# EFFECT OF COOLING SCHEME ON OVERALL STIFFNESS AND ULTIMATE STRENGTH OF R.C. BEAMS SUBJECTED TO FIRE

Mohamed A. Khalaf[1]

**Abstract**— Reinforced concrete structures may be subjected to fire due to different reasons. Behavior of reinforced concrete exposed to fire depends on its mix proportions and constituents and is determined by complex physicochemical changes caused by fire. Effect of fire elevated temperature on mechanical properties of different RC structural elements (beams, columns, slabs, …etc) depends on many factors; these factors are: element dimensions, fire temperature degree, time of fire exposure, properties of concrete and concrete materials, surface area to volume ratio, reinforcing steel ratio, stress level and type of end constraint of the structural element and finally the used cooling scheme. The main objective of this research is to investigate the effect of the most commonly three cooling schemes used in Egypt on the overall stiffness and the ultimate strength of RC beams. A total of 14 RC beams of dimensions (100x200x1200mms) were tested in flexure under three point load arrangement to determine the overall stiffness and the ultimate strength. Two beams were not subjected to any fire and were used as control beams. Twelve beams were subjected to fire; six of them were subjected to 300$^{o}$C for 2 hours and the other six were subjected to 650$^{o}$C for 4 hours. The used three cooling schemes were: cooling in air, cooling by water jet and cooling by $CO_2$ fire extinguisher. Test Results have shown that fire of 650$^{o}$C for 4 hours duration and fast cooling by water jet caused a significant reduction in the beam strength while fire of 300$^{o}$C for 2 hours duration and cooling either in air or by using $CO_2$ almost has no significant effect on beam strength. Fast cooling by water jet caused a considerable reduction in the beam strength and stiffness as well.

**Index Terms—** RC Beams; Overall stiffness, Ultimate Strength; Fire Temperature; Fire Duration; Cooling Scheme..



## 1 INTRODUCTION

Effect of fire elevated temperatures on strength and stiffness characteristics of different RC structural elements depends on many factors. The most important factors are element dimensions, fire temperature, fire duration, properties of concrete and concrete materials, surface area to volume ratio, reinforcing steel ratio, applied stress level, type of end constraint and finally the used cooling method [1,2,3]. Most researches done in this aspect studied the effect of fire temperature and fire duration extensively but few articles studied the effect of cooling schemes. The cooling method is a very important factor affecting the performance of RC structural elements. The most common cooling methods used around the world are air cooling (slow cooling) and water cooling (fast cooling). Generally cooling rates ranging from very slow (0.5$^{o}$C / min) to very fast (50°C / min). Normal strength concrete with a water/cement ratio of 0.65 exhibited no difference between water cooling and air-cooling when considering both the compressive strength and the bond strength [4]. This may imply that at the water/cement ratio of 0.65 the microstructure is not dense enough to be affected by the used cooling method. However for the denser concretes, quick cooling rate generates more micro-cracks. Cracking during the cooling process is due to transitional thermal creep and because the internal stresses could not be relieved [4]. Outer part of concrete cools down first but the inner part remains heated causing micro-cracking which considered a major cause of strength reduction.

**In 2018 Youssef et al [3]** had conducted an experimental program to investigate the effect of four extinguishing methods on the failure loads of 30 RC columns exposed to fire. Columns were of different surface area to volume ratios. Non-destructive testing (Core & Ultrasonic pulse velocity tests) were used to estimate the deterioration level of concrete due to fire. Test results had shown that by increasing the surface area to volume ratio or by increasing the cooling rate, the ultimate strength of RC columns decreased considerably. A mathematical model was proposed to estimate the failure loads of RC columns after fire exposure in order to decide if the columns after fire deserved repair and strengthening or not. Experimental results were compared to the results of the mathematical model to verify the accuracy of the proposed model.

**In 2011 Zhang et al [16]** had studied the effect of fire temperature degree, coarse aggregate type and cooling method on concrete compressive strength of standard cubes. Two different types of coarse aggregates were used (siliceous granite and lime stone). Concrete cubes were subjected to four different temperature degrees (150, 350, 550 and 750$^{o}$C) for 90 minutes duration and cooled by the two most commonly methods used in the previous researches (air cooling and water cooling). Test results showed that the concrete mechanical properties were generally decreased with increase in temperature. Calcareous aggregate concrete residual strength is higher than that of siliceous aggregate concrete at higher temperature. Generally, at lower temperature (below 200$^{o}$C) the cooling

- 1 *Assoc. Prof., Structural Engineering Department, Faculty of Engineering, Ain Shams University, Egypt.*
  *E-mail: mhamed_khalaf@eng.asu.edu.eg*

schemes have minimal impact on the heated concrete strength while they have a great effect on concrete strength at higher temperature (above 350$^{o}$C).

