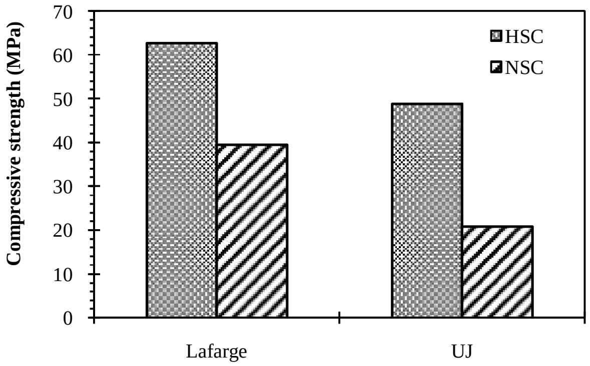

Figure 8: Effect of additives on concrete compressive strength

3.1.4 Effect of Extinguishing Agents on Concrete Compressive Strength

On completion of heating cycles, concrete specimens were cooled down by two modes: natural and quick cooling. For natural cooling: concrete specimens were left in the air to cool down to the ambient temperature whereas for quick cooling: concrete specimens were cooled down using water extinguisher or ABC dry chemical powder extinguisher followed by natural cooling [25]. All concrete specimens were heated up to the required set temperature for 2 hours before cooled down to ambient temperature. Figure 9 presents the effect of the cooling mode on concrete compressive strength. It seems that the cooling method has little effect on the compressive strength of concrete regardless if the hot concrete specimens cooled naturally or quickly.This can be attributed to the fact that water and the dry chemical powder are used for cooling only; there is no chemical reaction that may affect the concrete compressive strength.

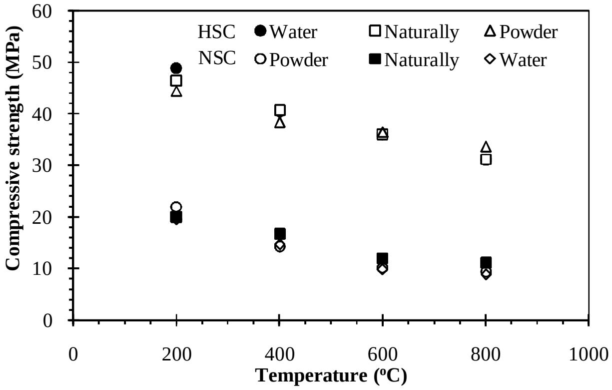

Figure 9: Effect of cooling mode on concrete compressive strength

Luo and Chan [26] studied the effect of water cooling on concrete compressive strength and found that water cooling caused only a little deterioration in concrete compressive strength. On another hand, Balendran, et al. [7] reported that the cooling method has a distinctive effect on high strength concrete compressive strength. The authors claimed that quick cooling leads to more drop-in HSC compressive strength when compared with slow cooling, the drop is pronounced at 400°C.Figure 10 represents a comparison between the obtained results in the present study andBalendran, et al. [27]results.

The authors studied the changes in compressive strength of HSC at 200°C, the results displayed that cooling water has a noticeable effect on concrete strength while according to the present research the effect of cooling water on concrete compressive strength is small.

