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Behaviour of Different Types of Concrete Beams after exposure to Elevated Temperatures

Laila Abd-EL-Hafez[1,3] ,Faisal Aldhafairi [1], Ahmed Hassan[2] , and Alaa Abouelezz[1]

[1] *Civil Engineering Department, Minia University, Minia, Egypt.*

[2] *Civil Engineering Department, Beni-suef University, Egypt.*

[3]*Civil Engineering Department, Nahda University, Beni-suef, Egypt.*

(3. Corresponding author: Ahmed Hassan email: Ahmed.bakhit@liverpool.ac.uk*)*

ABSTRACT

Concrete industry development allowed using different types of concrete more than conventional concrete as high strength and self-compacting concrete. Conventional concrete beams have a significant reduction in their strength after fire exposure. An experimental program is designed to investigate the effect of different levels of elevated temperature on the most common concrete types. Fifteen beams cast using Normal, Self-Compacting and High Strength concrete beams. Twelve beams subjected to 400 ^{o}C and 600 ^{o}C for one hour and two hours to study the beam behavior under indirect fire conditions. The exposure time has a great effect on the different beams behavior especially the normal concrete which has a dramatic reduction after subjected to 600 ^{o}C for 2 hours. Self-compacting concrete beam has acceptable behavior under elevated temperature conditions to 600 ^{o}C.

Keywords: Elevated Temperature, Normal, self-compacting, high strength concrete.

INTRODUCTION

In recent years the development of concrete industry is increased. Self-compacting (SCC) and high strength concrete (HSC) are the main types beside confidential normal concrete (NC). The number of researches was achieved to study the elevated temperature effect on the concrete element. The reduction after elevated temperature exposure to high strength concrete leads to losses in smaller specimens [1]. Self-compacting high strength concretes residual mechanical properties were similar to that of conventional HSC [2] while the risk of spalling for self-compacting high strength concrete was greater than that of conventional HSC. By increasing temperature level, the hot compressive strength of SCC decreased [3]. The grade of concrete had a significant effect on the residual strength of concrete, especially less than 400^{o}C. More reduction of strength reported with higher grades of SCC. But this difference was found to be less in the permanent strength loss stage [3]. Evaluating temperature distribution through the cross sections concluded by a simplified approach for reinforced concrete members under fire exposure[4]. The cooling method effected directly on the flexural strength and residual compressive the effect being more pronounced as the temperature increased [5]. The weight of the specimens significantly reduced with an increase in temperature. This reduction was very sharp beyond 800^{o}C. The effects of water/cement ratio and type of aggregate on losses in weight were not found to be significant. The results also revealed that the relative strength of concrete decreased as the exposure temperature increased [6]. Traditional concrete exposed to high temperature undergoes a series of physicochemical changes in its structure; causing gradual to a sharp loss in its mechanical strength and durability, cracking, and sometimes spalling [5-7]. Data compiled from fire experimental tests stipulated clear differences in performance between SCC and traditional concrete at elevated temperature because of

differences in microstructure properties represented in porosity, pore size distribution, and pores connectivity [8, 9]. Recently, most of the published works were directed towards understanding the thermal performance of SCC with emphasis on microstructure, phase composition, and mechanical and thermal properties [10-12].
In this study to evaluate the performance of different type of concrete normal, self-compacting and high strength concrete, fifteen beams were casted and tested. The temperature levels were 400^{o}C and 600^{o}C for 60 and 120 min exposure time.

EXPERIMENTAL PROGRAM

Test specimens geometric and materials configuration, and investigated parameters

Rectangular cross-sections of reinforced concrete beams casted with size 120 mm (width) × 300 mm (height) × 1400 mm length. All beams have the same reinforcement 2 bars 10 mm diameter for bottom, top reinforcement and 8-mm-diameter Stirrups are used for shear resistance, with spacing at 8 cm as shown in Fig. 1. Two different levels of elevated temperature 400°C and 600°C for one and two hours used to study the effect of elevated temperature levels and durations. The electrical furnace used to expose the specimens to the suggested rates of temperature levels. The furnace temperature rate are compatible according to ASTM 119 [13] as shown in Fig. 2. After elevated temperature exposure, Reinforced concrete beams were left to cool gradually for one day. Three points flexural testes used to evaluate the reduction of beam capacity after elevated temperature exposure for the control beams. The rest of the beams retrofitting by steel jacket technique and CFRP laminates technique, and then tested to ass the behavior and the beam capacity restore compared to the unheated control beams. Table (1) shows the all specimens, conditions and coding.

