# Strengthening of Circular Reinforced Concrete Columns with Steel Fiber Added to the Mix after Fire Exposure

Nasr Z. Hassan[1], Mostafa A. Osman[2], Doaa Y. Mohammed[3]

[1]Associate Professor, Civil Eng. Dept., Helwan University, Cairo, Egypt

[2]Associate Professor, Civil Eng. Dept., Helwan University, Cairo, Egypt

[3]Teaching Assistance, Civil Eng. Dept., Helwan University, Cairo, Egypt

*Abstract:* Columns are considered one of the most important structural elements in buildings; they transfer the load directly to the foundations. thus, their exposure to any variables or any extreme conditions such as fire may cause the collapse of the building as a result of buckling of columns.

The main objectives of this research are to investigate the effect of using the steel fiber reinforcing polymer on the strengthening of circular R.C Columns after exposure to fire. In the experimental program, the volume fraction of steel fiber, strengthening FRP area and method of Strengthening using FRP on the specimens varied in order to determine the effect of these variables on the specimen strength and axial displacement.

The experimental program consists of ten reinforced concrete short columns. A column was tested as a control column without steel fiber and without fire, nine columns with different percentages of steel fiber in the mix (0, 0.5%, 1.0%, and 1.5%) by weight, three specimens of the nine were tested only without fire, and six specimens were exposed to fire. then the columns were strengthened with glass fiber with strip of width (100mm, 200mm) respectively.

Experimental results indicated that adding steel fiber by different volume fractions increased the load carrying capacity of the reinforced concrete columns.

*Keywords:* FRP, axial displacement, steel fiber.

## I.  INTRODUCTION

The proposed technique of using steel fiber reinforced concrete reduces the manufacture and labor cost that is typically associated with conventional methods. Steel fiber reinforced concrete (SFRC) is used to reduce the problems occurring in concrete such as the weakness of concrete strength at the tension zone.

Strengthening of concrete structural members like Columns may be required on many cases such as Deterioration of structure due to environmental effect damage caused by accidents, upgrading loading requirements, revision in loading standards, and seismic retrofitting.

This research also includes a study of the effect of each variable on crack patterns, failure shape, load - deformation curves, steel strains, the stiffness, the ductility and energy absorption. From all these parameters a suggestion can be made to strengthen reinforced concrete columns after being exposed to fire.

## II.  EXPERIMENTAL PROGRAM

The experimental study herein tested ten reinforced concrete columns divided into four groups O, A, B and C. all specimens have same dimensions cross section, the cross section is circular section with dimensions 200 mm Diameter and 1250 mm Height. All columns have constant reinforcement. The longitudinal reinforced was 6Φ12 (grade 36/52) and 5Ø8 / m' was used (grade 24/35) as separate stirrups in transverse direction show in Figure (1).

Ten specimens are divided into four groups, the first group (GO) consisted only of column was cast without steel fibers and was examined under no fire conditions. The second group (GA) consisted of 3 columns with steel fiber (Vf)=0.5%, the two columns are exposed to fire for 2 hours at 600°c, and cooled in the open air then strengthened with glass fiber. The third group (GB) consisted of 3 columns with steel fiber (Vf)=1%, the two columns were exposed to fire for 2 hours at 600°c, and cooled by air then strengthened with glass fiber. The fourth group (GC) consisted of 3 columns with steel fiber ( Vf)=1.5%, the two columns were exposed to fire for 2 hours at 600°c, and cooled by air then strengthened with glass fiber. The width of the used strips in the columns was 20cm and 10cm; the distance between the strips is 10cm.
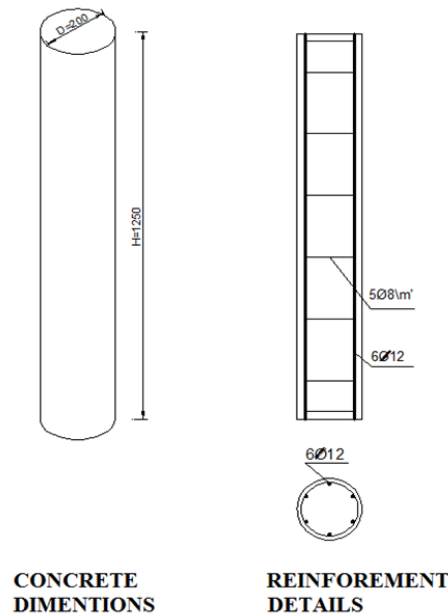


**Figure (1): Details of Typical Specimen.**

## III. MATERIAL CHARACTERISTICS

The materials used to cast the specimens were made from locally available materials (sand, dolomite, ordinary Portland cement and drinking water). A mix was designed to reach target cubic compressive strength of 250 kg/m2 after 28 days. High tensile ribbed steel bars of 12 mm diameter and yield stress of 360MPa were used as main steel of columns. Mild smooth steel 8 mm diameter and 240MPa were used as stirrups in all columns. Tests were carried out according to the Egyptian Standard Specification No. 262 / 2000. The used steel fiber with length 50 mm, diameter 0.5 mm, aspect ratio 100, density 78.5 KN/m3, an ultimate tensile strength of 1100 MPa, and an ultimate tensile strain of 2.2% (based on the manufacturer). The average characteristic concrete strength of tested cubes was 32.7 MPa, 25.8 MPa, 25.9 MPa and 28.5 MPa respectively relative to specimens of steel fiber volume fraction of 0.0%, 0.5%, 1.0 % and 1.5%.The use glass fiber with Dry fiber density 1.85 g\cm2 , dry fiber tensile strength 1.170 N\mm2 , dry fiber modulus of elasticity in tension 76 N\mm2 , cross section 95 mm2 , is show in Figure (2) and Figure (3).



