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سلوك الكمرات المسلحة بأسياخ من الالياف الزجاجية والمعرضةلدرجات حرارة عالية حتي ٢٠٠ درجة مئوية

Behavior of Concrete Beams Reinforced with Glass Fiber Bars under High Temperature up to 200 °C

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الملخص: تميزت العقود القليلة الماضية بتدهور العديد من الهياكل الخرسانية بسبب تآكل حديد التسليح الذي غالبًا ما يتطلب إصلاحات أو استبدالاه مكلفة. لكي مقبولة على نطاق واسع في صناعة البناء والتشييد، يجب دراسة جميع جوانب سلوكها الهيكلي لضمان تطبيقها الآمن. لا يزال الالياف الزجاجية تصبح قضبان في ظروف الحريق قيد التحقيق. من المعروف أن هياكل البناء يجب أن تستوفي متطلبات الالياف الزجاجية سلوك العناصر الخرسانية المسلحة بقضبان التسليح القوانين ذات الصلة. تشير معظمها إلى الوقت المتاح في الحريق قبل انهيار الهيكل. ولذلك، فإن الخاصية الحقيقية التي سيتم فحصها ليست رد الفعل على حريق بمزايا مثل القوة نفسه، ولكن قدرته على الحفاظ على الحمل عندما ترتفع درجات الحرارة بسرعة. يتميز حديد الاسياخ التسليح المصنعة من الالياف الزجاجية الطولية العالية، ومقاومة التآكل، وعدم المغناطيسية، والتعب العالي، والوزن الخفيف، والتوصيل الحراري والكهربائي المنخفض.

Abstract. GFRP bars are introduced now a days in reinforcing concrete elements. The main objective of this research work is to experimentally evaluate the use of GFRP bars as the main reinforcement for beams with different ratios under pure bending. Behavioral characteristics of such beams are exposed to high temperatures up to 200$^{o.}$C. In addition, different methods of cooling whether, cooled by air or by water are investigated. An experimental program was designed to achieve these objectives as follows: The experimental program included twelve beam specimens of 200*400 mm in cross section and 3000mm in length divided in four groups for comparisons. First group contains beams with different ratios of GFRP bars up to failure (ø 8, ø 10, ø 12). Second group contains beams with 2 ø 8 GFRP heated up to 150 ^{o} C and 200 ^{o} C then left to cool gradually in air then tested. Third group contains beams with 2 ø 10 GFRP heated up to 150 ^{o} C and 200 ^{o} C and sudden cooled then tested. Fourth group contains beams with 2 ø 12 GFRP heated up to150 ^{o} C and 200 ^{o} C and sudden cooled then tested. Data gathered at Crack stage and at the ultimate stage (load, span deflection and bar strain) were recorded and illustrated in tables and figures. Beams behaviors were greatly affected by the high temperature and the method of cooling. The most compatible percentage ratio of GFRP bars as main reinforcement was 2% for such beams. Results obtained in the present work provide a set of experimental data that can be used in the future to facilitate the design and modelling of composite reinforced concrete beams and slabs at elevated temperature. Conclusions were drawn and presented.

Keywords: Concrete, GFRP bars, High Temperature, Cooling.

1. Introduction

The last few decades have been marked by degradation of numerous concrete structures due to the corrosion of steel reinforcement that often-required costly repairs or replacement. In order for GFRP bars to become widely accepted in the construction industry, all aspects of their structural behavior must be studied to guarantee their safe application. The behavior of concrete elements reinforced with GFRP rebars in fire conditions is still under investigation. It is known that building structures must satisfy the requirements of the relevant codes. Most of these refer to the time available in a fire before the structure collapses. Therefore, the real property to be investigated is not the reaction to fire of the GFRP rebar itself but its capability to maintain the load when temperatures are rapidly raising. FRP has advantages like high longitudinal strength, corrosion resistance, nonmagnetic, high fatigue light weight and low thermal and electric conductivity. Cost saving issue studied was mainly due to the fact that the density of the glass fiber reinforcement is 40% that of the steel reinforcement and the actual cost of it is three quarter of that of stee per meter. The standard deviation of modulus of elasticity of GFRP bars were reasonable for manual manufacturing [1]**.** Tests done on beams with different resins for GFRP bars, it was found out that, tire carbon C330, tire carbon C500, Graphite carbon C,