## 2 OBJECTIVE

The main objective of this research is to study the effect of using three different cooling schemes (the most commonly cooling schemes used in Egypt) on the overall stiffness and the ultimate strength of RC beams. Ultimate strength is expressed in terms of the failure load while the overall stiffness is expressed in terms of the slope of load deflection curve. A total of 14 reinforced concrete beams of cross sectional dimensions 100x200 mms and span 1100 mm (total length 1200 mms) were tested in flexure under three point load arrangement to determine the overall stiffness and the ultimate strength. The tested 14 beams are as follows:

- Two beams were not subjected to any fire (control beams).
- Six beams were subjected to 300$^{o}$C for 2 hours.
- Six beams were subjected to 650$^{o}$C for 4 hours.

Three different cooling schemes were used:

- Cooling in air
- Cooling by water jet
- Cooling by $CO_2$ fire extinguisher

## 3 CONCRETE MATERIALS, TEST SPECIMENS, PROCEDURE AND RESULTS

### 3.1 Concrete materials

Concrete materials used in this research are Portland cement, crushed lime stone, natural sand and water. The used cement was ordinary Portland cement of grade N42.5 and all the physical, chemical and mechanical properties were determined according to Egyptian standard specifications ESS 4756/2007. Crushed lime stone was used as coarse aggregates and natural sand was used as fine aggregates with fineness modulus of 2.724. The concrete mix proportions were calculated to achieve 28 days cube compressive strength of 275 Kg/cm$^2$. Table (1) shows all concrete materials properties and the used mix proportions for one cubic meter of concrete. The average measured cube compressive strength after 7 and 28 days were 200 and 290 Kg/cm$^2$ respectively. The reinforcing steel used was high tensile steel of oblique ribs (grade 360/520) of 10 mm diameter. The used stirrups were plain bars made from mild steel (grade 240/350) of 8mm diameter.

### 3.2 Test Specimens

Experimental program in this research consisted of 14 RC beams. Details of these beams are as follows:

- Rectangular cross section (100x200 mms) : Width 100 mm - Total depth 200 mm – Effective depth 180 mms – Concrete cover 20 mms.
- Beam length = 1200 mms & Beam span = 1100 mms.
- Upper reinforcement: 2 bars of diameter 10 mms (grade 360/520).
- Bottom reinforcement: 2 bars of diameter 10 mms (grade 360/520).
- Stirrups are of 8mm diameter every 150mm (grade 240/350).
- 2 beams were not subjected to any fire (control beams).
- 6 beams were subjected to fire (300$^{o}$C for 2 hours) : 2 beams cooled in air + 2 beams cooled by water jet + 2 beams cooled by $CO_2$ fire extinguisher.
- 6 beams were subjected to fire (650$^{o}$C for 4 hours) : 2 beams cooled in air + 2 beams cooled by water jet + 2 beams cooled by $CO_2$ fire extinguisher.
- Figure (1) shows the beam dimensions and the reinforcement details.
- Figure (2) shows the steps of preparing the beams.
- Figure (3) shows the shape on beams before fire.
- Figure (4) shows beams subjected to 650$^{o}$C (4 hours).
- Figure (5) shows beams subjected to 300$^{o}$C (2 hours).
- Figure (6) shows the fire extinguishing process using $CO_2$.

### 3.3 Test Procedure and Results

All beams (except the 2 control beams) were subjected to fire and extinguished by the three previously mentioned methods, then all beams were tested in flexure using three point load arrangement until failure. Flexure test was carried out at Materials Laboratory - Faculty of Engineering – Ain Shams University – Cairo - Egypt. The flexture test was conducted in a steel frame using a hydraulic jack of 20 ton capacity to apply the load at the mid-span. Mid span defection was measured using mechanical dial gage. Figure (7) shows the test set-up for all the beams. The load was controlled manually by the hydraulic jack and the mid span deflection was measured by the mechanical dial gauges every 0.5 ton load intervals. Table (2) shows the load-deflection test results for the control case (average of the two control beams). Tables (3 and 4) show the load-deflection test results for beams subjected to (300$^{o}$C/2hrs) and (650$^{o}$C/4hrs) respectively.