Fig. 1: Geometry and steel reinforcement for tested beam

Table 1: Specimens coding for concrete beams

specimen	Temperature	Duration
N	25	-------
N 400 1 hr	400	1 hr
N 400 2hr	400	2hr
N 600 1 hr	600	1 hr
N 600 2 hr	600	2hr
S	25	-------
S 400 1 hr	400	1 hr
S 400 2hr	400	2hr
S 600 1 hr	600	1 hr
S 600 2 hr	600	2hr
H	25	-------
H 400 1 hr	400	1 hr
H 400 2hr	400	2hr
H600 1 hr	600	1 hr
H600 2 hr	600	2hr

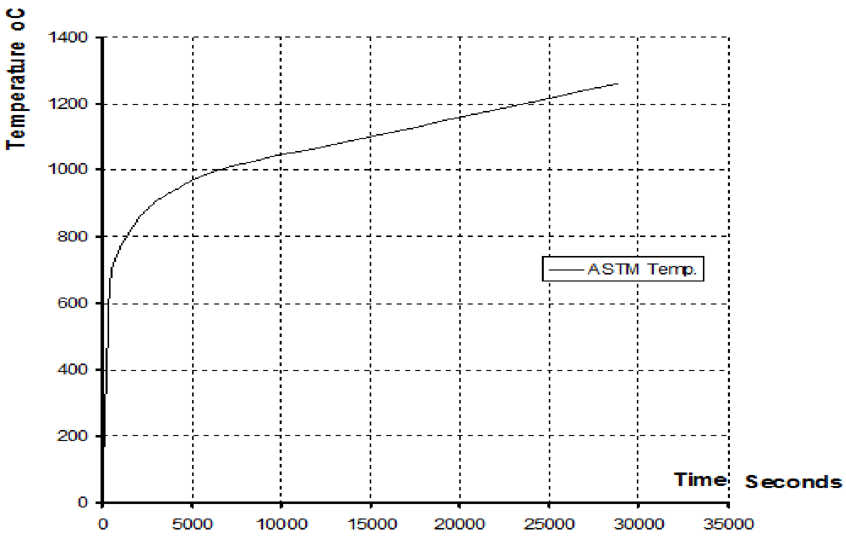


Fig. 2: ASTM 119 fire exposure testing curve[13]

Material properties and concrete mix preparations

The compressive strength for high strength concrete beams was designed to achieve 60 Mpa while normal and self-compacting concrete mix was designed to have the same grade 30 MPa. The main materials used for casting all concrete beams consisted of Portland cement equivalent to ASTM Type I, natural water and natural aggregates. NC contained gravel as coarse aggregate as reported in table (2) while SCC and HSC made by using dolomite as shown in table (3-4). Concrete rotating drum mixer with 0.125 m^3 full capacity was used to mix the concrete contains. For different types of concrete, coarse aggregate, Sand, and cement were dry mixed for two minutes. After the dry mix, the water was gradually added to ensure the concrete became homogeneous. For self-compacting concrete, Silica fume was used to increase the density, compressive strength and durability of the concrete, and also improve the fresh concrete performance with increased workability, and improved cohesiveness and stability. Sika ViscoCrete® -3425 is a third-generation super plasticiser for homogenous concrete, considered a powerful super plasticiser acting by means of different mechanisms. Sika Fiber is a monofilament polypropylene fibre for use in concrete mixes, which reduces the tendency for plastic and drying shrinkage cracking, improves abrasion resistance, reduces water migration, improves durability, reduces spalling, and increases the impact resistance of young concrete. The dolomite, sand, silica fume and cement were dry mixed. Then, the water was gradually added with the Sika ViscoCete -3425 and Sika Fiber, while mixing was performed for an additional two minutes, following which the concrete became homogeneous. Cubes 150 mm and cylinders with dimensions of 150*300 mm were casted to report the concrete mechanical properties at room temperature and after elevated temperature 400°C and 600°C exposure. ACI specifications were followed in the casting and curing system[14].