Magnesium oxide MNO, Iron oxide FeO, Aluminum oxide ALO and Magnesium Mg can be used for increased the efficiency of bars for temperature resistance. Resin mixed with carbon C330 with 10% has proven a very good efficiency in resistance to high temperature. Comparing to steel and GFRP bars, in terms of specific weight, tensile strength and ductility, the C. GFRP (C330-10%) bars has shown a very good competition. Also, elasticity of bars 63%. The bond strength of such bars is higher than steel specimens. C.GFRP proved significant success higher than steel and GFRP in terms of the highest tensile strength with concrete and bond strength before and after fire.it was found out that upper and lower reinforcement with C.GFRP(C330-10%)is a good trend compared to steel in terms of load capacity, ductility before and after burning[2]**.**The disadvantages of FRP could be stated as low stiffness, lack of standards, do not resist fire high coefficient of thermal expansion perpendicular to the fibers relative to concrete and insufficient data addressing long term fatigue, creep relaxation and chemical deterioration [1],[3],[4]. Due to the linear elastic behavior of FRP bars the flexural behavior of FRP reinforced beams exhibited no ductility as defined in the steel reinforced structures. Improving concrete properties, ACI 440 recommended for the FRP structures be over reinforced and designed so beams fail by concrete crushing rather than by rebar rupture [5]. Other countries, such as Japan (JSCE 1997b) and Canada (Canadian Standards Association (CSA) have established design procedures specifically for the use FRP reinforcement for concrete structures [6]. Tests were held to investigate bridge decks when exposed to elevated temperature, the maximum temperatures in the center of the heated zone were set to ≈230oC and ≈550ºC. The bottom rebars reached ≈140oC for an applied maximum temperature of 230oC and ≈400oC for 550oC. The two maximum temperatures were established to investigate the specimen's response in two distinct limit situations: when the rebars are close to the transition temperature Tg of the resin (≈180ºC for the used rebars), and when the resin completely evaporates and the rebars lose the bond to concrete in the heated zone [7]. Investigating the concrete cover in protecting concrete slabs subjected to fire, it was found that increasing bottom cover thickness increases fire resistance of flexure reinforced concrete elements. It must be noted that increasing cover results in effective depth decrease. Higher strength concrete loses more strength when exposed to the same heating condition than normal or lower compressive strength concrete. In addition of deflection increase for lower compressive strength concrete [8].
Experimental tests done on strengthened slabs by carbon fibers, it was found that gradual cooling showed better performance compared to sudden cooling. Stiffness increased by 32.23% stiffness 36.71% [9].

2. Experimental Program

2.1. The studied parameters are :

- Effect of GFRP ratio.
- Effect of rising temperature (room temperature,150°C,200°C).
- Effect of different methods of cooling (air cooled or water cooled).

2.2. Specimens

The experimental program was done in the concrete laboratory of the housing and building national research center (HBRC).
The test was carried out on 12 beam specimens, all the tested specimens have the same number of reinforcement bars and concrete dimensions as shown in **Fig. 1** and **Table 1.**
- The beams have a cross-section of b*t=200*400 mm and a length of 3000 mm and concrete strength of 50 MPa.
- The upper reinforcement of the beam was 2Ø 10 high strength steel of fy =362.3 MPa.
- The stirrups were mild steel ø 8 every 10 cm along beam length of fy =302.4 MPa.
- The lower reinforcement was either Ø8, Ø10, Ø12 GFRP bars. In this study the used GFRP bars were manufactured by ARMASTEK company. The GFRP bars are made of unidirectional E-glass fibers. They were manufactured by combining using the pultrusion process with a wrapping process to have a nominal diameter of 8,10 and 12 mm. The external surface of the rebars has a spiral wound yarn of fibers along the length with characteristics properties as follows:
- Ultimate tensile strength for bars =1600 Mpa
- Modulus of elasticity for GFRP bars = 35.50 GPa

- Maximum elongation for bars =2.1 - 3.1.
- Density= 2.2 g/m^3
- Heat conductance = 0.35.
- Unit expansion = 2.2 %

Figure 1 shows beam cross-section detailing and **fig.2** shows Placing Beams in the oven. Heat was well distributed inside the closed oven to ensure that beams were heated all around the four faces. Exposure time was for one hour. **Table 1** shows the twelve beam specimens and parameters investigated.

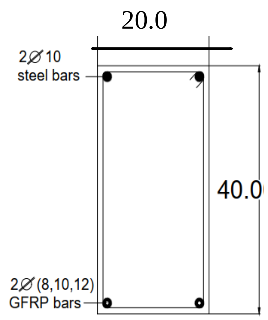

Fig. 1: Beam Cross-Sectional Area and Reinforcement Detailing

Fig. 2: Placing Beams in the oven

Table 1: Specimens Characteristics

Specimens	Glass fiber bar diameter	Burning condition	Cooling Method
Beam (1)	Ø8	-	-
Beam (2)	Ø10	-	-
Beam (3)	Ø12	-	-
Beam (4)	Ø8	Burned at 150°C	(A)
Beam (5)	Ø10	Burned at 150°C	(A)
Beam (6)	Ø12	Burned at 150°C	(A)
Beam (7)	Ø8	Burned at 200°C	(A)
Beam (8)	Ø10	Burned at 200°C	(A)
Beam (9)	Ø12	Burned at 200°C	(A)
Beam (10)	Ø8	Burned at 200°C	(W)
Beam (11)	Ø10	Burned at 200°C	(W)
Beam (12)	Ø12	Burned at 200°C	(W)

(A): Gradually cooled in air after exposed to heat;(W): Sudden cooled by applying water directly to the surface of the heated beam.

2.3. Experimental Instrumentation and Test Set up

The twelve specimens were tested under vertical increasing four-point (4-PB) load to assure pure bending up to failure. The experimental instrumentation and computerized test set up included in this section are presented in details with the following items for data recording:

2.3.1 Vertical Load

Vertical load was applied through a hydraulic jack accompanied by a load cell of 50ton capacity. The load cell was connected to a data logger used to record the load cell measurements of vertical load. The load was applied with a rate of 5 ton per minute.

2.3.2 Fire Application

The specimens where burnt in the fire lab in HBRC (Housing and Building research Center).The furnace is connected to two gas lines with a controlled ignition unit to induce fire beneath the specimen .The furnace can remain at the desired temperature by controlling the ignition of the gas procedure .Flame occurred away beneath the specimens.