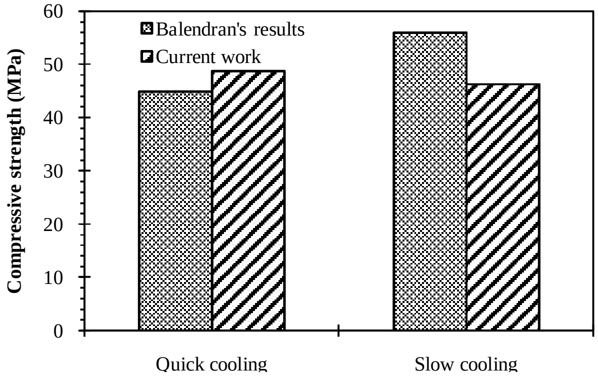

Figure 10: Comparison between Balendran's and the current research results

3.2 Concrete Splitting Tensile Strength

Photographs of both HSC and NSC specimens before and after tensile splitting are shown in Figure 11, while concrete splitting tensile strength values for both concrete samples are demonstrated in Figure 12. All concrete specimens were kept at the required set temperature for one hour before testing. It is seen that increasing the concrete specimen's temperature up to 200 °C leads to an increase in the tensile strength due to chemical reactions occur at low temperatures while increasing the concrete specimen's temperature above 200 °C leads to a decrease in the tensile strength as shown in Figure 12. The results presented in Figure 13 shows that the tensile splitting strength of HSC is reduced by around 30% when heated up to 800 °C for one hour before testing, but in the case of NSC, the concrete splitting tensile strength reduced by about 52%. The tensile strength at 600 °C decreased by about 32% for NSC and approximately reduced by about 18% for HSC.

Figure 11: Concrete specimens before and after splitting tensile testing

Ayudhya [28] confirmed that the splitting tensile strength of concrete decreases with temperature increase. This reduction in the concrete splitting tensile strength results from the changes that occur in concrete specimens during the heating process; as a result, the shrinkage will be experienced by the dehydration of cement paste. Also, the reduction in the tensile splitting strength with temperature increase can be attributed to the oscillation of the molecules or atoms of the material due to their internal energy which increases by increasing the temperature. Since the tensile splitting strength depends on the mean distance between the molecules/atoms within the material, then as the temperature increases, the mean distance between the molecules increases leading to a lower level of tensile splitting strength.

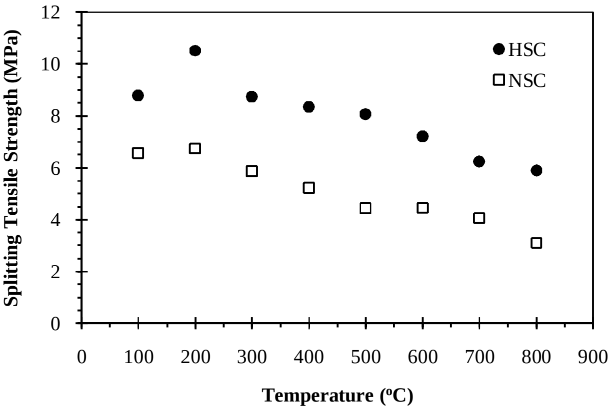

Figure 12: Concrete splitting tensile strength of heated concrete specimens

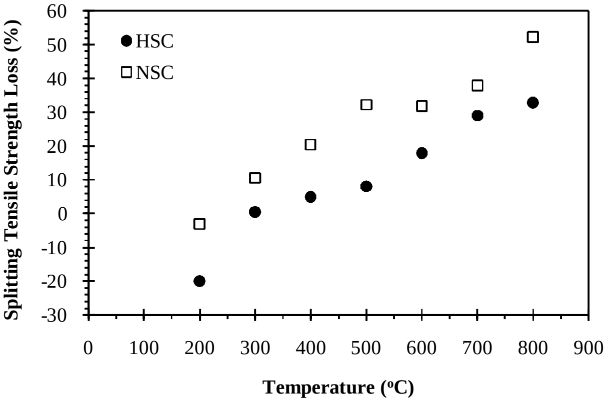

Figure 13: Splitting tensile strength loss as of heated concrete specimens

3.3 Concrete Impact Strength

The impact energies of heated NSC and HSC specimens at 100, 200, 300, 400, 500, 600, 700, and 800 °C and then cooled naturally are presented in Figure 14. The figure reveals that increasing concrete samples temperature before cooling down leads to a decrease in the impact energy required to break the concrete sample for both concrete mixes the NSC and HSC. For HSC specimens, increasing the temperature to 400 °C decreases the impact energy by about 41% while increasing the temperature to 800°C reduces the impact energy by 91%. On the other hand, increasing the temperature of NSC samples to 400 °C leads to a decrease in the impact energy by 58% and at 800 °C the specimens lost 92% of their impact strength.

