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Experimental Study of Behavior of Reinforced Concrete Columns with added Steel Fiber after Fire Exposure

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Abstract: The present study aims to evaluate the improvement of the general behavior of reinforced concrete columns strengthened by steel fiber after exposed to fire (Elevated Temperature). Ten R.C. columns with a circular cross section of 200 mm in Diameter and 1250 mm in Height and with different ratios of steel fibers in concrete mix (0.50%, 1.0% and 1.50%), were fabricated, then exposed to fire (Elevated Temperature), and different methods of fire-fighting were loaded up to failure. The results show that the strengthening with steel fiber increased the load capacity and stiffness of R.C. columns compared to control specimens. Exposing RC columns to fire causes deterioration in its behavior and of load capacity.
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Keywords: Experimental; Study; Behavior; Reinforced Concrete Column; Steel; Fiber; Fire Exposure

1. Introduction

In civil engineering, the use of composites is only beginning to gain acceptance because types of composite materials have not been economically competitive with traditional materials of building such as concrete or steel, and comprehensive design guidelines are not available [1-2]. Also, previous researshes indicate that concrete paste containing steel fiber had high tensile strength than that of plain concrete. Steel fiber reinforcement concrete (SFRC) is considered as a kind of method of strengthening concrete, it was used to reduce the problems occurred in concrete such as the weakness of concrete strength at critical zones and using of fibers may be lead to reduction of cracking under serviceability conditions and many researchers studied the properties of concrete mix had containing steel fibers [3:6]. Exposing reinforced concrete to high temperature causes deterioration in its properties. Concrete color provides a broad, general guide of temperatures. The main importance are losses in compressive strength, cracking and spalling of concrete cover, reduction in bond strength with reinforcement and increase in the risk of reinforcement corrosion due to high permeability and cracks and destruction of the bond between the cement and aggregates and the gradual deterioration of the hardened cement paste [7:11]. Also, it is important to study the change of reinforcement steel strength and stress-strain relationships due to temperature [12:14]. Literature studies indicate that the reduction of the strength happened in concrete at high temperatures, depends on some factors such as: specimen dimension, loading condition, concrete strength, temperature level, method of cooling, and heating duration [15-16]. Many researchers studied the effect of elevated temperature on R.C. columns show that the determination of fire resistance is essentially based on tabulated data containing the dimensions of the cross sections and values of concrete cover. Also, the buckling mode is observed at a temperature of about 500°C and a crushing failure mode is observed at lower temperatures [17-18].

2. Objectives

The scope of the present research was to study the effect of the following parameters on reinforced concrete columns with adding steel fiber to the mix:

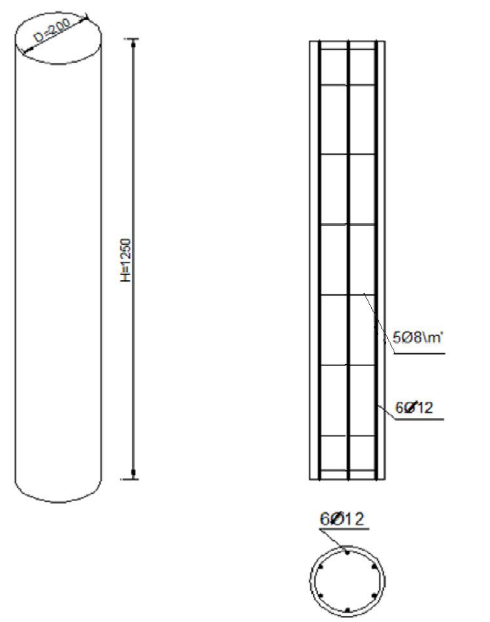
- Percentage of steel Fiber in the concrete mix of columns (Percentage 0.5%- 1%- 1.5% of the volume of concrete).
- Exposure to fire (Elevated Temperature at 500°c for 60 mins).
- Use different methods of fire-fighting.

3. Experimental Work

3.1. Program

The experimental program included ten specimens. All the specimens had a typical geometry. The columns have a circle cross section of 200 mm Diameter and 1250 mm Height. All the tested specimens have the same reinforcement ratio. The main reinforcement was six bars of nominal diameter of 12 mm and the concrete cover was 20 mm. The stirrups had a nominal diameter of 8 mm and shaped in closed circle form. These stirrups were arranged uniformly along the column height with internal spacing of 200 mm. Reinforcement of specimens are shown in Figure (1) and Figure (2). Figure (3) shows the formworks. The details of the specimens are listed in Table (1).

3.2. Materials



CONCRETE DIMENTIONS **REINFOREMENT DETAILS**

All Dimensions in mm

Figure (1) Details of typical specimen.