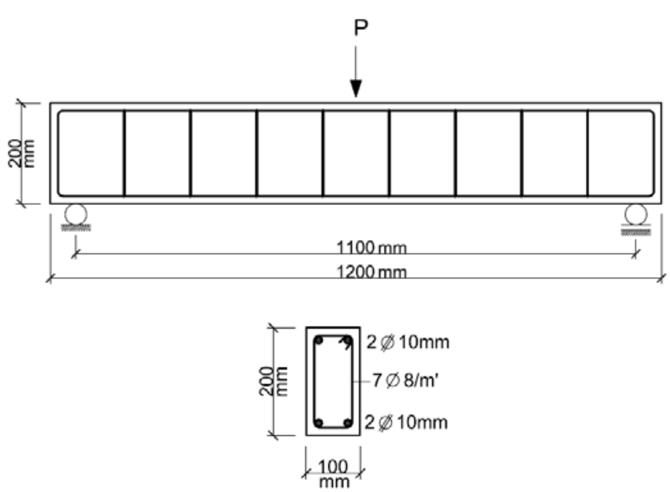


Figure (1): Beam dimensions and reinforcement details

TABLE 1: CONCRETE MATERIALS PROPERTIES AND MIX PROPORTIONS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fine Agg. | # (mm) | 4.75 | 2.36 | 1.18 | 0.60 | 0.30 | 0.15 |
| | % passing | 99.4 | 89.1 | 75.7 | 55.4 | 7.1 | 0.9 |
| Coarse Agg. | # (mm) | 37.5 | 31.5 | 28.0 | 20.0 | 10.0 | 5.0 |
| | % passing | 100 | 100 | 100 | 70.7 | 45.5 | 0.9 |

| Property | Fine Aggregates | Coarse Aggregates |
|---|---|---|
| Specific gravity | 2.640 | 2.660 |
| Unit weight (t/m3) | 1.610 | 1.635 |
| Crushing value (Los Anglos) | --- | 23.1% |
| % fine materials (by volume) | 1.80 | --- |
| % Absorption | --- | 1.8% |

| Cement (Kg) | Sand (Kg) | C. Stone (Kg) | Water (Liter) |
|---|---|---|---|
| 375 | 550 | 1200 | 220 |

Figure (2): Preparing of beams

Figure (3): Beams before fire

Figure (4): Beams subjected to 650$^{o}$C (4 hours)

Figure (5): Beams subjected to 300°C (2 hours)

Figure (6): Fire extinguishing using $CO_2$

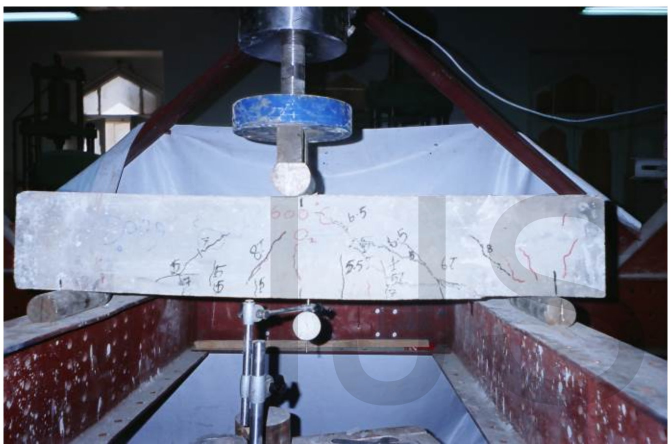

Figure (7): Test setup

Figure (8): Testing of control beam

Figure (9): Testing of beam subjected to 300°C (2 hours)

Figure (10): Testing of beam subjected to 650°C (4 hours)