Table 2: Normal Concrete mix proportions

fc (MPa)	w/c ratio	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Addicrete Bvf (LT/m^3)
30	0.43	400	1160	578	8%

Table 3: Self Compacting Concrete mix proportions

fc (MPa)	w/c ratio	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Silica Fume (kg/m^3)	Sikq Vis concrete (kg/m^3)	Sika Fiber(G) kg/m^3
30	0.36	310	650	650	35	4	0.90

Table 4: High Strength Concrete mix proportions

fc (MPa)	w/c ratio	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Silicq Fume (kg/m^3)	Super litter Addicrete Bvf
60	0.35	525	1200	550	78	4%

Experimental Program Setup and Testing

1000 KN universal testing machine used to do three points flexural test on the beams while elevated temperature tests are conducted using a 1200 ^oC electrical furnace as shown in Fig. 3. Central deflections of the tested beams are recorded using a linear variable differential transformer at beam center. Strains are monitors two strain gauges at different locations expected to undergo critical flexural strain at beam center and the other at the maximum shear at distance equal beam depth from the beam support as shown in Fig. 3.

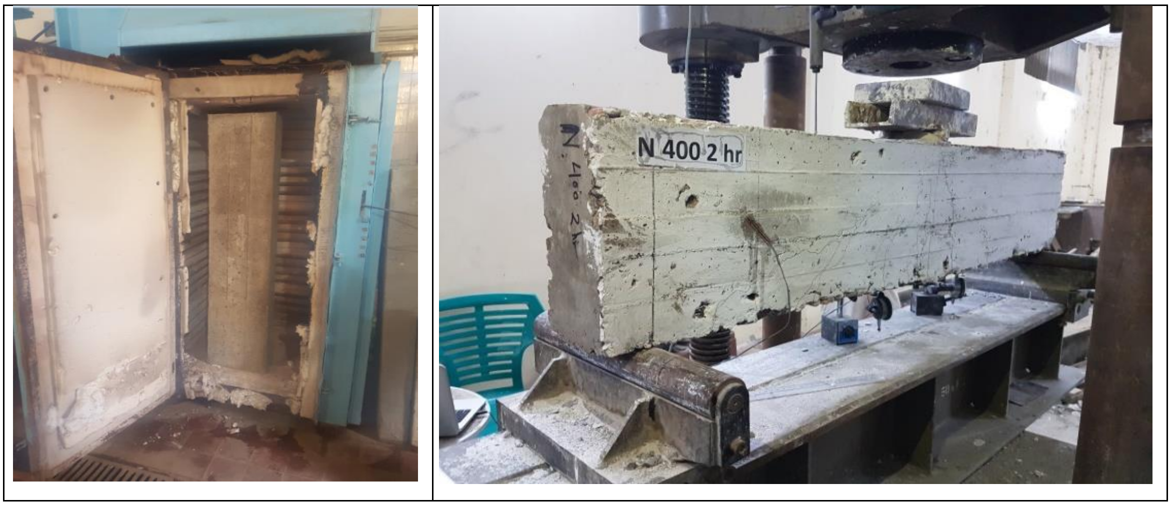


Fig. 3: Furnace and loading test setup.

RESULTS AND DISCUSSION

Results of tested Beams are reported to ass the effect of elevated temperature on different types of concrete beams.

Compressive strength and split tensile strength

Table 5 report the mechanical properties of different types of concrete according the design mix prepared before testing. Self-compacting concrete and normal concrete approximately had the same properties to report the difference after fire exposure.

Table 5. The compressive and tensile strengths of different types of concrete

Concrete Type	Compressive Strength (MPa)		28-day Tensile Strength (MPa)
	7 days	28 days	
Normal concrete	26	31.2	3.1
Self-compacting concrete	27	31.6	3.15
High strength concrete	50	62	5.8

External Evaluating after elevated temperature exposure on the different types of reinforced concrete beams.

One hour exposure time do not have a noticed changes for all exposed beams to 400^{o}C for all tested types of concrete while increase elevated temperature level to 600^{o}C for one hour have significance effect on NC. Concrete spalling start at 1 hour for NC and hair cracks noticed for SCC and HSC as shown in Fig. 4. The color of the beam surface tends to be grey after exposed to 400^{o}C for 2 hours, while the color of the beams exposed to 600^{o}C for 2 hours tends to be white grey. The spalling and cracks increased by increasing exposure time for NC, SCC and HSC respectively as reported in Fig.5. These changes are may be associated with the change in concrete composition and texture which was destructed during heating or the oxidization process which occurred to ferric component [15, 16]. At the start of cooling after elevated temperature time horizontal cracks in external concrete surface with full beam width were observed nearly at the location of each stirrup as shown in Fig. 5. It attributed to the thermal stresses induced in the beams by difference between the coefficient of thermal expansion of concrete and steel reinforcement. The increase the elevated temperature exposure type to 2 hours at 600 ^{o}C effected on HSC and SCC by have two or three transferee a hear cracks at the beam surface. These crack started at 400 ^{o}C for SCC beams with 2 hours exposure time. The NC beams have a noticed deterioration at 400 ^{o}C after 2 hours exposure time and significance and dramatic aggregate spalling at 600^{o}C after one and two hour respectively. Aggregate

Spalling of NC beams occurred slightly at 400°C and very significant at 600 °C. The violent at 600 °C or non-violent at 400 °C breaking off of pieces of concrete from the surface of a structural element this results agree with previous studies[17].