The tested columns of this experimental program were cast of concrete made of local materials in Egypt. Cement was ordinary portland cement, where coarse and fine aggregates were composed of siliceous sand and dolomite clean from impurities and good graded. High tensile ribbed steel bars of 12 mm diameter of grade of 36/52 were used as longitudinal steel and mild smooth steel of 8 mm diameter of grade of 24/35 were used as stirrups in all columns. Steel fiber type was corrugated has a thickness 0.5 mm, length 50 mm, aspect ratio (l/d) = 100 and denisty of 7800 kg/m^3. Percentages of steel Fiber in the concrete mix of columns (0.5%- 1%- 1.5%) of the volume of concrete. Internal electrical strain gauges (Type KFG, 10-120-C1-11) were used to measure the strain of the main steel of specimens. The gauge length was 10 mms, 119.8 ± 0.2 ohm resistance with gauge factor 2.11 ± 1 %.

Figure (2) Details of reinforcement steel.

Figure (3) The formworks.

3.3. Concrete Mix

Mixing was performed using a concrete drum mixer. First, sand, cement and aggregate were dry mixed until a homogeneous colour was gained, then the pour water was gradually added and mixed thoroughly. Mixing operation continued for a period of about three minutes after adding water until a uniform colour was obtained. Then, the steel fiber was added by the prescribed ratio for each concrete mix by volume vraction Vf equal (0.5%, 1.0% and 1.5%) of the volume of concrete. The concrete was cast in the molds and compacted by a vibrator to insure full compaction and cured by covering the specimens with moist burlap sheets until testing day. The standard cubes (150×150×150 mm) were cast and tested to determine the compressive strength of the concrete of test specimens. After one day, all specimens and the sides of steel shutters were demolded and all specimens were covered with wet canvas for seven days to insure good curing. The average compressive strength for cubes was 26.1 MPa for the mix without steel fiber and was (26.8- 27.5- 28.3 MPa) for mixes with Vf equal (0.5%- 1.0%- 1.5%), respectively.

Table (1): Details of Tested Specimens

Group	Column No.	Rft		Steel Fiber %	Fire (for 60 min at 500°c)	Fire-Fighting Method	Comments
		Long Steel	Stirrups				
Control Group One	C1	6Ø12	5Ø8/m′	0.00%	No Fire	—	Control Column
	C2	6Ø12	5Ø8/ m′	0.50%			
	C3	6Ø12	5Ø8/ m′	1.0%			
	C4	6Ø12	5Ø8/ m′	1.50%			
Group Two	C5	6Ø12	5Ø8/ m′	0.50%	Fire	Air	5 hr
	C6	6Ø12	5Ø8/ m′	1.00%			
	C7	6Ø12	5Ø8/ m′	1.50%			
Group Three	C8	6Ø12	5Ø8/ m′	0.50%	Fire	Water	15 min
	C9	6Ø12	5Ø8/ m′	1.0%			
	C10	6Ø12	5Ø8/ m′	1.50%			

4. Test Procedure

A smooth plastic pipes (pvc) were used for casting all the test column specimens and a wooden form around pipes to fix it and constrain movements were prepared. Specimens without fire were supplied with internal electrical-strain gauges before casting. The strain gauge fixed at the mid height of the main steel reinforcement within the columns. The electric strain gauge was connected to a digital strain instrument. Mechanical vibrator was used to ensure good compaction of concrete. All test specimens were casted in the same day and after 24 hours; all columns were cured using water. A special design for fire furnace was designed for the purpose of fire. The fire furnace system consists of two components; the gas pipes with six flame nozzles and the gas resource by gas cylinder. All specimens were tested centrically with clear height of 1250 mm using a loading system. The applied concentrated load was monotonically increased from zero up to final failure load. Axial column deformation was recorded at different loading stages. Also, horizontal displacements were recorded at different loading stages by the use of two linear variable differential transducers (LVTDs) which were applied at mid height of the column in two perpendicular directions.

5. Test Setup

All tests were carried out in the reinforced concrete laboratory of the Faculty of Engineering, ElMataria - Helwan University. Figure (4) shows the test setup used for experimentation:

A very stiff steel frame (1) consisting of vertical and horizontal I section was rested on the floor and used as a base to support the specimens. The load was applied vertically using a hydraulic jack (2) with 1500 KN capacity. Electrical pump was used; Steel plate (4) was put under the jack loading, the specimen (5). The jack was connected to standard I beam to keep it in a vertical position. A load cell (6) was directly located underneath the jack to measure the incresed load increments. The column rested on a cap (3) and we made a steel supported frame (7) round the column to fix it. The LVDTs were used to measure the axial deformations (10) and the horizontal displacements at mid of column height (9).