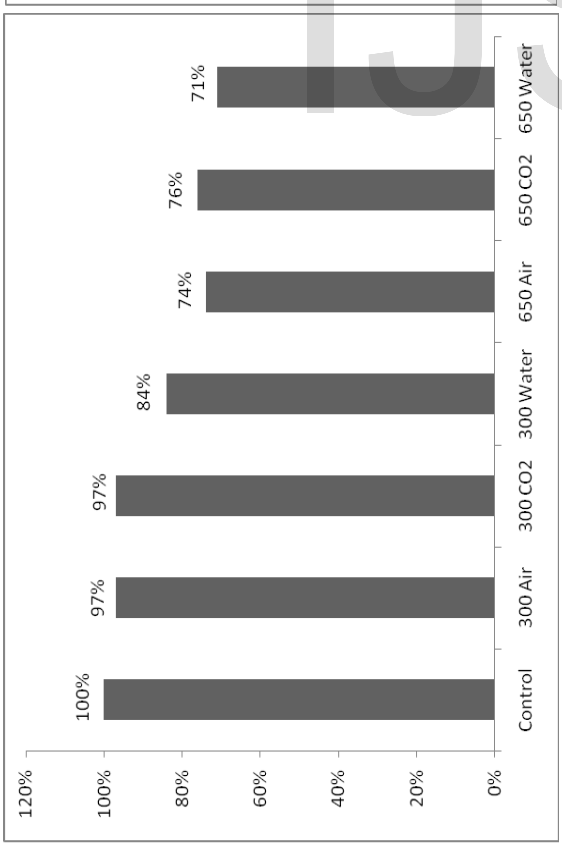


Figure (13): Ultimate loads as a percentage from the control case
(Each case represents an average of two beams)

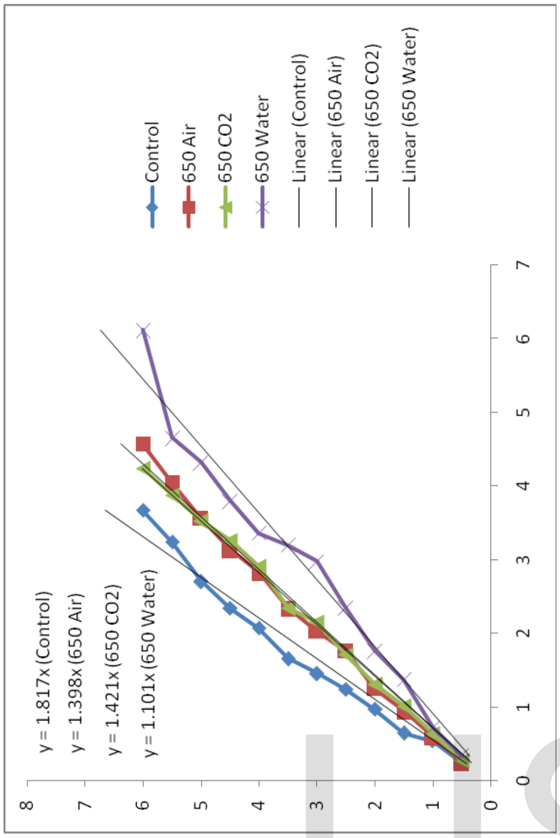


Figure (11): Load-Deflection curves for beams subjected to 300°C
for 2 hours compared to the control case

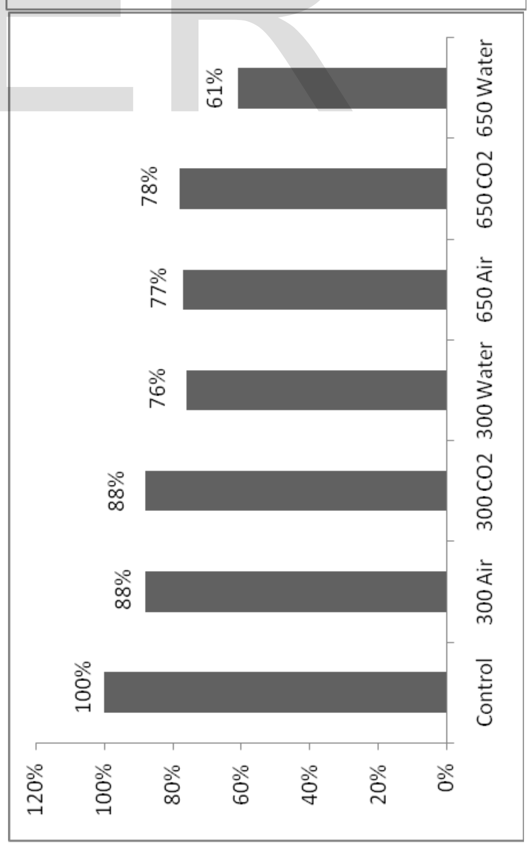


Figure (14): Overall stiffness as a percentage from the control case
(Each case represents an average of two beams)