**Figure (2): Steel Fiber.**          **Figure (3): Glass Fiber.**

## IV. SPECIMEN-PREPARATION

Test specimens were cast into PVC Smooth plastic pipes. All test specimens were casted in the same day and after 24 hours remove plastic pipes (PVC) for all columns and cured them with using water. A special fire furnace was designed for the purposes of fire. Six columns were strengthened by Glass Fiber after being exposed to the fire.

To measure strain used electrical strain gauges location in the mid height of the reinforcement steel column and used axial displacement and horizontal displacements were measured using LVDTs to accuracy of 0.01 mm, the horizontal displacement location at the mid height and the other at ¼ the height .

## V. ANALYSIS AND DISCUSSION

Table (1) illustrates the outcomes of the experiments for all tested specimens as the maximum loads, the cracking loads. For all tested specimens, by adding volume fraction of Steel fiber to the columns, the ultimate load increased compared to control specimen.

**Table (1): Test Results.**

| Specimens | % volume fraction | $P_{Cr}$ (kN) | $P_{failue}$ (kN) | Mode of Failure | $P_{failure.}/P_{failure. control}$ (CO) | $P_{failure}/P_{failure control}$ (C1A,C1B, & C1C) | Max. Displacement (mm) |
|---|---|---|---|---|---|---|---|
| CO | 0 | 227 | 702.3 | Crushing | 1 | -- | 4 |
| C1A | 0.50 | 249 | 723.3 | Crushing | 1.029 | 1 | 3.63 |
| C1B | 1.00 | 280 | 734.1 | Crushing | 1.045 | 1 | 3.5 |
| C1C | 1.50 | 350 | 943.4 | Crushing | 1.330 | 1 | 4 |
| C2A | 0.50 | 216 | 606.7 | Crushing | 0.863 | 0.838 | 3.66 |
| C2B | 1.00 | 246 | 709.8 | Crushing | 1.010 | 0.966 | 3.63 |
| C2C | 1.50 | 274 | 914.6 | Crushing | 1.302 | 0.969 | 5.21 |
| C3A | 0.50 | 275 | 744.7 | Crushing | 1.060 | 1.029 | 4.35 |
| C3B | 1.00 | 295 | 750.8 | Crushing | 1.069 | 1.022 | 3.70 |
| C3C | 1.50 | 300 | 920.6 | Crushing | 1.310 | 0.975 | 5.76 |

## VI. A COMPARISON BETWEEN THE COLUMNS WITH DIFFERENT STEEL FIBER CONTENT LOAD- DISPLACEMENT CURVES

Figure (4) show the relationship between the applied load and axial displacement. It is found that column (C1B) which has a volume fraction (Vf) of steel fiber equal to 1.00% is the most effective percentage in controlling the axial displacement. The results for columns (C1A), (C1B) with (CO), it was found that the measure of ductility increased by 15% and 27.5% respectively for both columns.
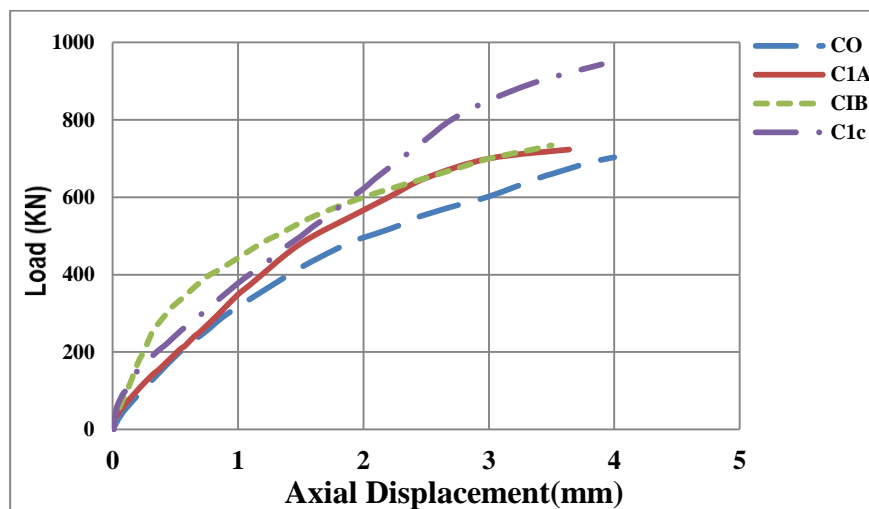


**Figure (4): Load-Axial Displacement Relationship.**

Figure (5) show the relationship between the applied load and axial displacement for three columns (C2A, C2B and C2C) which has a volume fraction (Vf) = (0.5%, 1.0%, 1.5%) and exposed to fire (at elevated temperature) for 2hours at 600°c and then strengthened with Glass fiber strips. Figure (6) show the relationship between the applied load and axial displacement for three columns (C3A, C3B and C3C) which has a volume fraction (Vf) = (0.5%, 1.0%, 1.5%) and exposed to fire (at elevated temperature) for 2hours at 600°c and then strengthened with Glass fiber strips.