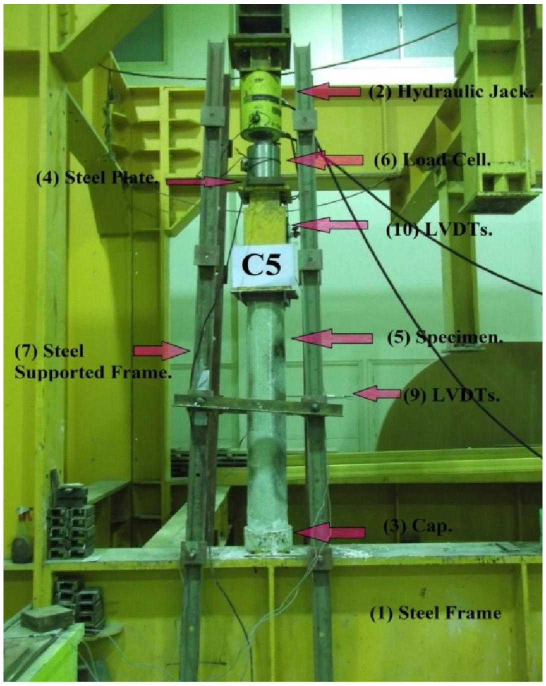


Figure (4) Test setup.

6. Test Results

The test results for all columns are summarized in Table (2). Figure (5) shows the crack patterns of all tested specimens and Figures (6 through 12) show the failure loads, deformations, stiffness, ductility and energy absorption for tested column specimens.

Table (2): The test results for all columns.

Group	Column no.	Cracking load P_{cr} (KN)	At Failure			Comments
			Failure load P_{ult} (KN)	Δ_{Axial} (mm)	$\Delta_{Horiz.}$ (mm)	
Control Group One	C1-0.00-NF-C	182	615	2.38	3.5	Control columns **No fire**
	C2-0.50-NF-C	330	724	2.3	3	
	C3-1.0-NF-C	355	758	2.24	2.8	
	C4-1.50-NF-C	424	778	1.95	2.2	
Group Two	C5-0.50-F-A	152	565	3.56	6.31	- **Fire** for 45 min at 500 °C - Cooling **Air**
	C6-1.0-F-A	222	644	3.1	5	
	C7-1.50-F-A	280	668	2.8	3.5	
Group Three	C8-0.50-F-W	118	535	4	9.5	- **Fire** for 45 min at 500 °C - Cooling **Water**
	C9-1.0-F-W	137	545	3.7	6.35	
	C10-1.50-F-W	143	567	3.4	4.9	

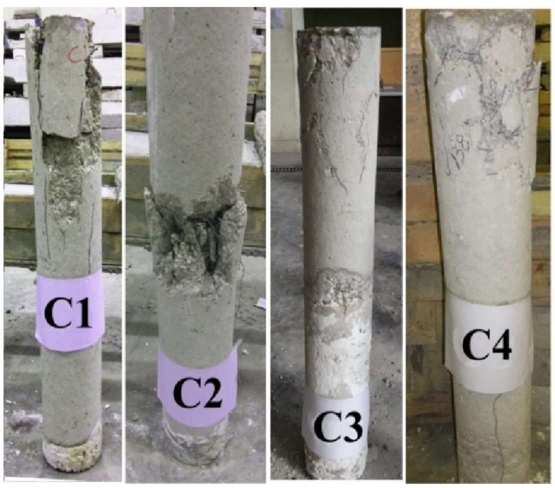


Figure (5) Crack Patterns for all specimens.

As shown in Figure (5), it can be seen that whenever increased the steel fiber content, the number and width of cracks decreased, it may be due to the crack arresting mechanism of the closely spaced fibers and the internal splices between fibers and concrete paste. And that was significantly in in case of without fire and in high content of fiber by Vf equal to 1.5%.

Fire-damage on studied RC columns started with visual observation of color change. In addition to, the cooling by water make the paste of the concrete columns deteriorate and add to it the crumbly texture and make the cover simple to separate and spalling.