At elevated temperatures concrete surfaces exposed to elevated temperature are significantly affected. Internal stress and thus cracks of varying sizes are generated owing to the inhomogeneous volume dilatations of ingredients and the built-up vapor pressure in the pores, especially at temperatures around 600°C. After 600°C, calcium hydroxide dehydration occurs and aggregates begin to deteriorate. As a result, the properties of reinforced concrete (RC) are negatively affected. These include loss in compressive strength and stiffness; cracking and spalling of concrete; destruction of the bond between the cement paste and the aggregates; the gradual deterioration of the hardened cement paste. The result is partial to full loss of structural capacity of these members and, unless strengthened they will not be capable of carrying imposed dead and live loads.

Fig. 4: Cracking phases for NC and SCC beams under 600°C for 1 hour

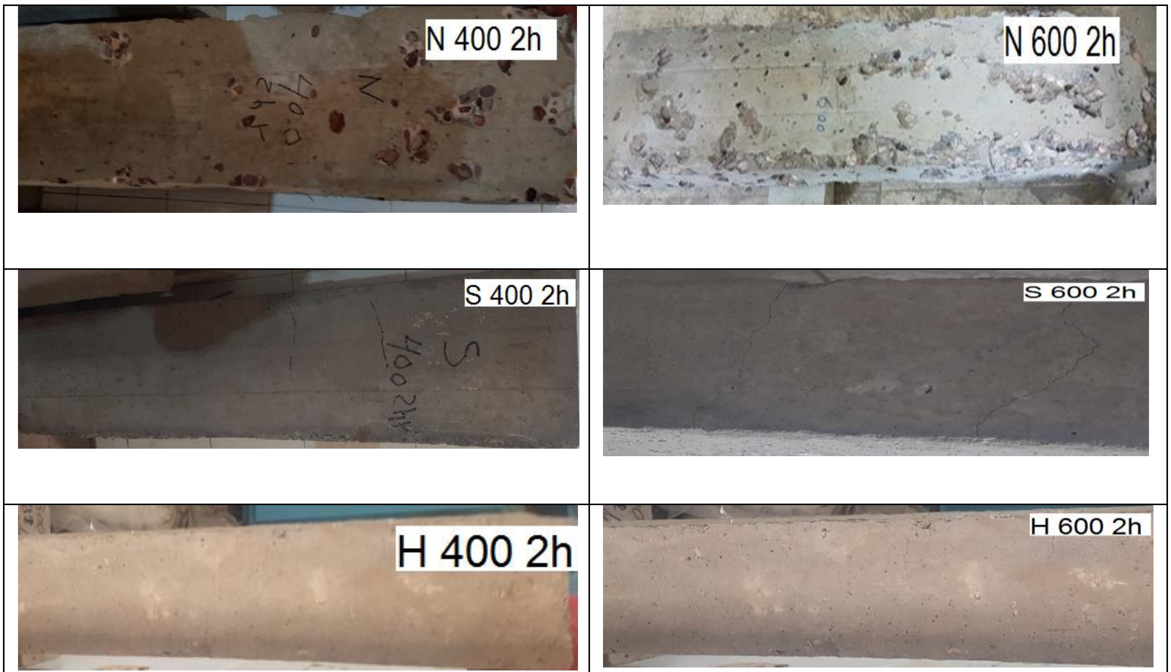
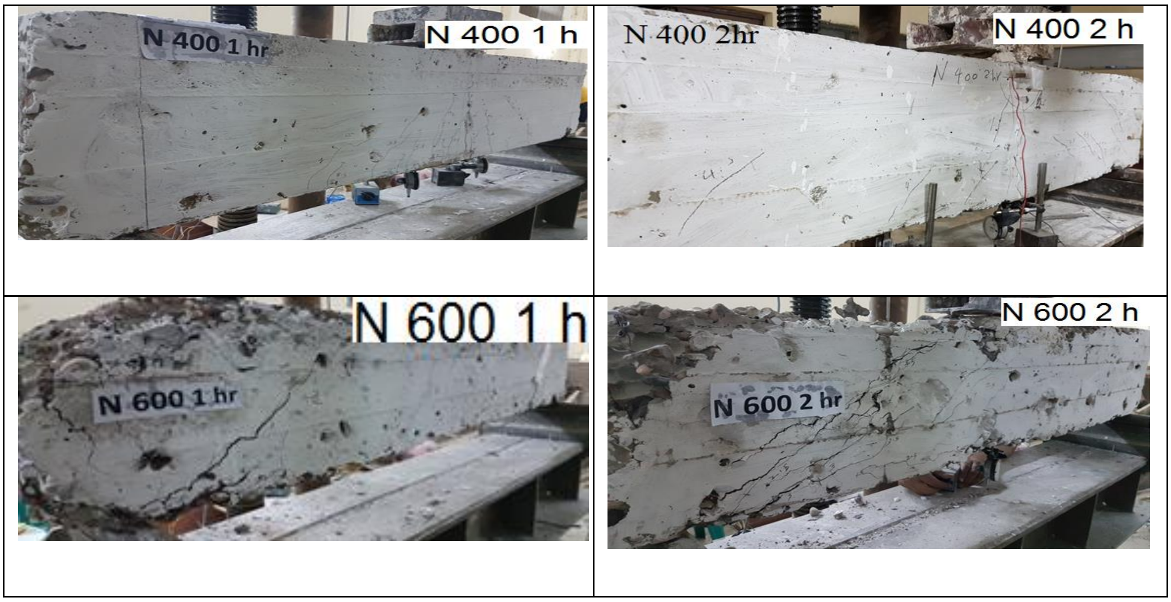