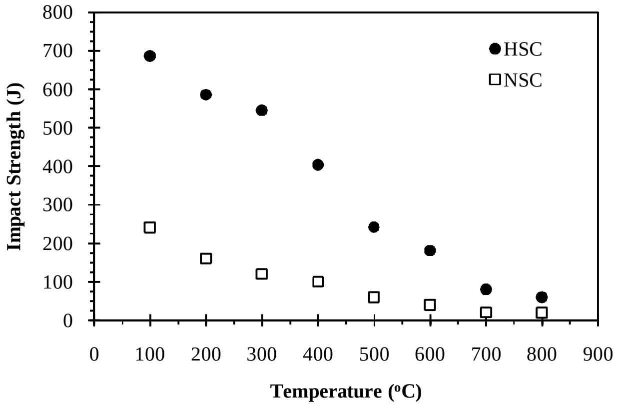

Figure 14: Impact energy of heated concrete specimens before cooled down to ambient temperature

Rao and Prasad [29] showed that the fracture energy increases as the compressive strength increases. The fracture energy is considered as the energy utilized in overcoming the cohesive forces due to aggregate bridging, friction force, and other mechanisms in the fracture zone. Darwin et al. [30] reported that high-strength concrete containing higher strength coarse aggregates like basalt attains significantly higher compressive strengths and fracture energy, while the normal strength concrete containing coarse aggregate strength like limestone has lower compressive strength values and fracture energy.

The results of the current study are compared to the results of Kulkarni and Patil [31] as shown in Figure 15. It is clearly seen that the absorbed energy to fracture decreases by increasing the NSC specimen temperature when it is heated for one hour before naturally cooled and tested. Although Kulkarni and Patil [31] results were for concrete grade 20 while grade 25 is used in the current study; both results show a decline in the absorbed energy to fracture as the temperature increases.

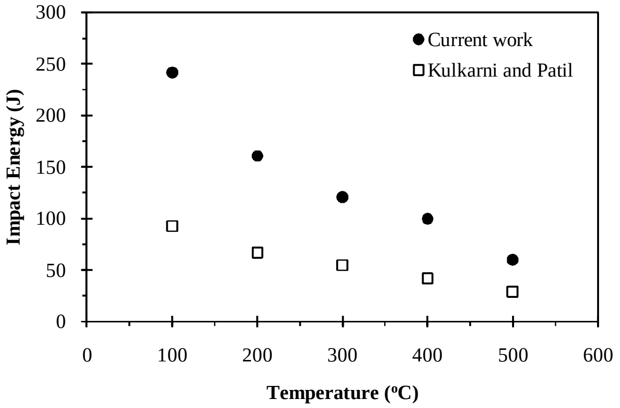

Figure 15: Comparison between impact energies of the current study and Kulkarniand Patil results

Furthermore, the impact energy of heated NSC and HSC specimens after cooled down by different cooling modes is presented in Figure 16. Three cooling modes were used: for the slow cooling mode, the specimens were left in the air until they reached the ambient temperature, while for the quick cooling mode two procedures were implemented. In the first procedure, the hot concrete specimens were submerged in cold water for 1 minute and then followed by natural cooling to room temperature, while in the second procedure the hot specimens were subjected to the extinguishing agents until the specimen's temperature decreases then followed by natural cooling to room temperature.

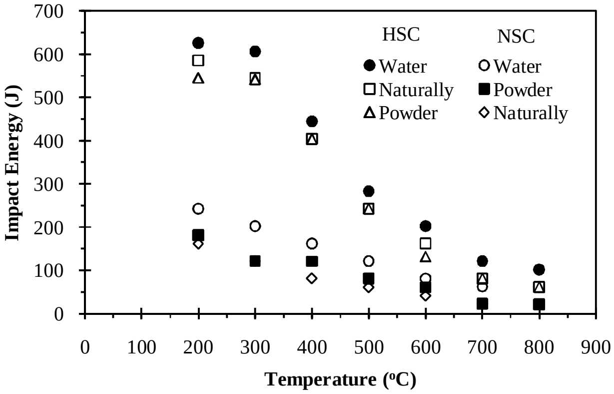

Figure 16: Effect of cooling mode on heated NSC and HSC impact Energy.