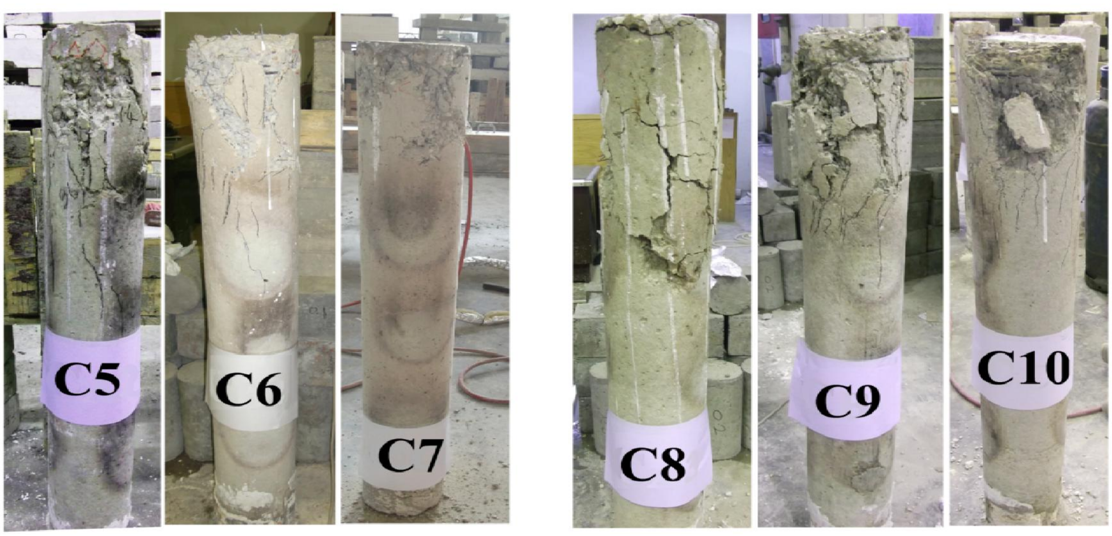


Figure (6) the failure loads for all specimens shows that adding of steel fibers can enhanced the capacity of reinforced concrete columns and was significantly by adding (Vf) equal to 1.50%. Also the (Vf) equal to 1.0% showed the best rating in an enhanced capacity ratio in case of no fire and in case of fire and cooling in the air.

- In spit of the decreasing in capacity in case of fire and cooling in the air, the steel fiber enhanced the residual capacity whenever the content increase.

- In case of fire and cooling by water, adding steel fiber has a slight enhance in load capacity of studied RC columns.

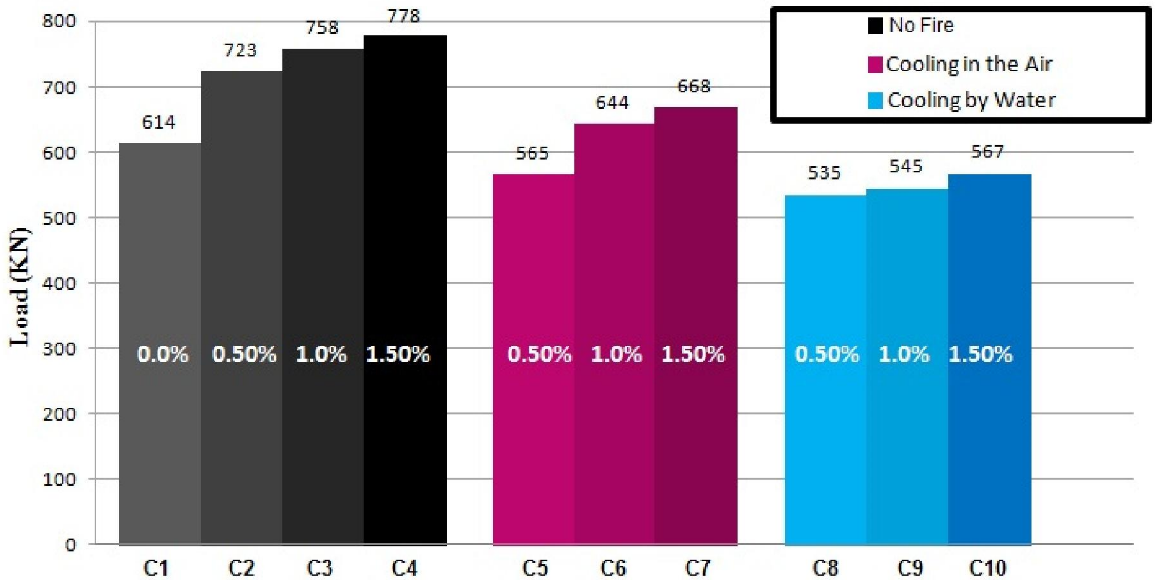
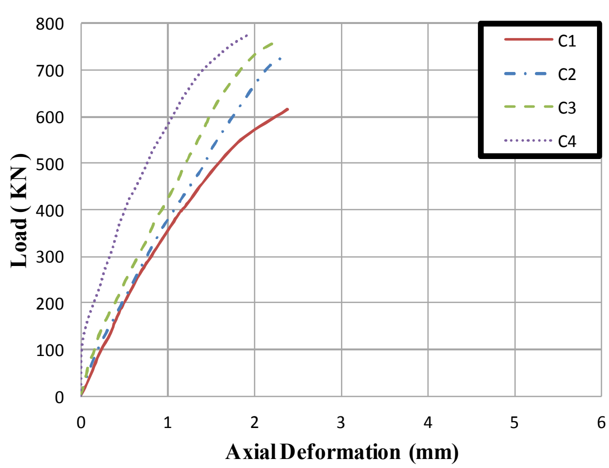


Figure (6) Failure loads for all specimens.

Adding steel fiber in mixture by Vf equal (0.50%, 1.0% and 1.50%) decreased the axial deformations of RC columns by 3.5%, 6.25% and 22%, respectively, compared by the control column without steel fiber. Also decreased the horizontal displacements of RC columns by 16.7%, 25% and 59%, respectively, compared by the control column without steel fiber. It is may due to the bonding between steel fibers with the surrounding concrete. As shown in Figure (7) Steepness and linearity of deformations curves increased as the content of steel fiber increased. The reason could be due to the participation of the vertical components of steel fibers with the main steel in carrying stresses, it is clear in C4 which having the high fiber content by Vf = 1.50%. The participation of the vertical component of steel fiber is may be similar to the behavior of spiral stirrups.