Fig. 5: Cracking phases for beams under different temperature for 2 hours exposure time

Structural performance of NC, SCC and HSC after exposed to different levels of elevated temperature

Crack pattern and mode of failure

NC and SCC control beams cracked after three points flexural test which had similar shape and the ultimate loads of two beams. This results due to the approximation of NC and SCC mechanical properties. All beams failed by Flexural failure mode except the NC beams exposed to 600 ^{o}C which have shear cracks inclined at 45 degrees with the horizontal near the support. The dramatic reduction of the NC compressive strength after 600 ^{o}C changes the mode of failure of these beams to shear failure. The increasing of exposure time from one to two hours has a noticed effect on the crack pattern which appears clearly with 600 ^{o}C. SCC and HSC beams exhibited a good crack resistance compared to NC beams exposed to 400 ^{o}C and 600 ^{o}C for one and two hours. Increasing the exposure time for 400^{o}C have a noticed effect on the SCC and HSC beams failure mode after testing on contract of NC beams which have a great effect and spalling in concrete cover especially after 2 hours exposure time. At the end of testing some crushing Cracks due to compression failure appeared at the top surface. The increasing of crack width and the reduction of beams capacity after elevated temperature due to the residual concrete strength after elevated temperature exposure which are much less than at room temperature. The average reduction in residual concrete compressive strength is more pronounced in NSC than SCC and HSC. All mode of failure due to three point loading system for control beams before and after elevated temperature exposure are shown in Fig. 6.