2.3.3 Deformations

To assess the variation in deformation at confining elements, the relative deformation curves corresponding to load were developed for each specimen. The specimens were rested on welded steel rods welded to steel beams. The deflection was measured at the bottom of the middle span of the beam and under the two points of the applied load. Test set up and all data gathered were computerized. Load -Deflection curves of the tested specimens are plotted in figures. The deflection recorded by LVDT 1 at center of the beam and the deflection recorded by LVDT 2 at 30 cm away from the center to the right along with the deflection recorded by LVDT 3 at 30 cm away from the center to the left.

2.3.4 Strain gauges measurements

To assess the variation in strains in GFRP main reinforcements, the relative strains were measured by strain gauge attached to the GFRP bar by adhesive tape and silicon. Curves corresponding to load tensile strain relationships were recorded for each specimen, Load -GFRP Bar Strain curves are illustrated in figures.

2.3.5 Recording of Cracking Behavior and Mode of Failure

The developments of cracks in each specimen during testing was carefully observed and recorded by marking the cracks at crack load and the corresponding deflection and GFRP bar strain. Also, the failure mode for each specimen is clarified and discussed.

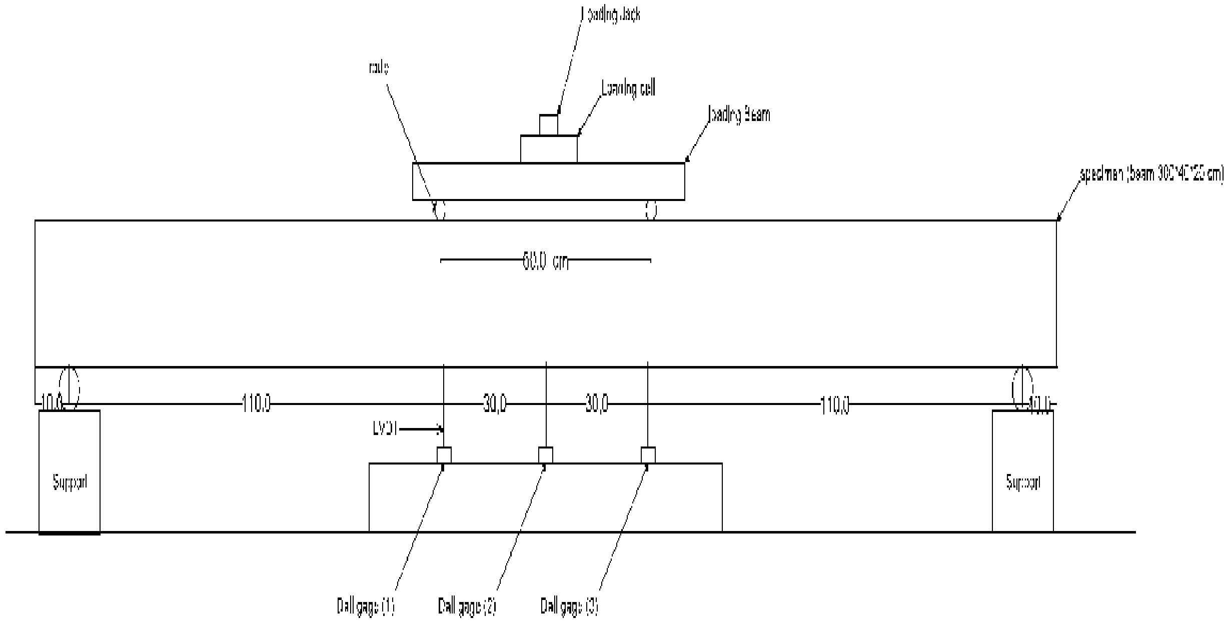

Fig 3: Test Set Up

3. Results And Discussion

3.1. Concrete Cubes Test Results

Twelve Concrete cubes of dimensions (150*150*150) mm were taken from the same concrete mixture of the beams. Cubes were heated and cooled with the accompanied beams and exposed to the same conditions. Concrete cube compression test results are presented in **table 2** that shows that, compressive strength for cubes burned up to 150 °C and were air cooled were 93%, compressive strength for cubes burned up to 200 °C and were air cooled were 62% and compressive strength for cubes burned up to 200 °C and were water cooled were 79%.

Table 2: Concrete Cube Test Results

Cube specimen	Compressive strength N/mm^2	Percentage Ratio %
Reference	53	100
150 °C -A	49.3	93
200 °C -A	32.6	62
200 °C -W	42.0	79

3.2. GFRP Bars Test Results

Twelve GFRP bars samples. three for each diameter of one-meter long were heated and cooled with the accompanied beams and exhibited the same conditions. Bars heated then cooled by water exhibited less in loss of its tensile strength. **Table 3** summarizes bars tensile strengths according to experimental conditions. **Figure 4** shows percentage ratios between ultimate tensile strength for GFRP bar results.