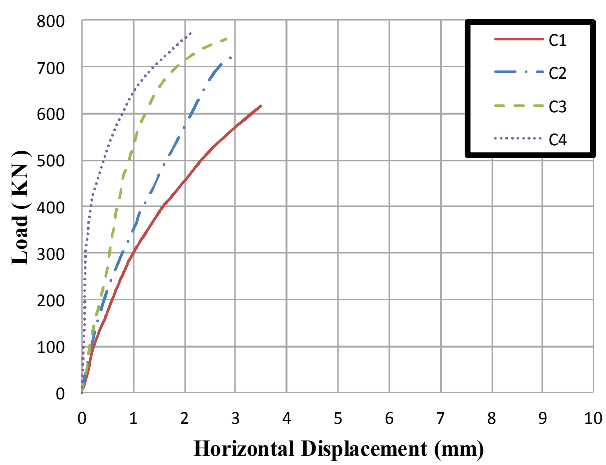
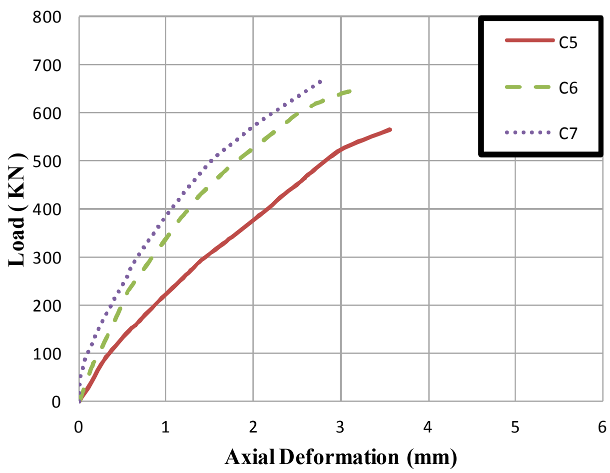


Figure (7): Deformation relationships for specimens (C1, C2, C3 and C4).



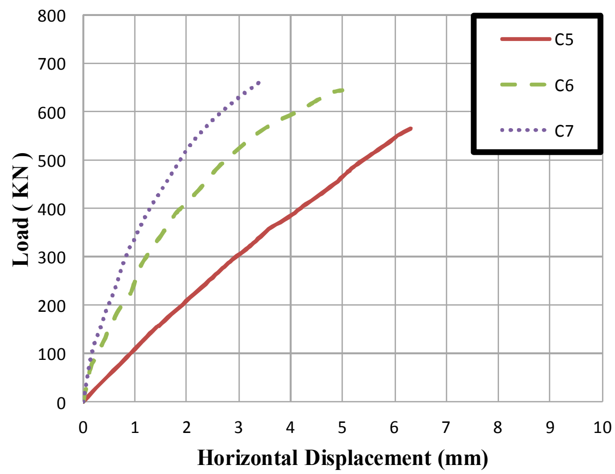
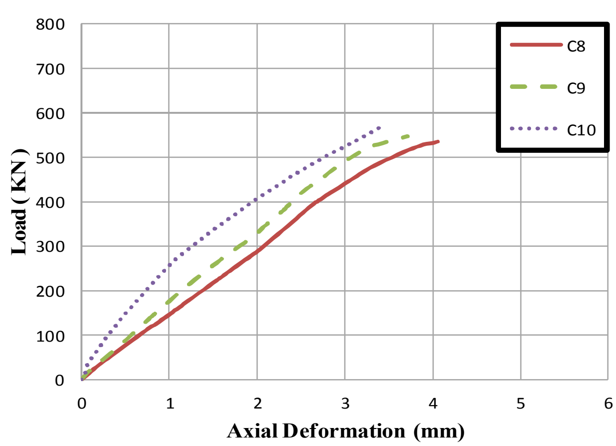


Figure (8): Deformation relationships for specimens (C5, C6 and C7).

The effect of fire can observed in the high axial and horizontal deformation values as shown in Figure (8). Whenever the volume fraction (Vf) increased, the deformations decreased. The reason may be due to effects of steel fibers and bonding between steel fibers with the surrounding concrete which will act as confinement to the concrete. Also found that the behavior in the load-axial deformation curves of C6 and C7 with (Vf) equal to 1.0% and 1.50%, respectively was close.

Figure (9) shows that in case of cooling by water, the studied RC columns give non-true displacement and deformations due to the spalling of some parts of concrete and the puffy shape taken after fire and cooling by water. The results can be explained the reason of the high values of the horizontal displacement in column C8. Also, It is observed from the Figure that the slope of horizontal-displacement curve of column C8 is very decline and was the most affected column by the water cooling and fire, this could be explained due to the low content of steel fiber. The comparisons shows that the cooling by water causes un-controlled deformations and displacements.