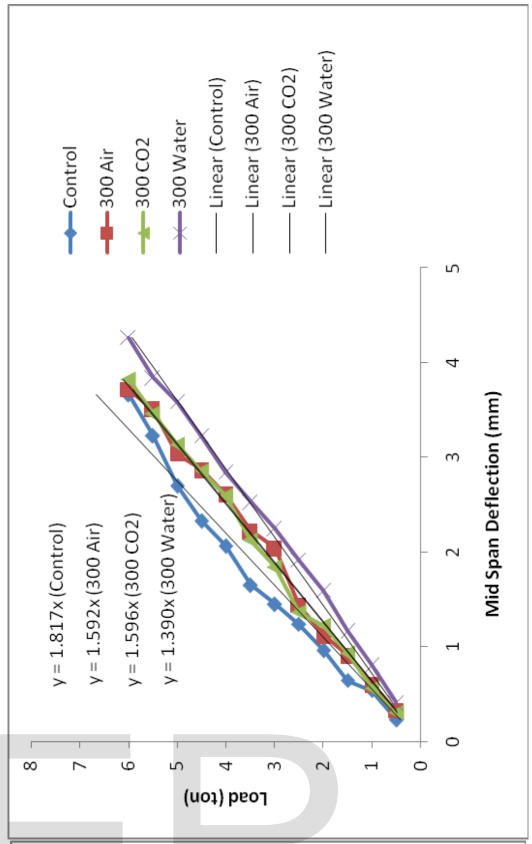


Figure (12): Load-Deflection curves for beams subjected to 650oC
for 4 hours compared to the control case

TABLE (2): LOAD-DEFLECTION RESULTS
(FOR CONTROL BEAMS)

| Control | | | | | |
|---|---|---|---|---|---|
| Load (ton) | Deflection (mm) | Load (ton) | Deflection (mm) | Load (ton) | Deflection (mm) |
| 0.5 | 0.23 | 2.5 | 1.23 | 4.5 | 2.33 |
| 1.0 | 0.53 | 3.0 | 1.45 | 5.0 | 2.7 |
| 1.5 | 0.64 | 3.5 | 1.65 | 5.5 | 3.23 |
| 2.0 | 0.96 | 4.0 | 2.06 | 6.0 | 3.66 |
| P (max.) = 8.6 ton & P = 1.817 Δ | | | | | |

TABLE (3): LOAD-DEFLECTION RESULTS
(BEAMS SUBJECTED TO 300$^{o}$C FOR 2 HOURS)

| 300 Air | | 300 CO2 | | 300 Water | |
|---|---|---|---|---|---|
| Load (ton) | Deflection (mm) | Load (ton) | Deflection (mm) | Load (ton) | Deflection (mm) |
| 0.5 | 0.32 | 0.5 | 0.30 | 0.5 | 0.41 |
| 1.0 | 0.60 | 1.0 | 0.56 | 1.0 | 0.81 |
| 1.5 | 0.91 | 1.5 | 0.93 | 1.5 | 1.17 |
| 2.0 | 1.12 | 2.0 | 1.22 | 2.0 | 1.59 |
| 2.5 | 1.43 | 2.5 | 1.36 | 2.5 | 1.91 |
| 3.0 | 2.04 | 3.0 | 1.84 | 3.0 | 2.25 |
| 3.5 | 2.22 | 3.5 | 2.12 | 3.5 | 2.53 |
| 4.0 | 2.61 | 4.0 | 2.59 | 4.0 | 2.84 |
| 4.5 | 2.87 | 4.5 | 2.85 | 4.5 | 3.22 |
| 5.0 | 3.03 | 5.0 | 3.13 | 5.0 | 3.58 |
| 5.5 | 3.51 | 5.5 | 3.46 | 5.5 | 3.84 |
| 6.0 | 3.71 | 6.0 | 3.82 | 6.0 | 4.26 |
| P (max.) = 8.3 ton P = 1.592 Δ | | P (max.) = 8.3 ton P = 1.596 Δ | | P (max.) = 7.2 ton P = 1.390 Δ | |