Table 3: GFRP Bar specimen Test Results

GFRP Bar specimen	Ultimate Tensile Strength								
	ø8			ø 10			ø 12		
	Load KN	Strength N/mm²	%	Load KN	Strength N/mm²	%	Load KN	Strength N/mm²	%
Reference	45	895.7	100	75	995.4	100	85	1082	100
150°C -A	42.8	851.9	95	72	955.5	96	81.5	1038	95
200 °C -A	40.5	806.1	89	68	903.4	90	74.8	952.8	88
200 °C -W	43.7	869.8	97	70	928.9	93	80.3	1022	94

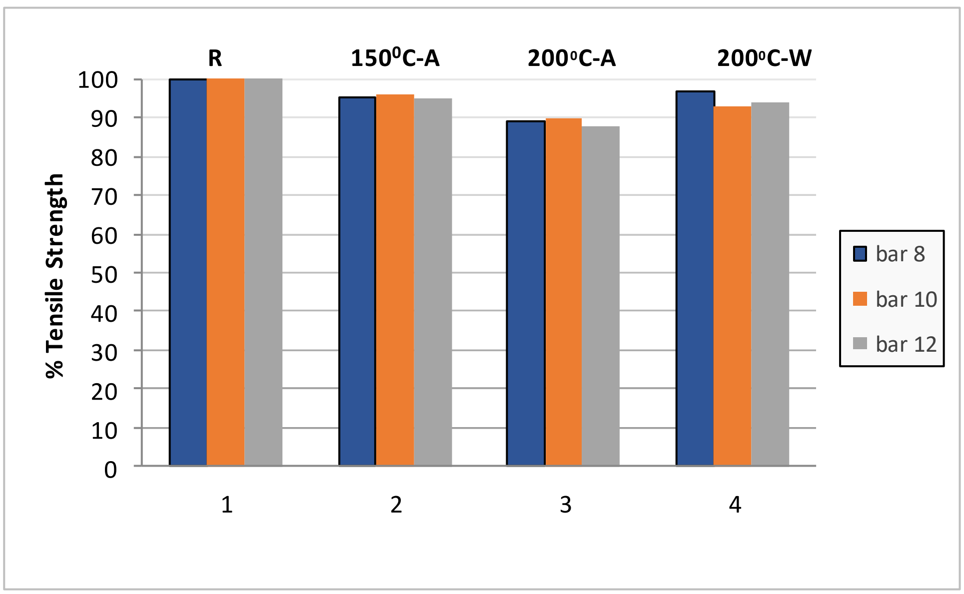

Fig: 4 Percentage Ratios for Bars Tensile Test Results.

3.3. Beam Specimen Test Results

At crack stage, load, bar strain and mid- span deflection were recorded. Also, at Ultimate stage, load, bar strain and mid- span deflection were recorded.

Stiffness, to assess the variation in beam stiffness with increased vertical loading and top deflections, the secant stiffness, defined as the ratio between the crack load and the corresponding mid span deflection, was used.

Stiffness at initial crack= crack load / corresponding deflection KN/mm.

Ductility, Ductility index= ultimate deflection /yield deflection
Whereas yield deflection is considered the deflection at 75% of the ultimate load.

- Beam 2: Changing beam reinforcement from 2 Ø 8 to 2Ø 10 resulted in:

- Crack load increased to be 164 % and corresponding deflection increased to be792%.
- Bar strain increased to be 24349%
- Ultimate load increased to be 224% and corresponding deflection increased to be 209%.
- Maximum measured bar strain decreased to be 78 %
- Stiffness decreased to 20%.
- Ductility increased to be 106 %.

- Beam 3: Changing beam reinforcement from 2Ø 8 to 2Ø 12 resulted in:

- Crack load increased to be 164%, and corresponding deflection increased to be 142%.
- Bar strain increased to be 396% .
- Ultimate load increased to be 108% and corresponding deflection decreased to be 44%.
- Maximum measured bar strain decreased to be 38 %.
- Stiffness increased to be 110%.
- Ductility increased to be 209 %. Results are summarized in **table 4** and shown in **fig. 5.**

Table 4. Percentage Ratio for Results for First comparative group.

First Comparative Group	At Crack Stage			At Ultimate Stage			Stiffness	Ductility
	Load	Bar Strain	Mid* Defl.	Load	Bar Strain	Mid* Defl.		
B1Ø 8	100	100	100	100	100	100	100	100
B2 Ø 10	164	24349	792	224	78	209	20	106
B3 Ø 12	164	396	142	108	38	44	110	209

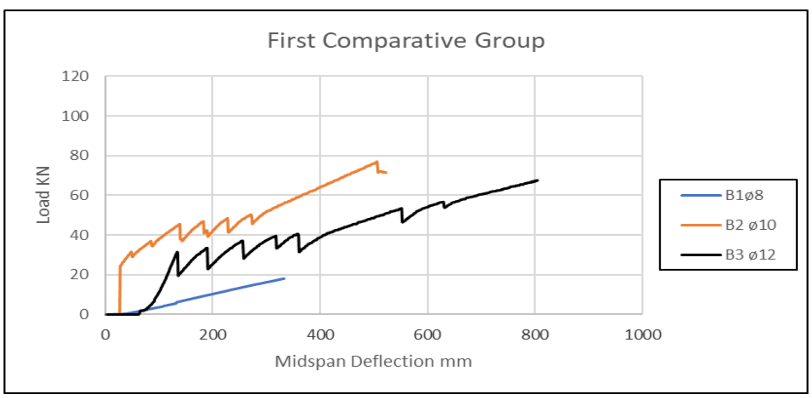

Fig. 5: Load -midspan deflection for first comparative group.