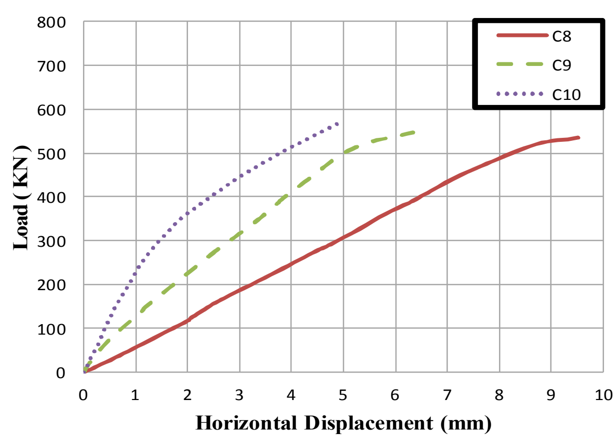


Figure (9): Deformation relationships for specimens (C8, C9 and C10).

For the control columns (C1, C2, C3 and C4) adding steel fiber increased the stiffness, according to the crack arresting mechanism of the closely spaced fibers and the internal splices between fibers and concrete paste. Figure (10) shows that the column C4 with Vf = 1.5% is more stiffner than the other columns, increased by 125.4% compared C1 without fibers. And for cases of fire and cooling, whenever fiber content increased the stiffness increased, however exposure the studied RC columns to fire may causes loss in their stiffness and increase in their ductility as shown in Figure (11). For specimens that were exposed to fire and cooling in the air and those exposed to fire and cooling by water, the stiffness decreased by average 58.3% and 202.5% respectively, this shows that cooling by water deteriorate the stiffness and increased the ductility of RC columns regardless of fiber content. The column C8 which has a volume fraction (Vf) = 0.50% is more ductile than the other columns due to the low volume of fraction of 0.50% and cooling by water.

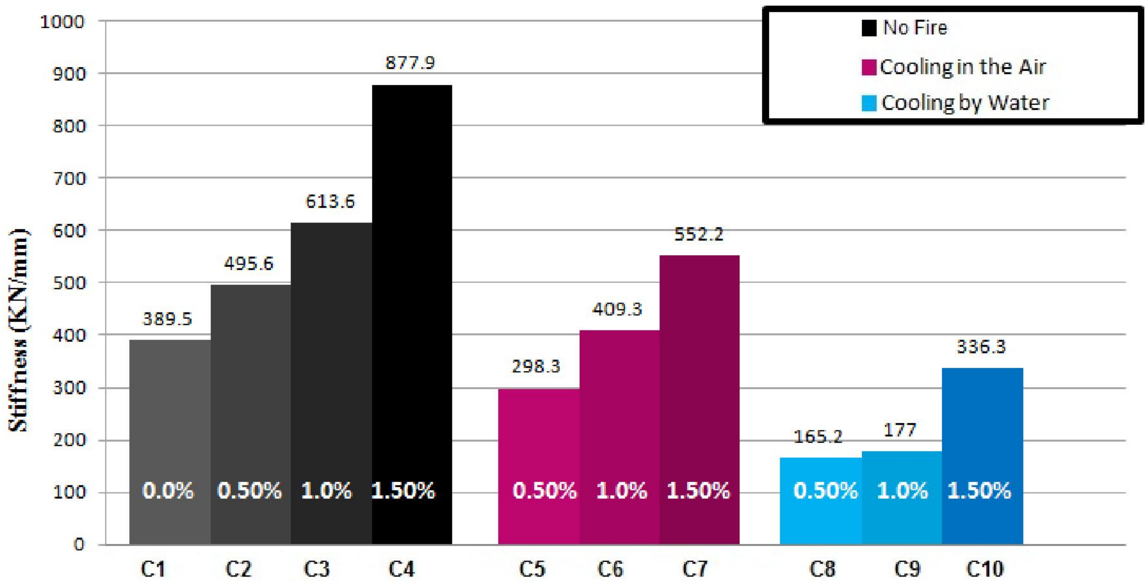


Figure (10) Stiffness for all specimens.