TABLE (4): LOAD-DEFLECTION RESULTS
(BEAMS SUBJECTED TO 650$^{o}$C FOR 4 HOURS)

| 650 Air | | 650 CO2 | | 650 Water | |
|---|---|---|---|---|---|
| Load (ton) | Deflection (mm) | Load (ton) | Deflection (mm) | Load (ton) | Deflection (mm) |
| 0.5 | 0.24 | 0.5 | 0.26 | 0.5 | 0.33 |
| 1.0 | 0.59 | 1.0 | 0.63 | 1.0 | 0.71 |
| 1.5 | 0.94 | 1.5 | 1.01 | 1.5 | 1.36 |
| 2.0 | 1.24 | 2.0 | 1.30 | 2.0 | 1.76 |
| 2.5 | 1.75 | 2.5 | 1.70 | 2.5 | 2.33 |
| 3.0 | 2.02 | 3.0 | 2.14 | 3.0 | 2.97 |
| 3.5 | 2.34 | 3.5 | 2.34 | 3.5 | 3.19 |
| 4.0 | 2.82 | 4.0 | 2.90 | 4.0 | 3.35 |
| 4.5 | 3.13 | 4.5 | 3.25 | 4.5 | 3.79 |
| 5.0 | 3.55 | 5.0 | 3.52 | 5.0 | 4.31 |
| 5.5 | 4.04 | 5.5 | 3.87 | 5.5 | 4.65 |
| 6.0 | 4.56 | 6.0 | 4.23 | 6.0 | 6.11 |
| P (max.) = 6.4 ton P = 1.398 Δ | | P (max.) = 6.5 ton P = 1.421 Δ | | P (max.) = 6.1 ton P = 1.101 Δ | |

## 4 DISCUSSION OF TEST RESULTS

**A)** As mentioned before the experimental program was consisted of 14 RC beams of dimensions and reinforcement details as explained earlier in section (3.2). The tested 14 beams are as follows:

- Two beams were not subjected to any fire and were used as control beams.
- Six beams were subjected to 300$^{o}$C for 2 hours.
- Six beams were subjected to 650$^{o}$C for 4 hours.

Three different cooling schemes were used (the most commonly cooling methods used in Egypt):

- Cooling in air
- Cooling by water jet
- Cooling by $CO_2$ fire extinguisher

All beams were tested in flexure using three point load arrangement as shown in figure (7). All beams were failed in shear because the span to depth ratio is 5.5 (i.e. relatively short span beams). Shear failure modes are shown in Figures (8, 9 and 10) for control, (300$^{o}$C/2hrs) and (650$^{o}$C/4hrs) beams respectively. Beam dimensions (span and cross sectional dimensions) were chosen to fit the dimensions of the loading frame and to have failure loads reasonable to the hydraulic jack capacity. For each beam two important factors were determined experimentally:

- Failure load: Shear failure mode was obtained for all beams. Beam ultimate strength was expressed in terms of the obtained failure load.
- Overall stiffness: The value of beam overall stiffness was determined from the slope of the best fitting straight line of the load-mid span deflection curve. Load-mid span deflection curves for all beams are shown in Figures (11 and 12). Figure (11) shows Load-mid span deflection curves for (300oC/2hrs) beams compared with the control beam. Figure (12) shows Load-mid span deflection curves for (650$^{o}$C/4hrs) beams compared with the control beam. Beams overall stiffness are shown on all curves and given also in Tables (2, 3 and 4).

**B)** Table (2) shows the average values of load and mid span deflection test results of the two control beams (beams were not subjected to any fire). From this table, it can be noticed that the average failure load for the two control beams was 8.6 ton and the average overall stiffness was 1.817 ton/mm. These values will be taken as reference for the rest 12 beams subjected to fire for comparison purposes.

**C)** The first group of beams subjected to fire was a group of 6 beams. This group was subjected to 300$^{o}$C for two hours. The reason behind using temperature degree of 300$^{o}$C is that this temperature degree is resulting from burning the most commonly used materials in the residential buildings and the time duration of 2 hours is a reasonable time (not too long and not too short). Two beams were cooled in air, two beams were cooled using $CO_2$ fire extinguisher and the last two beams were cooled using water jet. Table (3) and Figure (11) give the ultimate strength and the overall stiffness for this group of beams. It should be noted that the results shown in these table and figure are the average values for the two beams for each cooling scheme. Table (3) and Figure (11) show that the failure loads for beams cooled by air, $CO_2$ and water are 8.3, 8.3 and 7.2 ton respectively. The overall stiffness for beams cooled by air, $CO_2$ and water are 1.592, 1.596 and 1.390 ton/mm respectively. Comparing these results with those of the control case (as shown in Figure 13), it can be noticed that for beams cooled by air or $CO_2$ almost there is no change in the values of failure loads and the overall stiffness is about 88% from that of the control case. For beams cooled by water jet, the failure load decreased by 16% and the overall stiffness decreased by 24% compared with the control case. This significant reduction in strength and stiffness can be attributed to cracks resulting from the big difference in temperature between concrete outer surface and the inside concrete zone resulting from sudden cooling by water jet (thermal shock). This result emphasize the danger of using sudden cooling for concrete elements subjected to fire even the fire temperature is not too high and the fire duration is not too long.