3.4. Effect of High Temperature and Method of Cooling

3.4.1 For Beams Reinforced with 2 GFRP bars of Ø 8 (Second comparative group) :

Second comparative group contains B1, B4, B7and B10 as they were exposed to two levels of high temperature (150°**C** and 200°**C**) and two methods of cooling (gradually or suddenly). Taking B1 as a reference, Percentage Difference in results at crack stage and at ultimate stage (load, bar strain and mid-span deflection) are calculated along with beam stiffness and ductility

- (Beam 4) was burned to 150° c and air cooled resulting in:
  - Crack load increased to be 102 %, and corresponding deflection increased to be 818 %.
  - Bar strain increased to be 19633 %.
  - Ultimate load increased to be188 % and corresponding deflection increased to be 301%.
  - Maximum measured bar strain increased to be 103%.
  - Stiffness decreased to be 12%.
  - Ductility decreased to be 9%.
- (Beam 7) was burned to 200°c and air cooled resulting in:
  - Crack load decreased to be 17 %, and corresponding deflection increased to be 155 %.
  - Bar strain increased to be 193%.
  - Ultimate load increased to be 205% and corresponding deflection increased to be 319 %.
  - Maximum measured bar strain increased to be 110%.
  - Stiffness decreased to be 53%.
  - Ductility decreased to be 9%.
- (Beam10) was heated 200°c and water cooled resulting in:
  - Crack load increased to be 122 % and corresponding deflection increased to be 847 %.
  - Bar strain increased to be 1311 %.
  - Ultimate load increased to be 177% and corresponding deflection increased to be 281 %.
  - Maximum measured bar strain decreased to be 13 %.
  - Stiffness decreased to be 14 %.
  - ductility decreased to be 10 %.

It can be seen that, for concrete beams reinforced by 2 GFRP bars of Ø 8, when exposed to heat then cooled all characteristics increased while stiffness and ductility decreased. Percentage ratios for Results of Beams Reinforced by Ø 8 are shown in **table 5**. **Fig.6** shows Load -Midspan Deflection for Beams with Ø 8.

Table 5: Percentage Difference in Results for Second comparative group.

Second comparative group	At Crack Stage			At Ultimate Stage			Stiffness	Ductility
	Load	Bar Strain	Mid Defl.	Load	Bar Strain	Mid Defl.		
B1 - 8- RT (#)	100	100	100	100	100	100	100	100
B4-8-150°C-A	102	19633	818	188	103	301	12	9
B7-8-200°C-A	83	193	155	205	110	319	53	9
B10-8-200°C-W	122	1311	847	177	13	281	14	10

(#) percentage referenced to the specimen (B1- Room Temperature)

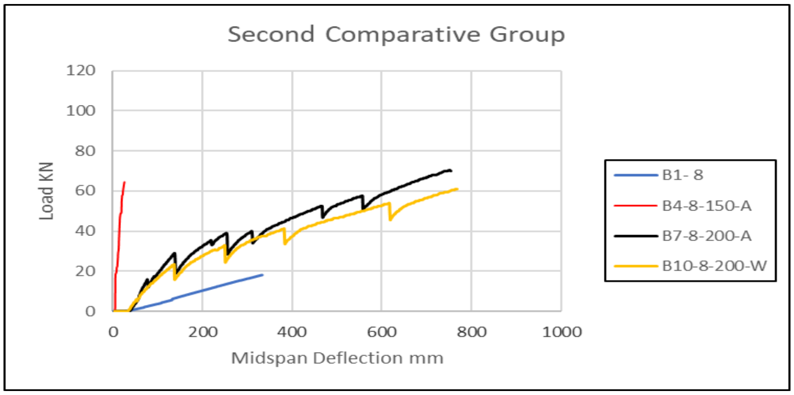

Fig.6: Load -midspan deflection for beams with Ø 8.

3.4.2 For Beams Reinforced with 2 GFRP Bars of Ø 10 (Third comparative group) :

Third comparative group contains B2, B5, B8and B11 as they were exposed to two levels of high temperature (150**°C** and 200**°C**) and two methods of cooling (gradually or suddenly). Taking B2 as a reference. Percentage Difference in results at crack stage and at ultimate stage (load, bar strain and mid-span deflection) are calculated along with beam stiffness and ductility.

- (Beam B5) was burned to 150°c and air cooled resulting in:
- Crack load decreased to be 89 % and corresponding deflection decreased to be 50%.
- Bar strain decreased to be 2%.
- Ultimate load increased to be 131%, corresponding deflection increased to be 147 %.
- Maximum measured bar strain increased to be 145%.
- Stiffness increased to be 178%.
- Ductility increased to be 103%.

- (Beam B8) was burned to 200°c and air cooled resulting in:
- Crack load decreased to be 71%, and corresponding deflection decreased to be 37%.
- Bar strain decreased to be 1%.
- Ultimate load increased to be 123% and corresponding deflection increased to be 149%.
- Maximum measured bar strain increased to be 138 %.
- Stiffness increased to be 188%.
- Ductility increased to be 102%.

- (Beam B11) was burned to 200°c and water cooled resulting in:
- Crack load decreased to be 50% and corresponding deflection decreased to be 41%.
- Bar strain decreased to be 3%.
- Ultimate load increased to be 133% and corresponding deflection increased to be 165 %.
- Maximum measured bar strain increased to be 146 %.
- Stiffness increased to be 122 %.
- Ductility was the same.