In terms of impact strength, the susceptibility of HSC to temperature is much higher when compared to NSC as can be clearly seen in Figure 16. A dramatic loss in the impact energy values obtained for heated HSC and ranged between 84 to 90 %, while for the heated NSC the loss ranged between 75 to 89 % when the specimens heated up from 200 to 800 °C. The figure reveals that regardless of the mode of cooling, the loss in the impact energy values for both HSC and NSC specimens was considerable and summarized in Table 5. Zhang and Bicanic [32] studied the effect of slow and quick cooling on the impact energy of concrete beams, the results presented in their published work show that the impact energy of concrete beams decreases more when the beams cooled down from high temperature to room temperature quickly. Figure 17 shows a real photograph for the deformed concrete specimens after conducting impact tests for both NSC and HSC grades.

Figure 17:HSC and NSC deformed concrete specimens after conducting impact tests

3.4 Concrete Thermal Conductivity

Thermal conductivity is the ability of the material to conduct heat. Concrete thermal conductivity affected by many factors such as the moisture content, type of aggregate, porosity, density, presence of fiber, and temperature[16]. Therefore, the importance of studying concrete thermal conductivity arises since low thermally conductive concrete is a construction solution in buildings; low thermal conductivity results in a higher thermal resistance, and hence can reduce energy losses through the fabric of a building and prevent the spread of smoke, heat and high temperature through it.

Table 5: Impact energy loss (%) values for heated HSC and NSC

Temperature °C	**HSC cooled by water**	**HSC cooled naturally**	**HSC cooled by powder**
300	3.2	6.9	0.7
400	29.0	31.0	25.9
500	54.8	58.6	55.6
600	67.7	72.4	75.9
700	80.7	86.2	85.2
800	83.9	89.7	88.9
Temperature °C	**NSC cooled by water**	**NSC cooled by powder**	**NSC cooled naturally**
300	16.7	33.1	25.0
400	33.3	33.7	50.0
500	50.0	55.4	62.5
600	66.7	66.9	75.0
700	74.6	87.8	86.9
800	75.0	88.8	87.5

The thermal conductivity values for HSC and NSC specimens used in the current study were measured at room temperature to be 4.204 and 4.08 respectively. The values obtained are not far from those published in the literature. Although the obtained thermal conductivity for HSC is slightly higher than NSC but on average, the thermal conductivity of conventional normal strength concrete, at room temperature, is reported to be within the range from 1.4 to 3.6 W/m.°C[33]. According to Venkatesh [34], cement has the highest thermal conductivityout of all concrete components, and conductivity of water is lower than half of the conductivity of cement paste and hence increasing the water/cement ratio will drop down the thermal conductivity of the concrete. Yan, et al. [16]studied the thermal conductivity of concrete and claimed a value of around 2.33 W/m.°C. The difference between Yan's results and the current research results is due to the difference in the concrete mixture properties, the natural composition of aggregates like mineral properties of aggregates. The orientation of crystals also affects the conductivity as conductivity increases with the increase in crystal properties of aggregates.

4. CONCLUSION

The effect of elevated temperatures on the mechanical properties of concrete was studied by conducting a series of experiments following standard procedures. The investigation procedure includes the compressive strength, splitting tensile strength, and impact testing for heated NSC and HSC for a heating duration between 30 minutes to 4 hours. Moreover, the thermal conductivities of concrete specimens were estimated. The compressive strength loss for the heated NCS and HCS increases as the temperature and the heating duration increase where the loss increased from 5% at 400°C to 23% at 800°C for heated HSC specimens based on 30 min heating duration and from 6% at 400°C to 26% at 800°C for heated NSC specimens. When heated at 800°C for 240 minutes, the loss in compressive strength was estimated to be 58% for HSC specimens and 74% for NSC specimens. The presence of the additives in the concrete mixture increases the compressive strength by 28% for HSC and by about 90% for NSC. The addition of a super plasticizer to concrete mixes reduces the required quantity of water to prepare a homogeneous concrete mix and hence increases the compressive strength. It is concluded that the cooling methods used in the current study have little effect on the compressive strength of concrete regardless of the specimens cooled naturally or quickly. The splitting tensile strength of HSC is reduced by around 33% when the specimens are heated to 800°C for 1 hour, while reduced by 52% in the case of NSC under the same conditions. It has been found that exposing concrete specimens to high temperatures before cooling down and testing leads to a similar reduction in the impact energy to fracture the specimens for both HSC and NSC.