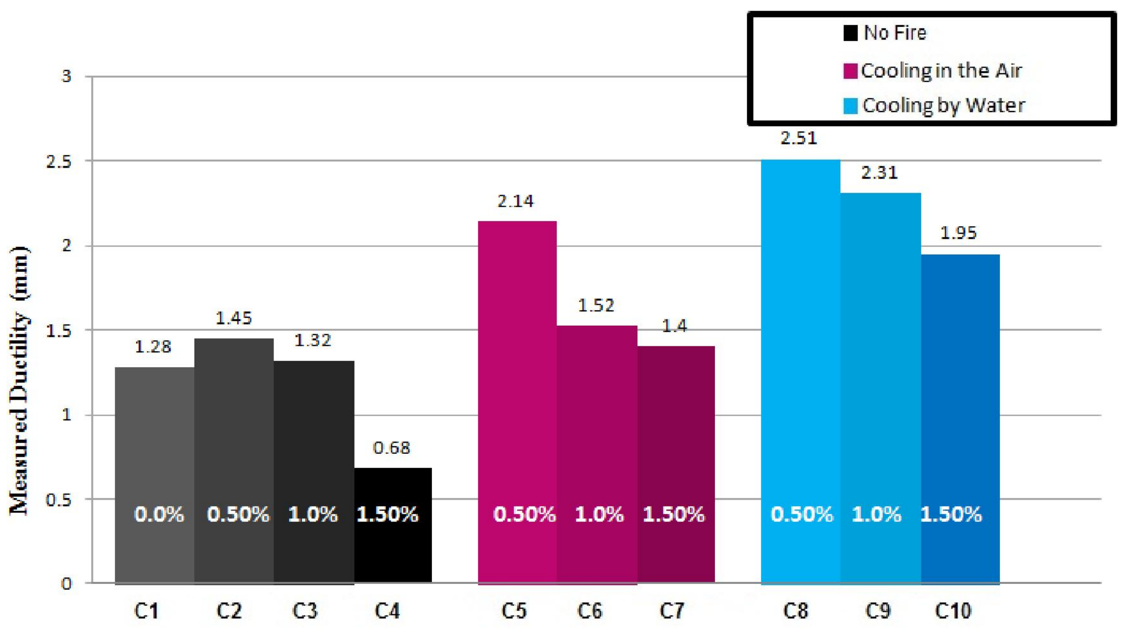


Figure (11) Measured Ductility for all specimens.

Figure (12) shows values of energy absorption for all specimens. The energy absorbed by the element or structure are given by the area under the load-axial deformation curve. The results shows convergent values, because of the variation of the ductility which incresed in cases of fire and cooling in air or by water.

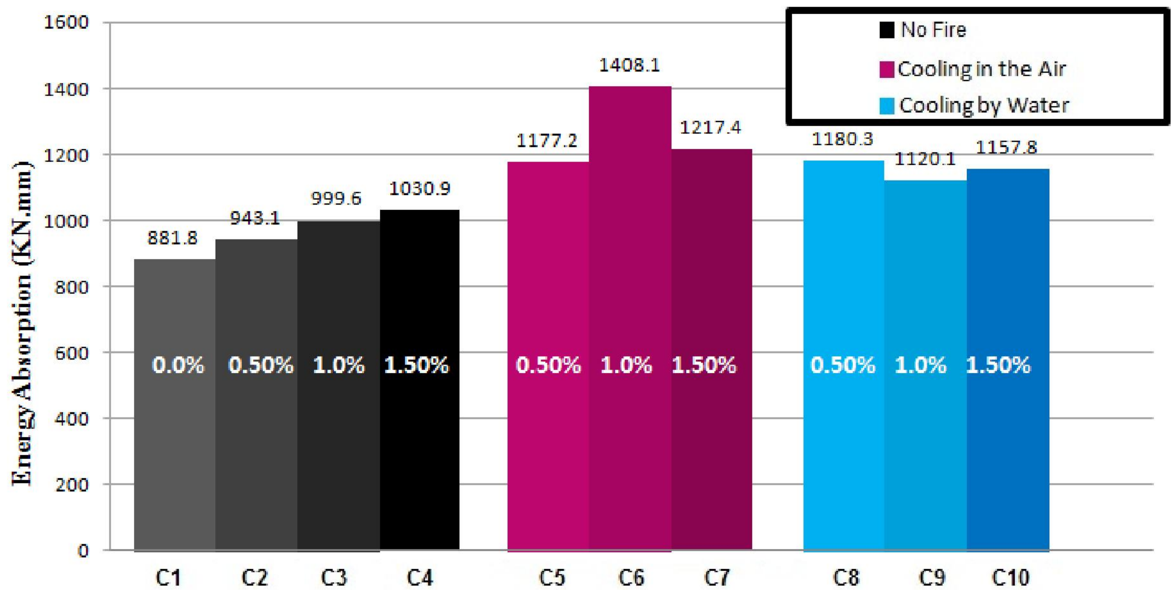


Figure (12) Energy absorption for all specimens.

For the column spicmens (C1, C2, C3 and C4) with no fire, non of the strain of reinforcement steel reached to the yielding point. However, it was found that the reiforcement strain is decreased as the steel fiber ratio increased which may indictes that the steel fiber in the column had contribution and exhbited some strains.

7. Comparison of Experimental Results and Theoretical Equations

Using the theoretical equation of the ACI 318 section 7.10.5 [19], to calculate the axial compression capacity of a tied column omitted the factor of safety Ø, three times of the three models shown in Table (3), which provid a different reduction factors in strengths due to fire, and then compared the calculated results with the experimental results sre shown in Figure (13).

The ACI Code equation as following:

Pu = 0.8 [0.85 fc´ (Ag – Ast) + fy Ast]…. (Eq. 1) [19]

Where:

fc´ = compressive strength of concrete = 0.8*Fcu.

fy = yield strength of reinforcing bar.

Ag = a gross area of cross section of the column.

Ast = the area of reinforcement steel in a cross section.

All columns have a section with diameter equal to 200 mm and reinforcement steel 6 Ø 12.