The higher volume fraction of Steel fiber the recorded axial displacement was higher than in columns. The reason may be due to the effect of the fire exposure on the bond between steel fibers and the surrounding concrete which will act as confinement to the concrete. However, for column (C3B), the steel fiber was able enhance the axial displacement. Hence by increasing the volume fraction (Vf) of Steel fiber.
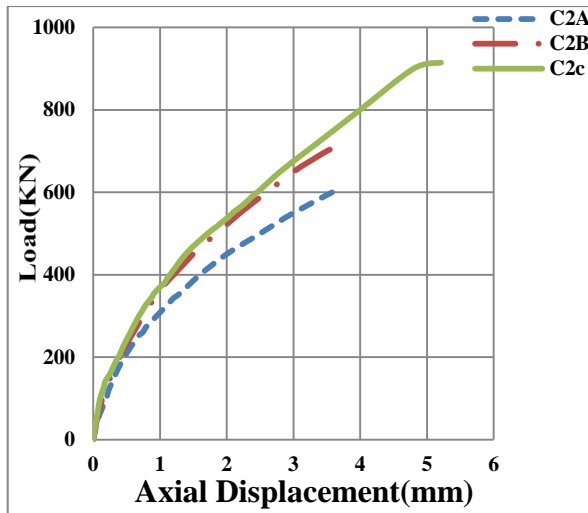


**Figure (5): Load-Axial Displacement.**
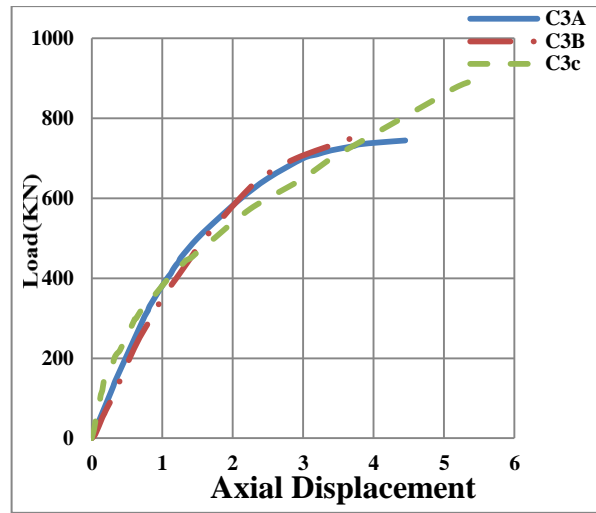


**Figure (6): Load-Axial Displacement.**

## VII. STIFFNESS AND DUCTILITY

Figure (7) and Figure (8) show the results Stiffness and ductility. This is obvious especially for the column (C1C) which has a volume fraction (Vf) = 1.5%, which is more stiffener than the other columns, it recorded an increase in the stiffness by 10.1%.
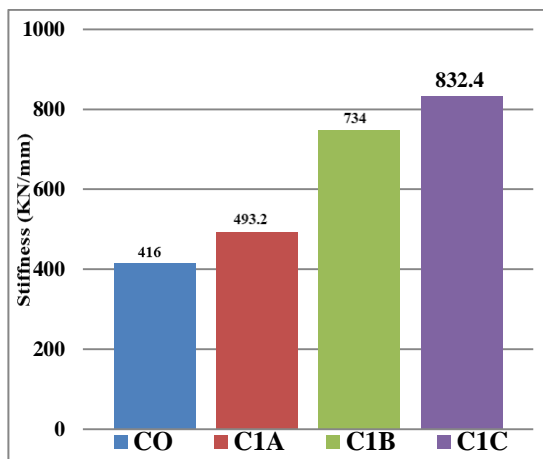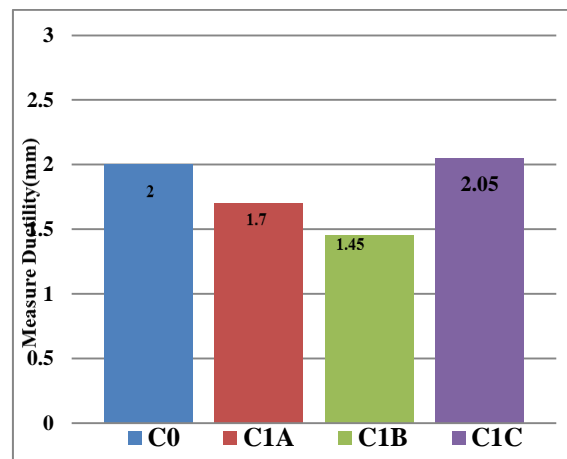