REFERENCES

1. S. Yehia and G. Kashawneh. **Performance of Structure Exposed to Extreme High Temperature**,*Open Journal of Civil Engineer*, pp.154-161, 2013. https://doi.org/10.4236/ojce.2013.33018
2. U. Schneider. **Concrete at high temperatures - A general review**,*Fire safety journal*,vol.13, pp. 55-68, 1988.
3. B. Ramakrishna, B. Harshini, G.N.K. Lakshmi, K. Sangireddy, K. Pavan Krishna Prasad. **Influence of fly ash on the properties of recycled coarse aggregate concrete**, *International Journal of Emerging Trends in Engineering Research*, vol. 8, no. 5, pp. 2097-2100, May 2020. https://doi.org/10.30534/ijeter/2020/101852020
4. M.S. Latha, B.M. Naveen Kumar, M. Revanasiddappa, R. Deepika, and M.P. Rudraswamy. **Strength Characteristics of High Performance Concrete using Bagasse Ash and Slag Sand**, *International Journal of Emerging Trends in Engineering Research*, vol. 8, no. 6, pp. 2486-2489, June 2020. https://doi.org/10.30534/ijeter/2020/45862020
5. V. Kodur, T. Wang, and F. Cheng. **Predicting the Fire Resistance Behavior of High Strength Concrete Columns**,*Cement and Concrete Composite, National Research Council Canada,* vol.26, pp.141-153, 2004.
6. R. S. Patil.**Effect of Elevated Temperature and Type of Cooling on M20 Grade Concrete Using**

Fibers,*International Journal of Science and Research,* vol.3, pp.2319-7064, 2014.