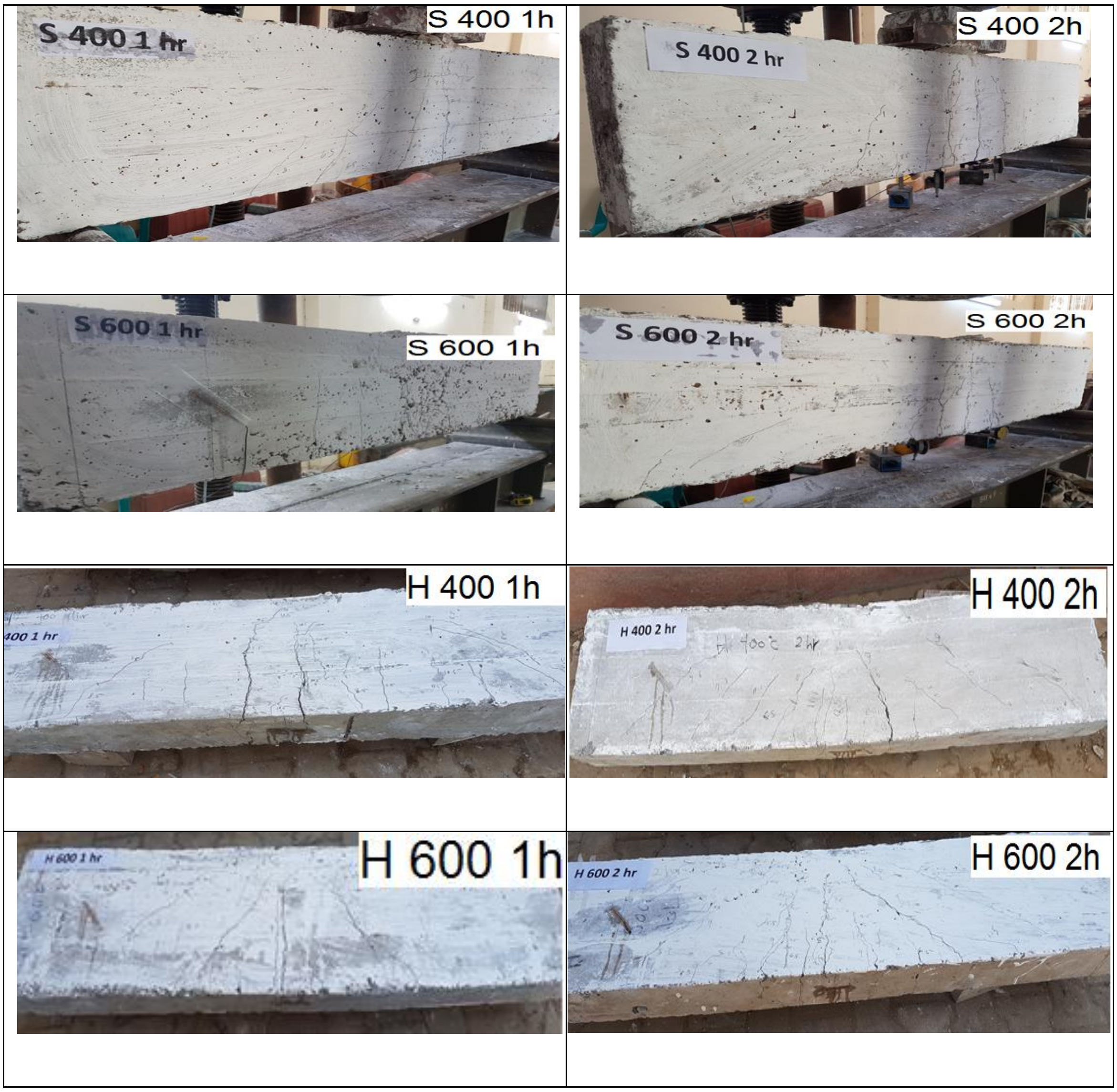


Fig. 6: Crack pattern and mode of failure at different exposure time for NC, SCC and HSC beams

Load deflection curve

NC and SCC beams had approximately the same failure load and HSC beams have increasing in failure load by 20% although the HSC compressive strength was 600 Kg/cm^2. The compressive strength of HSC did not have a great effect in beam capacity where the beam cross section was rectangular section and the failure mode was flexural failure mode. The central deflection of NC, SCC and HSC beams were 4, 6, and 6.8 mm respectively which reflect the increasing of SCC ductility than NC beams. Increasing the exposure time decreased failure load otherwise the deflection curves have the same trend approximately for NC beams as shown in Fig. 7. The influence of exposure time were appear clearly for the beam failure load which reduced from 82% for 1 hour exposure time to 72% after exposure to 2 hours of 400 ^{o}C. This influence was a dramatic behaviour for NC beams under 600^{o}C at any exposure time which reduced beam capacity by 42% and 36% for one and two hours respectively. NC beams After 400 ^{o}C. The reduction of beam capacity due to the reduction in concrete strength and steel reinforcement yield strength. This reduction in strength is attributed to the development of thermal stresses and the changes take place in the physical and chemical properties of concrete. The failure load reduction of SCC and HSC beams did not have a major reduction on beams capacity compared to control beam after two hour exposure time to 400^{o}C. The significance reductions of SCC beam were reported at 600^{o}C at 2 hours exposure time which reaches to 80% compared to control beams as shown in Fig.8. SCC had a good performance compared to NC beams. The good homogenous of SCC concrete mix and using dolomite as coarse aggregate which have good properties compared to gravel used in NC beams. The addition of fibers on self-compacting and high strength concrete mixes turned out to be sufficient protection against spalling just allow to cracks due to the varation of thermal expansion of steel and concrete. During the heating process neither thermal nor explosive spalling were noticed.