**Figure (7): Stiffness.**



**Figure (8): Measure of Ductility.**

Figure (9) and Figure (10) show that the stiffness of the columns decreased after exposure to fire; meanwhile strengthening the columns with Glass fiber strips did not have a significant effect on column load stiffness, the columns became more ductile after being exposed to fire.
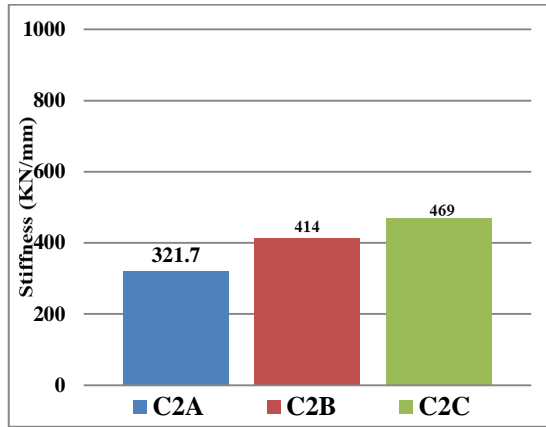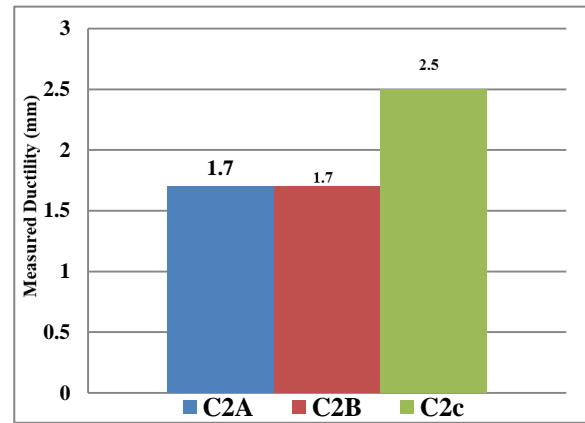
**Figure (9): Stiffness.**



**Figure (10): Measure of Ductility.**

Figure (11) and Figure (12) show that in case of fire and strengthening with Glass fiber strips of width 200mm, the results showed that the stiffness of the columns increased with increasing the volume fraction of Steel fiber used. That is why (C3C) which has volume fraction of Steel fiber equal to 1.50% is stiffer than the other columns. By comparing between the ductility values of columns (C3B) and (C3C), the recorded results showed an increase in ductility by 44.8%.
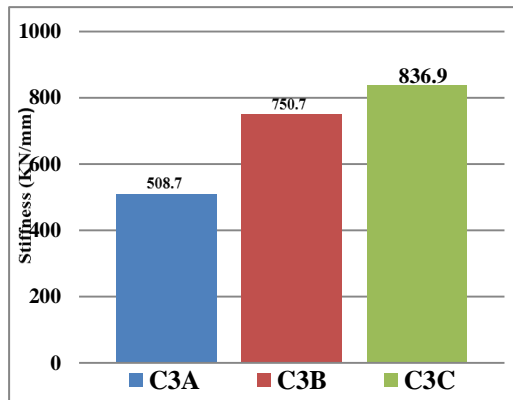


**Figure (11): Stiffness.**
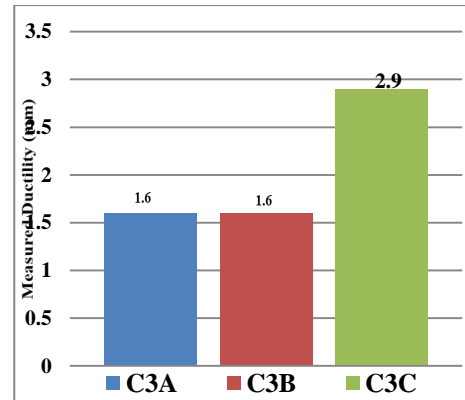


**Figure (12): Measure of Ductility.**

## VIII.   A COMPARISON BETWEEN THE COLUMN EFFECT OF FIRE AND STRENGTHENING LOAD- DISPLACEMENT CURVES

In general, it is noticed that the fire has a bad effect on axial displacement values which were relatively high; in addition, the strengthening with Glass fiber did not control the axial displacement. Show in the Figure (15) after being exposed to fire, the axial displacement of column (C2C) recorded an increase by 21.5% compared of the column (C1C) and The comparison between (C2C) and (C3C) recorded an increase in the value of axial displacement by 9.5%.
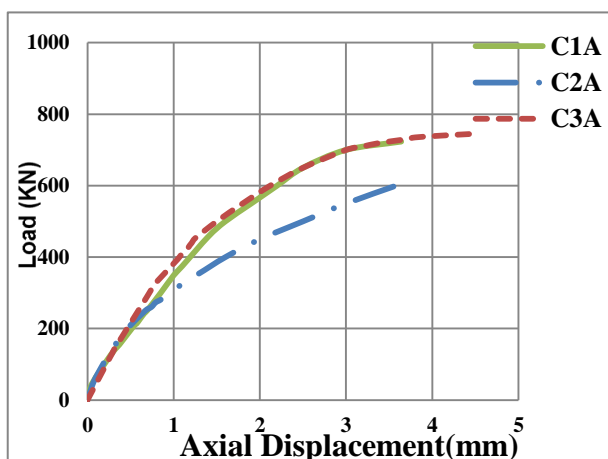