7. R. Balendran, W. Tang, A. Nadeem, P. Kamineni, and T. Masood. **Effect of Cooling Methods on Residual Compressive**, *Our World in Concrete & Structures*, 26th Conference, Singapore, pp.233-240, 2003.
8. M.S. Ahmad. **Effect of Sustained Elevated Temperature on Mechanical Behavior of Reinforcing Bar**,*Science Direct*, vol.173, pp.905-909, 2017.
9. G. A. Khoury. **Compressive Strength of Concrete at High Temperatures: a reassessment**,*Magazine of Concrete Research*, vol.44, no. 161, pp.291-309. 1992. https://doi.org/10.1680/macr.1992.44.161.291
10. R. Sarshar, and G. A. Khoury.**Material and Environmental Factors Influencing The Compressive Strength of Unsealed Cement Paste and Concrete at High Temperatures**,*Magazine of Concrete Research,* vol.45, pp.51-61. 1993.
11. M. Imam.**The Concrete**, 4th ed., Mansoura University, Egypt, Alam Alkottob publisher, 2003.
12. S. AlBtoosh. **The Impact of the Exposure to Fire and Fire Extinguishing Agents on the behavior of Jordanian Construction Materials**, M.S. thesis, The University of Jordan, Amman, Jordan, 2017.
13. Ministry of Public Works and Housing in Jordan.**The General Technical Specification for Buildings in Jordan**, Amman, Jordan, 1996.
14. C. Dos Santos, and J. Rodrigues. **Experimental Testing on The Residual Mechanical Properties of Ordinary Concretes after Fire**,*Journal of steel structure and construction,* vol.15, pp.22-27, 2012.
15. W. Song, and J. Yin.**Hybrid Effect Evaluation of Steel Fiber and Carbon Fiber on the Performance of the Fiber Reinforced Concrete**,*Materials,* vol.9, pp.1-12, 2016. https://doi.org/10.3390/ma9080704
16. K. Kima, S. Jeonb, J. Kimb, and S. Yan.**An Experimental Study on Thermal Conductivity of Concrete**,*Cement and Concrete Research,* vol.33, pp.363-371, 2003.
17. A. Lau, and M. Anson.**Effect of High Temperatures on High-Performance Steel Fiber Reinforced Concrete**,*Cement and Concrete Research,* vol.36, pp.1698–1707, 2005.
18. Americas Chemical Manufacturers.**Chemical Admixture**, Skokie, Illinois, 2017.
19. B. Toumi, M. Resheidat, Z. Guemmadi, and H. Chabil.**Coupled Effect of High Temperature and Heating Time on the Residual Strength of Normal and High-Strength Concretes**,*Jordan Journal of Civil Engineering,* vol.3, pp.322-330, 2009.
20. M. Li, C.X. Qian, and W. Sun.**Mechanical Properties of High-Strength Concrete after Fire**,*Cement and Concrete Research,* vol.34, pp.1001-1005, 2004.
21. The Concrete Countertop Institute.**The importance of water/cement ratio in concrete countertop mix design**, Girard, 2011.
22. N. Apebo, and J. Shiwua.**Effect of Water-Cement Ratio on the Compressive Strength of gravel - crushed over burnt bricks concrete**,*Civil and Environmental Research,* vol.3, pp.2224-5790, 2013.
23. The Constructor Civil Engineering Home.**Properties of Concrete**, Mishara, Gopal, 2017.
24. A. M. Ahmad.**The Effect of Admixtures on Concrete Properties**, M.S. thesis, University of Khartoum, Khartoum, Sudan, 2010.
25. W. Botte, and R. Caspeele, **Post-cooling properties of concrete exposed to fire**,*Fire Safety Journal,* vol.92, pp.142–150, 2017. https://doi.org/10.1016/j.firesaf.2017.06.010
26. X. Luo, and S. Chan. **Residual Compressive Strength and Microstructure of High-Performance Concrete after Exposure to High**,*Materials and Structures/Materiaux et Constructions,* vol.33, pp.294-298, 2000.
27. R. Balendran, T. Maqsood, and A. Nadeem.**Effect of cooling method on residual compressive strength of high strength concrete cured for 28 days and 180 days and heated to elevated temperatures**,*Our World in Concrete & Structures, Singapore*, 26th Conference, Singapore, pp.183-190, 2001.
28. B. Ayudhya.**Compressive and Splitting Tensile Strength of Autoclaved Aerated Concrete (AAC) Containing Perlite Aggregate and Polypropylene Fiber Subjected to High Temperatures**,*Songklanakarin Journal of Science and Technology,* vol.5, pp.555-563, 2011.
29. G. Rao, and B. Prasad.**Fracture Energy and Softening Behavior of High-Strength Concrete**,*Cement and Concrete Research,* vol.32, pp.247–252, 2001.
30. D. Darwin, S. Barham, R. Kozul, and S. Luan.**Fracture Energy of High-Strength Concrete**,*ACI Materials Journal*, 98-M45, 2001 https://doi.org/10.14359/10731
31. D. Kulkarni, and S. Patil.**Laboratory and Analytical Study of Permeability and Strength Properties of Pervious Concrete**,*International Journal of Engineering and Technology,* vol.3, pp.106-118, 2011.
32. B. Zhang, and N. Bicanic.**Fracture energy of high-performance concrete at temperatures up to 450 ^{o}C**,*In: Fourth International Conference on' Fracture Mechanics of Concrete and Concrete Structures' (FRAMCOS 4),* Cachan, France, 28 May-1 June, pp.461-468, 2001.
33. Z. P. Bažant, and M. F. Kaplan.**Concrete at High Temperatures: Material Properties and Mathematical Models**, Longman Group Limited, Essex, UK, 1996.
34. K. Venkatesh.**Properties of Concrete at Elevated Temperatures**,*ISRN Civil Engineering*, 2014, Article ID 468510, https://doi.org/10.1155/2014/468510.