It can be seen that, for concrete beams reinforced by 2 GFRP bars of Ø 10, when exposed to heat then cooled crack stage characteristics decreased while ultimate stage characteristics as well as stiffness and ductility increased. Percentage ratios for results of beams reinforced by Ø 10 are shown in **table 6. Fig. 7** shows load -midspan deflection for Beams with Ø 10.

Table 6. Percentage Difference in Results for Beams Reinforced by Ø 10(#).

Third Comparative Group	At Crack Stage			At Ultimate Stage			Stiffness	Ductility
	Load	Bar Strain	Mid Defl.	Load	Bar Strain	Mid Defl.		
B2 -10-RT	100	100	100	100	100	100	100	100
B5-10-150°C-A	89	2	50	131	145	147	178	103
B8-10-200°C-A	71	1	37	123	138	149	188	102
B11-10-200°C-W	50	3	41	133	146	165	122	100

(#) percentage referenced to the specimen (B2-10-RT)

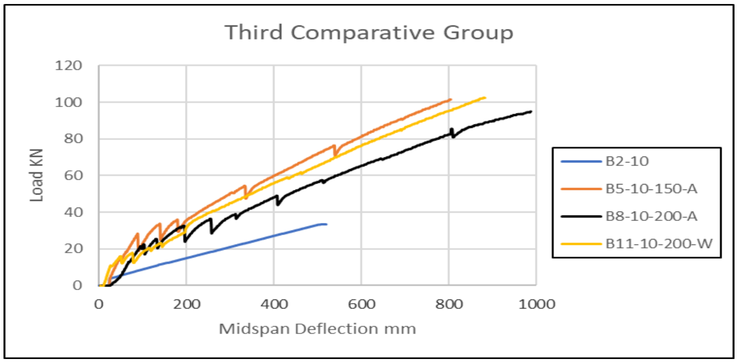

Fig.7: Load -midspan deflection for third comparative group beams with Ø 10.

3.4.3 For Beams Reinforced with 2 GFRP Bars of Ø 12 (Fourth comparative group) :

Fourth comparative group contains B3, B6, B9and B12 as they were exposed to levels of high temperature (150° **C** and 200° **C**) and two methods of cooling (gradually or suddenly). Taking B2 as a reference. Percentage Difference in results at crack stage and at ultimate stage (load, bar strain and mid-span deflection) are calculated along with beam stiffness and ductility.

- (Beam 6) was burned to 150°C and air Cooled resulting in:

- Crack load decreased to be 95% and corresponding deflection increased to be 361%.
- Bar strain increased to be 110%.
- Ultimate load increased to be 287% and corresponding deflection increased to be 630%.
- Maximum measured bar strain increased to be 280%.
- Stiffness decreased to be 26%.
- Ductility decreased to be 53%.

- (Beam 9) was burned to 200°C and air Cooled resulting in:

- Crack load decreased to be 1%, bar strain decreased to be 1% and corresponding deflection decreased to be 1%.
- Ultimate load increased to be 181%, and corresponding deflection increased to be 411 %.
- Maximum measured bar strain increased to be 198%.

- Stiffness decreased to be 1 %.
- Ductility decreased to be 53 %.

- (Beam 12) was burned to 200°C and water Cooled resulting in:

- Crack load decreased to be 69% and corresponding deflection increased to be 14%.
- Bar strain decreased to be 69 %.
- Ultimate load increased to be 277%, and corresponding deflection increased to be 637%.
- Maximum measured bar strain increased to be 261%.
- Stiffness decreased to be 47%.
- Ductility to be 52%.

It could be seen that for concrete beams reinforced by 2 GFRP bars of Ø 12, when exposed to heat then water cooled, crack stage characteristics decreased while ultimate stage characteristics increased. stiffness and ductility decreased. Water cooling stopped GFRP bars from deterioration from the accumulated heat in the concrete section. Percentage ratios for Results of Beams Reinforced by Ø 12 are shown in **Table 7**. **Fig. 8.** shows the load -midspan deflection relationships for Beams with Ø 12.

Table 7. Percentage Difference in Results for Beams Reinforced by Ø 12(#)

Fourth Comparative Group	At Crack Stage			At Ultimate Stage			Stiffness	Ductility
	Load	Bar Strain	Mid Defl.	Load	Bar Strain	Mid Defl.		
B3 -12-RT	100	100	100	100	100	100	100	100
B6-12-150°C-A	95	110	361	287	280	630	26	53
B9-12-200°C-A	1	1	1	181	198	411	1	53
B12-12-200°C-W	69	69	148	277	261	637	47	52

(#) percentage referenced to the specimen (B3/RT)

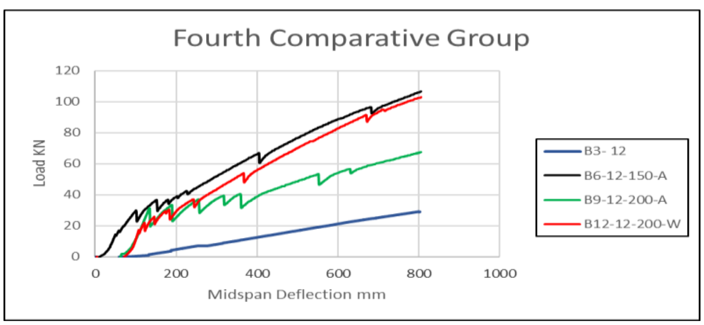

Fig.8: Load -Midspan deflection for fourth comparative group beams with Ø 12.