**D)** The second group of beams subjected to fire was a group of 6 beams. This group was subjected to 650$^o$C for four hours. The reason behind using temperature degree of 650$^o$C is that this temperature degree represents the severe fire temperature and duration in most of the residential buildings (as stated in many articles in the literature) and the time duration of 4 hours is a too long time (i.e. this case represents one of the most severe fire cases). Two beams were cooled in air, two beams were cooled using $CO_2$ fire extinguisher and the last two beams were cooled using water jet. Table (4) and Figure (12) give the ultimate strength and the overall stiffness for this group of beams. It should be noted that the results shown in the mentioned table and figure is the average values for two beams for each cooling scheme. Table (4) and Figure (12) show that the failure loads for beams cooled by air, $CO_2$ and water are 6.4, 6.5 and 6.1 ton respectively and the overall stiffness for beams cooled by air, $CO_2$ and water are 1.398, 1.421 and 1.101 ton/mm respectively. Comparing these results with those of the control case (as shown in Figure 14), it can be noticed that for beams cooled by air or $CO_2$ the reduction in failure loads and overall stiffness is about 25% and 23% respectively compared with those of the control case. For beams cooled by water jet, the failure load decreased by 29% and the overall stiffness decreased by 39% compared with the control case. These reduction percentages in strength and stiffness can be attributed to the previously mentioned thermal shock. In addition of that, the temperature degree 650$^o$C for 4 hours causes a complex physicochemical changes in concrete due to the evaporation of the hydrated water (one of the essential components of the C-S-H hydrated cement paste) which considered very dangerous since it represents the beginning of concrete complete disintegration. This result emphasize clearly the danger of using sudden cooling of RC structural elements subjected to either limited fires or severe fires as well.

## 5 Conclusions

Based on the obtained test results and the aforementioned discussion, the following points can be concluded:

1. Exposure to 300$^o$ C for two hours and cooling in air or by using $CO_2$ fire extinguisher almost has no significant effect on the ultimate strength but causes 12% reduction in the overall stiffness.
2. Exposure to 300$^o$ C for two hours and fast cooling by water jet causes a significant reduction in both strength and overall stiffness (16% and 24%respectively).
3. Exposure to 650$^o$ C for four hours has a significant effect on both strength and overall stiffness. Exposure to 650$^o$ C for four hours and cooling in air or by using $CO_2$ fire extinguisher causes an average reduction in strength and overall stiffness about 25% and 23% respectively. On the other hand, fast cooling by water jet causes a reduction in strength and overall stiffness by 29% and 39% respectively.
4. Cooling in air or by using $CO_2$ fire extinguisher almost has the same effect on both strength and stiffness. Fast cooling by water jet is considered the worst cooling scheme.

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## References

[1] Youssef Awad, Mohamed A. Khalaf, Yehia A. Ali "Effect of fire temperature and duration on ultimate strength of RC columns with different cross sectional shapes" International Journal of Scientific and Engineering Research (IJSER), April 2018.

[2] Youssef Awad, Mohamed Kohail, Mohamed A. Khalaf "Effect of Fire Extinguishing Method and Surface Area to Volume Ratio on Ultimate Strength of RC Columns Subjected to Fire" International Journal of Scientific and Engineering Research (IJSER), July 2018.

[3] Mohamed A. Khalaf "EFFECT OF COOLING SCHEMES ON ULTIMATE STRENGTH OF REINFORCED CONCRETE COLUMNS SUBJECTED TO FIRE" - Scientific bulletin of faculty of Eng., Ain Shams University, June 2006.

[4] Balendran R .V, Maqsood T, Nadeem A, "Effect of cooling method on residual compressive strength of high strength concrete cured for 28 days and 180 days and heated to elevated temperatures", 26th Conference on OUR WORLD IN CONCRETE & STRUCTURES: 27 - 28 August 2001.

[5] Jensen E, "Assessment of Concrete Deformation and Failure Behavior during a Standard Fire Test and a Controlled Heating Rate Test", ACI Spring Convention, April 2015.