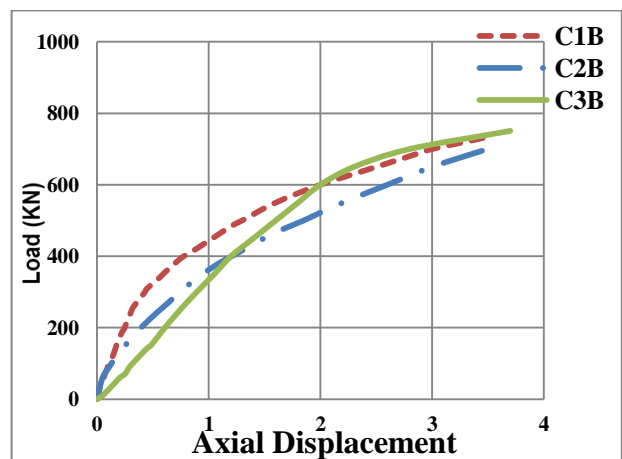**Figure (13): Load-Axial Displacement.**
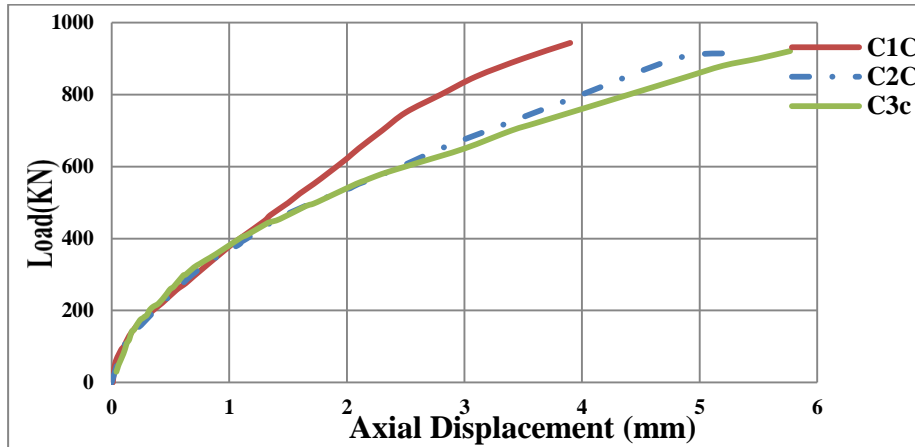


**Figure (14): Load-Axial Displacement.**

**Figure (15): Load-Axial Displacement Relationship.**

## IX.   STIFFNESS AND DUCTILITY

Figure (16) and Figure (17) show the results Stiffness and ductility, It can be seen that the strengthening with a strip of width 100mm or 200mm did not affect the ductility and stiffness of columns in this group; at variance the column (C3A) which exposed to fire and strengthened with a strip of width 200mm, is stiffer than the other columns at the same time it has the least column ductility.
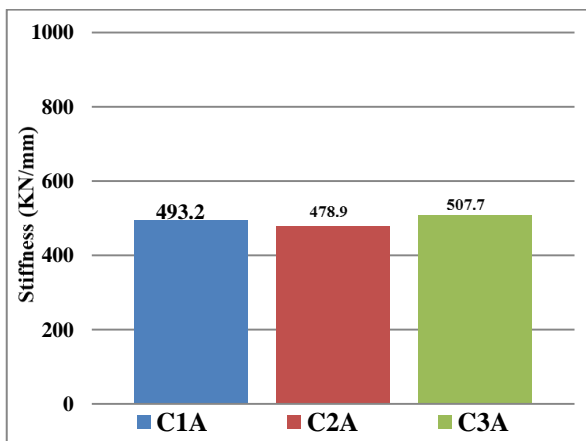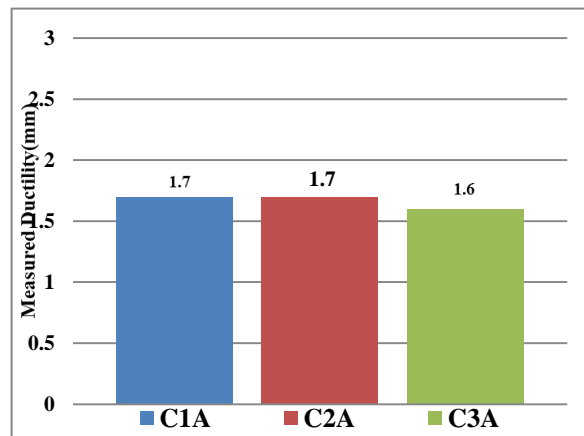


**Figure (16): Stiffness.**



**Figure (17): Measure of Ductility.**

According to figure (18,19,20 and 21), It is found that the fire has an observed bad effect on the stiffness of the columns this was significant especially in case of strengthening with Glass fiber strip with 100mm width The column was not exposed to fire is the least column in ductility.
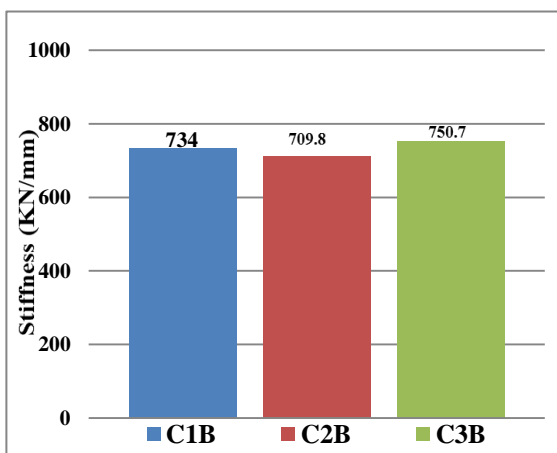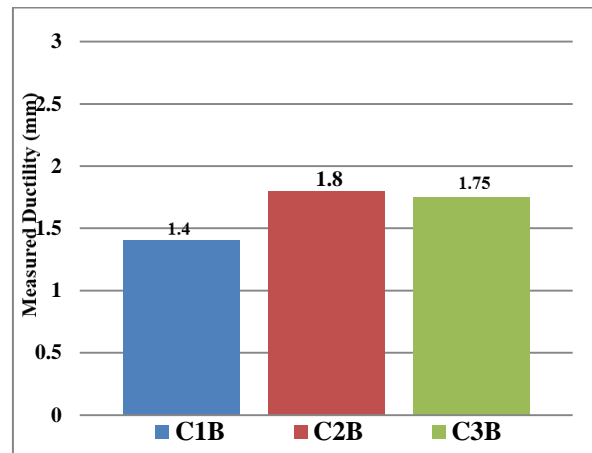