The residual compressive strength results of the tested specimens of 60 MPa after exposure to 400 and 600°C temperatures are given in Fig. 9. The relationship between beam capacity and exposure temperature was found to be similar to that reported previously [5]. Up to 400°C only a small part of the original strength was lost, almost the same about 16% for HSC. The severe beam capacity loss occurred mainly within the 400-600°C range. These losses at 600°C are in the range of 20-27%, for one and two hours respectively. The effect of elevated temperature on the load deflection curve started rapidly for HSC at 400^{o}C for 1 hour while the main influence of SCC beams clearly appeared at 600^{o}C for 2 hour.

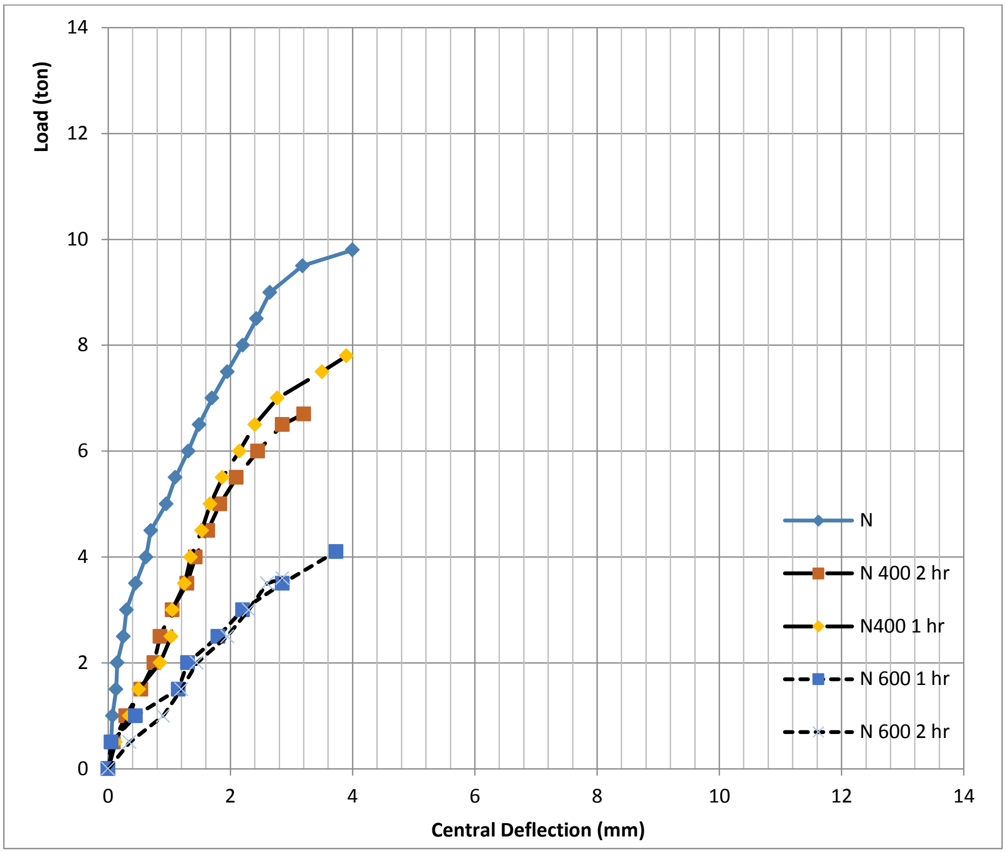


Fig. 7: Load deflection curve for normal concrete beams under different level of temperature and different exposure time