[6] Technical Note, Izbicki T, McDonald, David B,"Fire Resistance of Reinforced Concrete Buildings", Concrete reinforcing steel institute, No. 52, 2015.

[7] Arel H. S, Yazıcı S, "Effect of Different Parameters on Concrete-Bar Bond under High Temperature", ACI MATERIALS JOURNAL, V. 111, No. 6, November-December 2014.

[8] Bikhiet M.M, El-Shafey N.F *, El-Hashimy H.M, "Behavior of rein-

forced concrete short columns exposed to fire", Alexandria Engineering Journal, May 2014.

[9] Xiao J, Hou Y, Huang Z, "Beam test on bond behavior between high-grade rebar and high-strength concrete after elevated temperatures", Fire Safety Journal, V.69, 2014.

[10] Lublóy É, György B.L, "TEMPERATURE EFFECTS ON BOND BETWEEN CONCRETE AND REINFORCING STEEL", JOURNAL OF FACULTY OF CIVIL ENGINEERING, V.26, 2014.

[11] Thesis,Emberley R. L, Leonard D. A, "A Study into the Behavior of Reinforced-Concrete Columns under Fire Exposures using a Spreadsheet-Based Numerical Model", WORCESTER POLYTECHNIC INSTITUTE, May 2013.

[12] Jansson R, "Fire Spalling of Concrete theoretical and experimental studies", stockholm, Sweden, 2013.

[13] Yehia S, Kashwani G, "Performance of Structures Exposed to Extreme High Temperature—An Overview", Open Journal of Civil Engineering, 2013.

[14] Technical Note, Sebaaly J, "Fire effects on concrete", Fellow constructor, 2014.

[15] Pothisiri T, Panedpojaman P, "Modeling of bonding between steel rebar and concrete at elevated temperatures", Construction and Building Materials, V.27, 2012.

[16] Zhang Q, Yuan G, Dong Y, "Influence of Cooling Methods and Standing Time on Different Aggregate Concrete Strengths after Elevated Temperature", Advanced Materials Research, ISSN: 1662-8985, Vols. 250-253, pp 155-159, 2011.

[17] Raut N, Kodur V.R, "Response of Reinforced Concrete Columns under Fire-Induced Biaxial Bending", ACI Structural Journal, September 2011.

[18] Dimia M .S, Guenfoud M, Gernay T, Franssen J-M, "Collapse of concrete columns during and after the cooling phase of a fire", Journal of Fire Protection Engineering, 21(4) 245–263, 2011.

[19] Fawzi N. M, Essa M. S, Kadhum M. M, "BEHAVIOUR OF FIRE EXPOSED REINFORCED CONCRETE COLUMNS", Journal of Engineering, Number 3, Volume 17, June 2011.

[20] Thesis, Nassar K. M, Shihada S, "Improving Fire Resistance of Reinforced Concrete Columns", Islamic University of Gaza, 2011.

[21] Henry M, Suzuki M, Kato Y, "Behavior of fire-Damaged Mortar Under Variable Re-Curing Conditions", ACI Materials Journal, V.108, 2011.

[22] Yaqub M, Bailey C.G, "Repair of fire damaged circular reinforced concrete columns with FRP composites", Construction and Building Materials, 25, 2011. 1

[23] TECHNICAL NOTE, "Fire Damaged Reinforced Concrete–Investigation, Assessment And Repair", Vic Roads, April 2011.

[24] Amr I. I. Helmy, "Fire Protection of Reinforced Concrete Columns Retrofitted Using Advanced Composite Materials" 10th.ICSGE conference, Faculty of Engineering, Ain Shams University, 2003.

[25] S.H.Okba, A.I.I.Helmy, K.M.Morsy, "Retrofitting of Reinforced Concrete Columns Subjected to Fire Using Advanced Composite Materials" ICPCM conference, Faculty of Engineering, Ain Shams University, Cairo, Egypt, 2003.

[26] E.A.Nasr, A.I.Helmy, K.M.Morsy, "The Structural Behavior of RC Beams Subjected to Fire and Retrofitted using Advanced Composite Materials" ICPCM conference, Faculty of Engineering, Ain Shams University, Cairo, Egypt, 2003.

[27] F.A.Shaker, M.M.Abdel Wahab "Assessment of Fire Damaged Rebars Using Surface Hardness Methods" ICPCM conference, Faculty of Engineering, Ain Shams University, Cairo, Egypt, 2003.