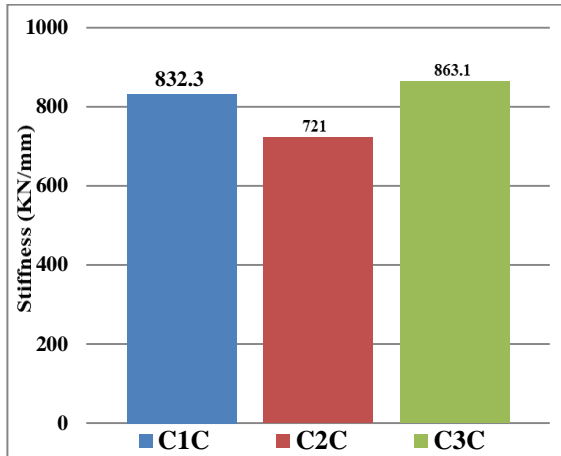**Figure (18): Stiffness.**



**Figure (19): Measure of Ductility.**

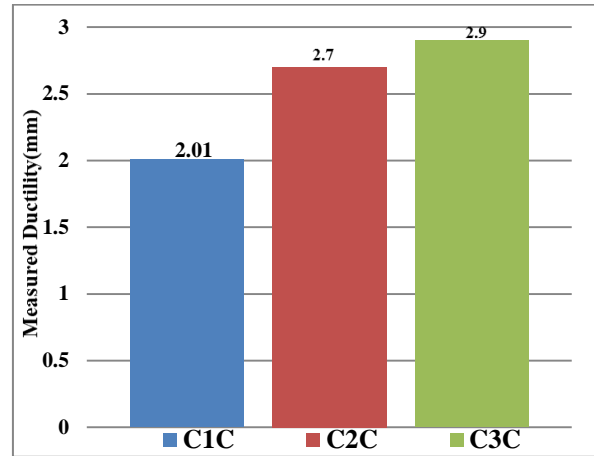Page | 24

**Figure (20): Stiffness.**



**Figure (21): Measure of Ductility.**

## X.   VARIATIONS WITH CODES MODELS

Used Model (1) show Euro code 2, ENV BC2 Design of concrete structures, General Rules and Rules of Buildings, DD. ENV, 1995[1], Model (2)  show International workshop "Fire Design of concrete structures" University of Coinbra, Portugal, November 2007[2] , Model (3) show Effect of Fire Damage on the structural properties of steel elements, April 30, 2011 University of Pittsburgh, according to ASTM - A514 [3] and used Model Equation From the ACI 318 section 7.10.5 [4] , the result are show in Figure (22) and Figure (23).
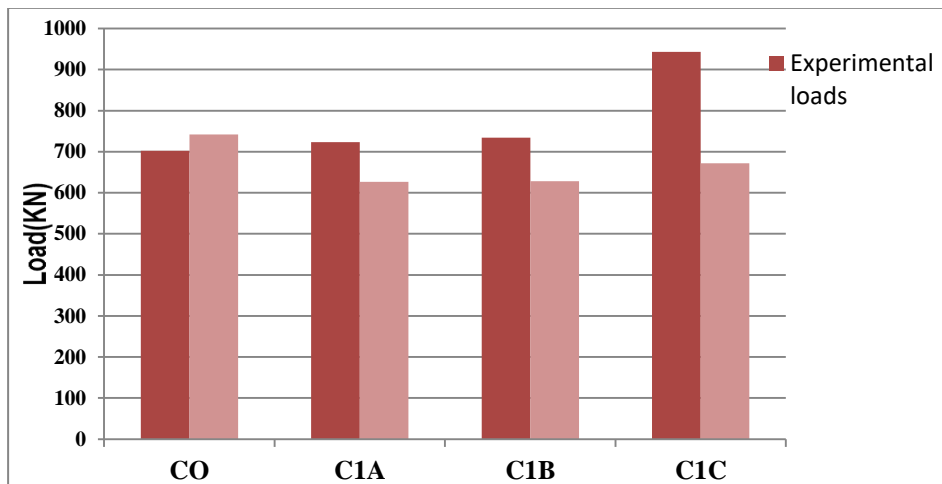