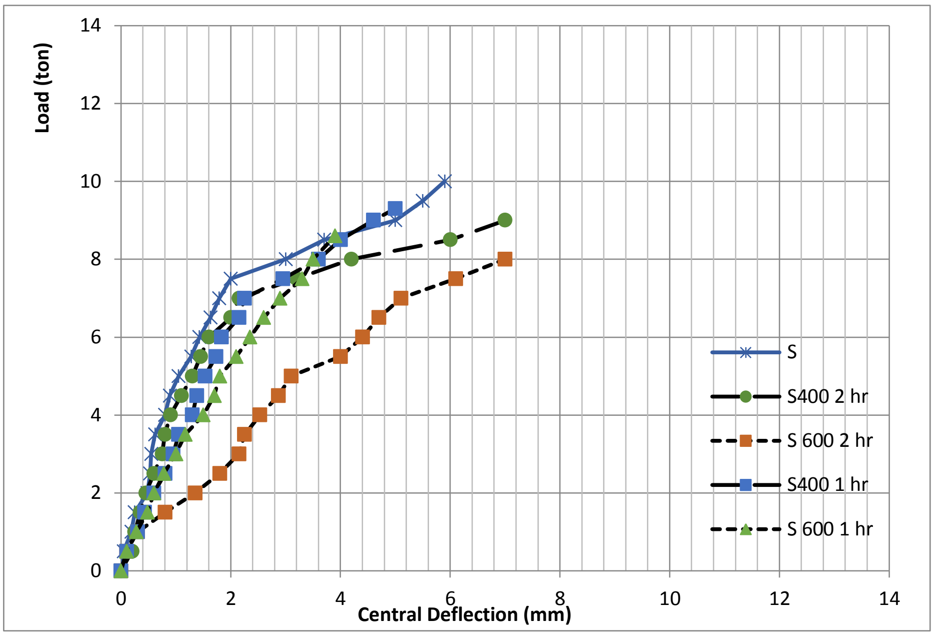


Fig. 8: Load deflection curve for self-compacting concrete beams under different level of temperature and different exposure time

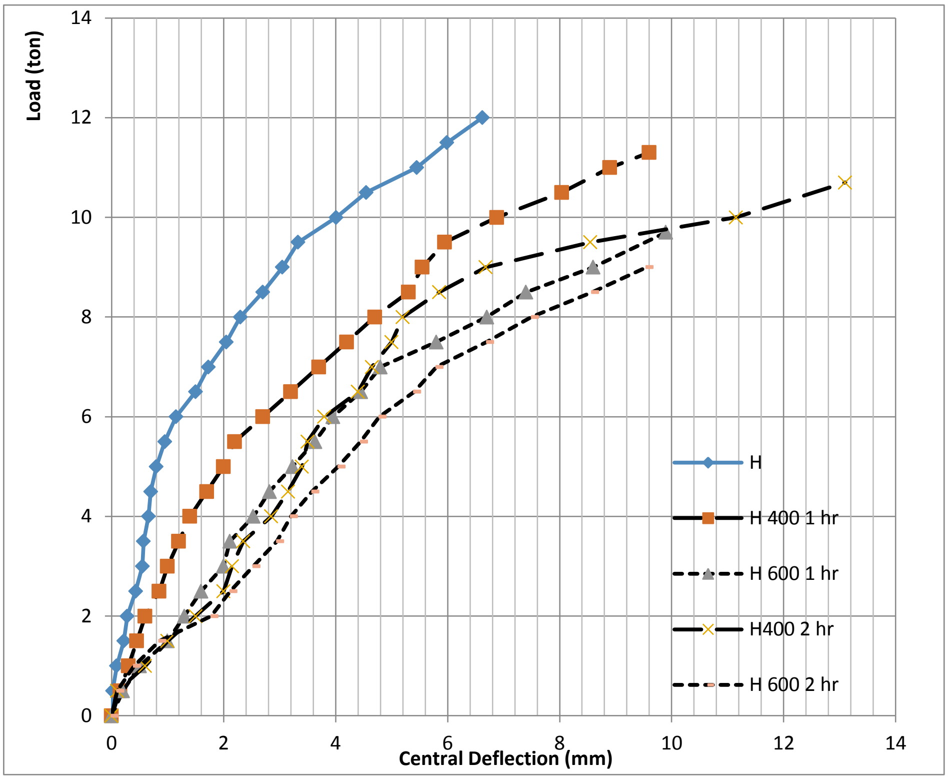


Fig. 9: Load deflection curve for high strength concrete beams under different level of temperature and different exposure time

4. CONCLUSIONS

1- A dramatic effect on the Normal concrete beam behaviour reported by increasing the exposure time of elevated temperature especially with high level of temperature more than 600^{o}C.
2- Self-compacting and High strength concrete beams exhibited a good crack resistance compared to NC beams exposed to 400 ^{o}C and 600 ^{o}C up to two hours.
3- The crack width and cracks number increased for NC beams cracks compared to SCC and HSC after exposure to 400 ^{o}C besides the spalling for NC only.
4- HSC had rapid effect after elevated temperature exposure on the load deflection curve at 400^{o}C for 1 hour while SCC beams effected clearly at 600^{o}C for 2 hour.

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