3.5. Load- Deflection Behavior and Mode of Failure

All Beams, had the same crack pattern. Flexure cracks were initiated at middle taking its way up and spreading right and left along the total length of the beam as shown in **Fig.9**.

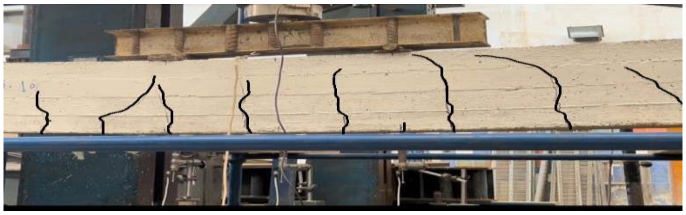

Fig.9: Crack pattern.

For all Beams, Load- Deflection curves showed two main stages with significant changes in the slope of the curves. The first stage started from initial loading up to cracking load and has nearly linear behavior, referred to as uncracked behavior. The second stage started from cracking load and is characterized by reduction in stiffness and terminated with failure at ultimate load. **Figs. (10,11)** show percentage of crack load and corresponding deflections. **Fig. 12** shows percentage of bar strains at crack loads. **Figs. (13,14)** show percentage ultimate loads and corresponding deflections. **Fig. 15** shows percentage of bar strains at ultimate loads. **Fig.16** shows stiffness for the four comparisons. **Fig. 17** shows ductility for the four comparisons. As it is seen from the four comparisons Beams reinforced with Ø 10 gave best results for stiffness and ductility that is to say compatibility of performance for the concrete section reinforced by Ø 10 taking into consideration GRFP ratio 2% to the concrete cross section (200*400) mm.

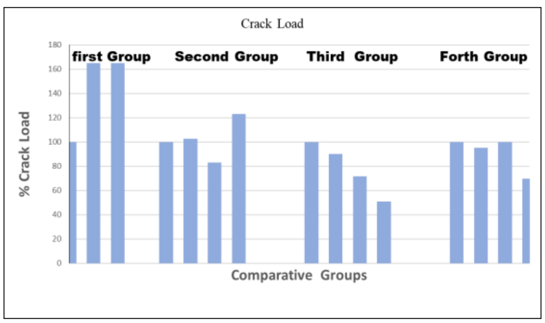

Fig.10. % Crack load.

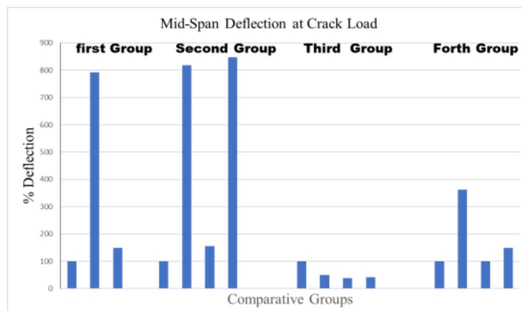

Fig.11. % Midspan deflection at crack load.

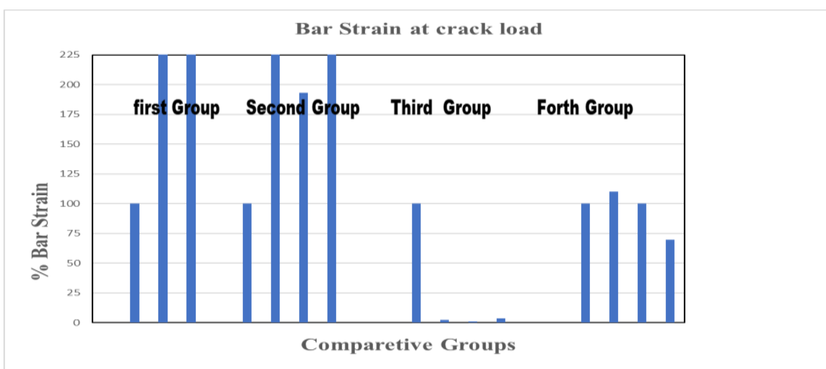

Fig.12. % Bar Strain at crack load.