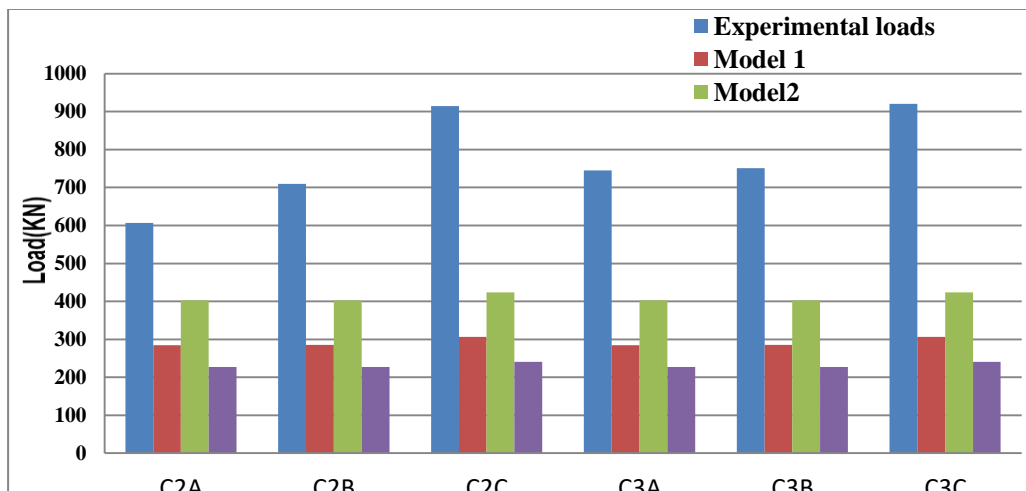**Figure (22): Experimental Loads Versus Used [0.0%, 0.5%, 1.0%and 1.5%] Model Loads [4].**



**Figure (23): Experimental Loads Versus Used [0.5%, 1.0%and 1.5%] Model Loads [1], [2], [3], [4].**

**Variation with reference (Hanna Suliman Al-Nimry   and Aseel Mohammad Ghanem) Results [5].**

All column specimens were designed as short columns with a circular cross section of 192 mm diameter and an unsupported length of 900 mm. six steel deformed rebars of 10-mm diameter and Transverse reinforcement was provided using 6-mm diameter deformed ties at a uniform spacing of 150 mm. The ties were provided at 60 mm.

**Table (2): Test Specimens [4].**

| Specimen designation | Fire condition | Strengthening condition | Fu(KN) |
|---|---|---|---|
| Control CH0-A | No Fire | _____ | 989.1 |
| CH2-G1L | Fire (2 hours) | wrapped with1 layer  of GFRP | 790.5 |
| CH2-G2L | Fire (2 hours) | wrapped with 2 layer of GFRP | 1045.3 |

**Table (3): Response Parameters for Test Specimens.**

| Specimen designation | Fire condition | Volume Fraction(Vf)% | Strengthening condition | Fu(KN) |
|---|---|---|---|---|
| Control C1A | No Fire | 0.5% | _____ | 723.3 |
| C2A | Fire (2 hours) | 0.5% | wrapped with Strip of GFRP 100mm | 606.7 |
| C3A | Fire (2 hours) | 0.5% | wrapped with Strip of GFRP200mm | 744.7 |
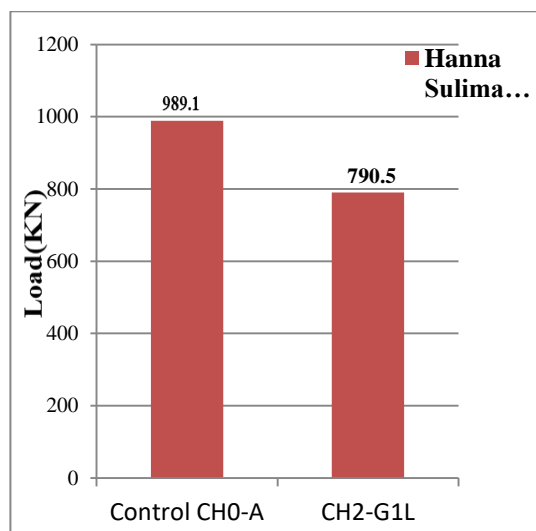


Reduction Ration 20%.

Residual Ration 80%.
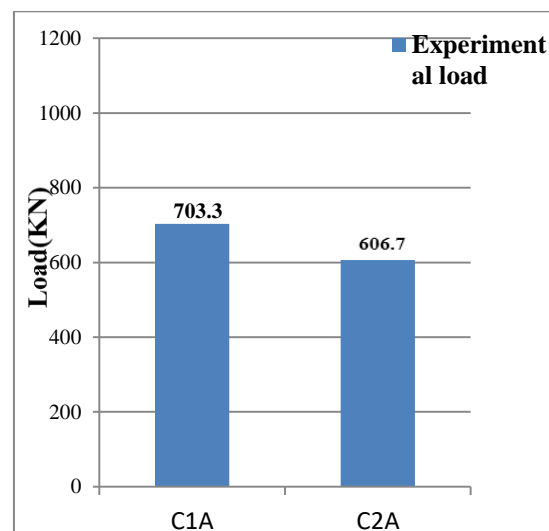


Reduction Ration 13.7%.

Residual Ration 86.3%.