Table (3): The different models.

Model (1) Euro code [15]	This reference provides a reduction factors K and K´ in the strengths of concrete and steel duo to fire exposure as function in temperature T, in°c.
Model (2) International workshop [20]	This reference provides a reduction factors in the strength of concrete and the concret with adding steel fibers duo to fire exposure as function in temperature T, in°c.
Model (3) ASTM - A 514 [21]	This reference provides a reduction factors in the strengths of concrete and steel duo to fire exposure as function in temperature T, in°c.

As shown in Figure (13), the experimental result of the control column C1 which has Vf equals 0.0% and with no fire, is in good agreement with the ACI equation. And due to fire and cooling in the air, the capacities of columns (C5, C6, C7) decreased, however, still those results more than the models results by average of 51%. Also, in case of fire and cooling by water, the capacities of columns (C8, C9, C10) decreased, even less than the case of cooling air, however, still those results more than the models predictions by average of 34.3%, but the variance decreased. The used prediction models are very conservative in dealing with the case of exposed to fire, hence the reduction values in models are more than the actual reduction capacities obtained according to the experimental results. So, the experimental results is significantly more than the theoretical results.

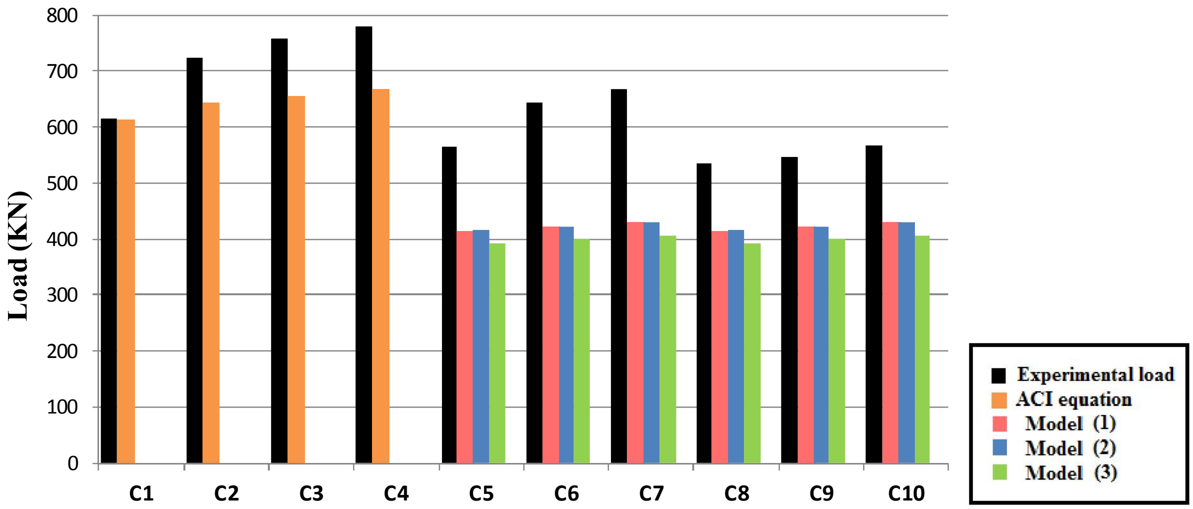


Figure (13) Experimental loads versus Theoretical loads.

8. Conclusions

From the tested results, the main conclusions which can be drawn from the current research can be as followings:-

1. Adding steel fiber in mixture by Vf equal (0.50%, 1.0% and 1.50%) increased the load capacity of R.C. columns by 17.7%, 23.3% and 26.5%, respectively, compared by the control column without steel fiber.
2. In spit of the decreasing of capacity due to fire, the steel fiber enhanced the residual strength of columns whenever the content ratio increases.
3. Exposure to fire and cooling by water made the concrete paste of the studied columns deteriorate and added to it the crumbly texture and made the cover simple to separate and spalling of some parts of column concrete.
4. For specimens that were exposed to fire and cooling in the air and those exposed to fire and cooling by water, the failure load decreased by average 20.8% and 37.2%, respectively compared to the same Vf of steel fiber for specimens without fire. this shows that the deterioration in capacity of R.C. columns due to cooling by water is more than the case of cooling in the air.
5. Exposure to fire and cooling by water increased the ductility of the tested RC columns which has Vf of steel fiber ratio equal to 0.50%, 1.0% and 1.5% by 73%, 75% and 186%, respectively compared to the same Vf of steel fiber for specimens without fire.
6. For specimens that were exposed to fire and cooling in the air and those exposed to fire and cooling by water, the stiffness decreased by average 58.3% and 202.5%, respectively compared to the same Vf of steel fiber for specimens without fire, this shows that cooling by water deteriorate the stiffness of RC columns for any proportion of steel fiber content used.
7. The control specimen without steel fiber or fire, was in good agreement with the ACI model equation. However, the used prediction models in this study are conservative in dealing with the case of columns exposed to fire. The reduction values in models are more than the reduction capacities obtanied according to the test results.

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