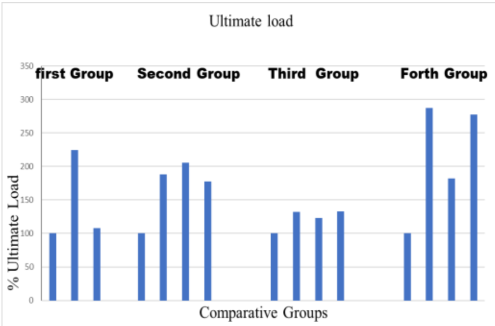

Fig.13. % Ultimate load

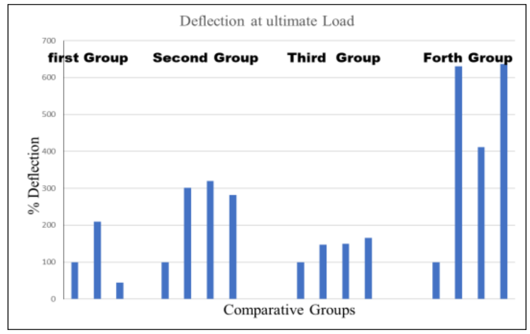

Fig.14. % Ultimate deflection

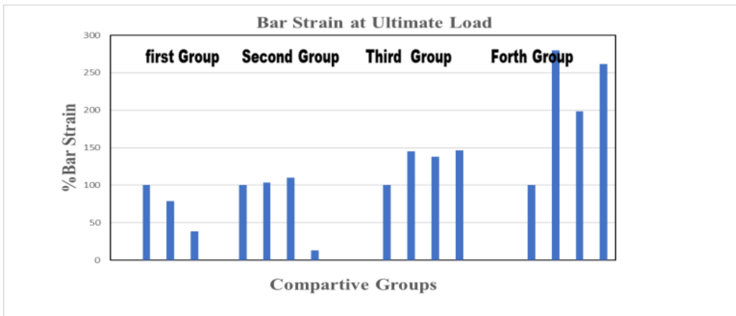

Fig.15. % Bar Strain at Ultimate load.

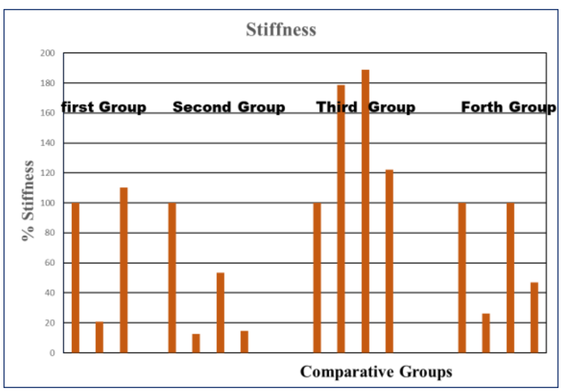

Fig.16. Stiffness for the four comparisons.

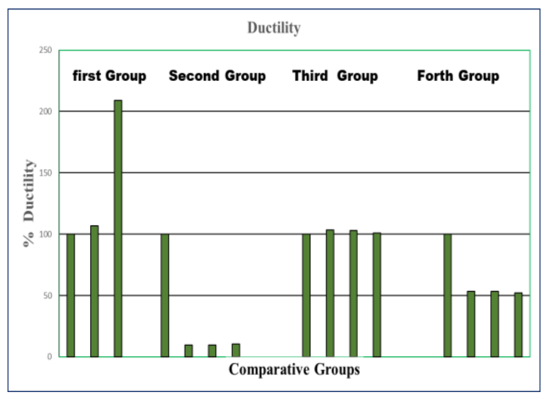

Fig.17. Ductility for the four Comparisons.

4. Summary and Conclusions

The behavior of concrete elements reinforced with GFRP rebars in fire conditions is still under investigation. It is known that building structures must satisfy the requirements of the relevant codes. Most of these codes refer to the time available in a fire before the structure collapses. Therefore, the real property to be investigated is not the reaction to fire of the GFRP rebar itself but its capability to maintain the load when temperatures are rapidly raising. The main objectives of this research work were: the experimental evaluation of GFRP bars usage as a main reinforcement for beams with different ratios under pure bending and the behavioral characteristics of such beams when exposed to high temperatures 150°C, 200°C whether cooled by air or by water.

Twelve beams reinforced with either 2 ø 8, 2 ø 10 or 2ø 12 GFRP bars were tested at room temperature or after heating up to 150°C and 200°C. Beam specimens were cooled either by air or water. Concrete beams with cross-sectional area of 200*400 mm and 3000 mm length, were tested under pure bending showing the following results:

- Promising results with smooth curves of load - deflection relationships and bond slippage did not occur.
- Using 2 ø 10 high grade steel in the compression zone as stirrup hangers made sure that the beams did not fail in compression or did not exhibit sudden collapse.
- Using good quality concrete of 500 kg/cm2 and sufficient cover of 2 cm reduced high temperature effects on GFRP bars main reinforcement.
- The Resin involved in manufacturing of the GFRP bars is very much affected by the exposure to high temperature 150 oC and 200 oC for one hour and then cooled by different ways of cooling. The bars became stiffer and deflections were decreased for more thicker bars (8,10 &12).
- Ductile failure with no bond slippage occurred throughout the experimental program for all beams.
- It’s obvious that still we are in need of steel bars in concrete elements as the GFRP bars are very ductile with no yield point.
- Water sudden cooling for concrete cubes and GFRP bars gave better tensile strength results than air gradual cooling.
- Increasing GFRP bar ratio resulted in increasing crack and ultimate loads along with crack stiffness and ductility.
- GFRP bar ratio of 2% as main reinforcement for beams showed better performance for stiffness and ductility compared to higher or lower ratios.
- For beams reinforced by ø8, ø10 & ø12, high temperature exposure made beams stiffer and with stand higher loads as exposure temperature goes high, the sudden cooling method was effective in increasing crack and ultimate loads along with crack stiffness and ductility.
- Using mild steel stirrups every 200 mm along the beam’s length ensured concrete section confinement and compatibility when using GFRP bars as main reinforcement.

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Conflict of Interest. The authors have no financial interest to declare in relation to the content of this article.

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