The residual strength of the tested specimens in our research are rather high compared to the residual strength of the specimens experimented by Hanan Suliman [4]; this may be due to the difference in the used concrete mix, in our research the specimens contained steel fiber in their concrete mix where in the reference the specimens did not contain any steel fibers. This means that the steel fiber used in the concrete mix has a positive effect on the strength and capacity of columns.
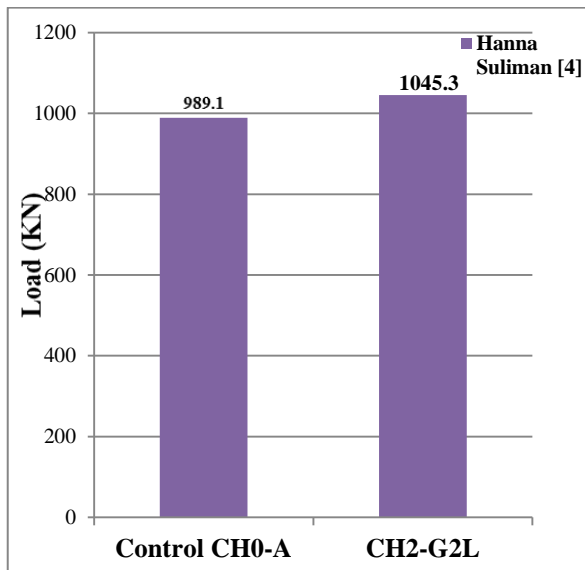
Increased Ration 5.7%                                  Increased Ration 5.9%
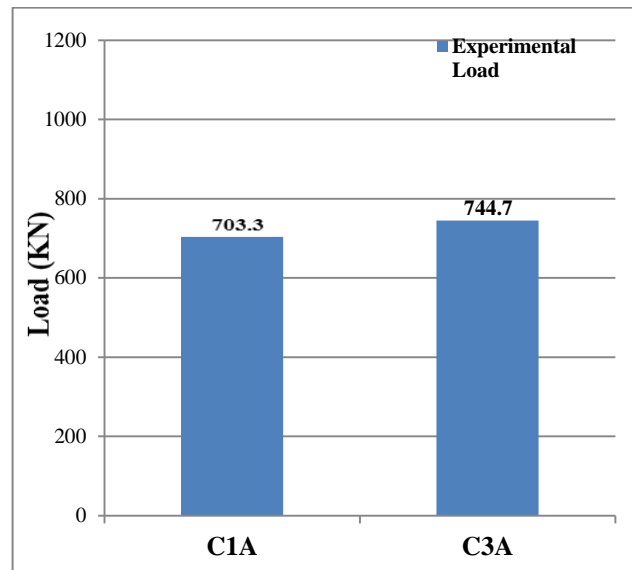
By variation between both ration we will notice that they were approximately the same, this may be interpreted that the used steel fiber in our experimental program together with using GFRP gave the same result as that was given by the program used in the reference. They used full strengthening with GFRP.

## XI.  CONCLUSIONS

1- By increasing the steel fiber volume fraction, the number of cracks and their width decrease this may be due to the action of the closely spaced fibers and the concrete paste.

2- Adding steel fiber to the mixture by different volume fractions 0.5%, 1% and 1.50%) increased the load carrying capacity of the reinforced concrete columns by (2.8%, 4.2% and 25.5%) respectively compared to the control column without fiber.

3- Adding steel fiber to the concrete affected the stiffness of the concrete columns, as the volume fraction of steel fiber increased by (0.5%, 1% and 1.50%) the stiffness increased by 15.7%, 44.4% and 50% respectively.

4- By subjecting the columns to high temperature, a general deterioration was obvious in their properties; this appeared as a loss in the compressive strength, cracking and spalling of concrete, destruction in the bond between the cement paste and the aggregates and finally crushing and splitting of the concrete parts.

5- For strengthening of specimens with strips of fiber glass the failure load increased with increased the width of the strip from 100mm to 200mm, the failure load also varied with the variance of the steel fiber volume fraction.

## XII.  VARIATIONS WITH CODES MODELS

1. The tested specimens (CO, C1A, C1B, and C1C) which contained a volume fraction of steel fiber (0%) are considered the control specimens; those specimens complied with the ACI equation.

2. The models were rather conservative especially in dealing with the case of fire; hence the used reduction factors caused a reduction in the loads which is high relative to the actual experimental results.

3. In the model equations there is not a term that considers the volume fraction  of steel fiber that was added to the tested specimens.

4. The experimental result of the control column (CO) which has (Vf) equal 0.0% with no fire and without strengthening, is in good agreement with the ACI equation by average (0.95%).

5. Due to fire and strengthening with GFRP strips of width 100mm, the capacities of columns (C2A, C2B, C2C) with (Vf) equals (0.5%, 1.0% and 1.5%) respectively the compressive strength decreased compared to  the control columns with the same volume fraction. However, still those results are more than the models results by average (2.51 %), due to added steel fiber ratio.

6. In the case fire and strengthening with GFRP strips of Width 200mm, the capacities of columns (C3A, C3B, C3C) with (Vf) equals (0.5%, 1.0% and 1.5%) respectively the compressive strength increased, compared to the control columns with the same volume fraction. However, still those results are more than the models results by average (4.1%), may be due both the added steel fiber and the strengthening.

## REFERENCES

[1] Euro code 2, ENV BC2 Design of concrete structures, General Rules and Rules of Buildings, DD. ENV, 1995.

[2] International workshop (2007): "Fire Design of concrete structures" University of Coinbra, Portugal, November.

[3] Effect of Fire Damage on the structural properties of steel elements, April 30, (2011) University of pittsburgh, according to ASTM - A 514.

[4] CEN. Eurocode 2 (1995): design of concrete structures, Part 1-2: structural fire design. Final draft, pr ENV 1992-1-2, European Committee for Standardization, Brussels.