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Replacement of steel rebars by GFRP rebars in the concrete structures

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Abstract

Glass fiber reinforced polymer (GFRP) has been confirmed to be the solution as a major development in strengthened concrete technology. Synthesis of GFRP rebars by using the longitudinal glass fibers (reinforcement material) and unsaturated polyester resin with 1% MEKP (matrix material) via manual process. GFRP rebars have diameter 12.5 mm (this value is equivalent to 0.5 inch; it's most common in foundations application). GFRP surfaces are modified by the inclusion of coarse sand to increase the bond strength of rebars with concrete. Then, the mechanical characterizations of reinforced concrete with GFRP rebars are performed and compared with that of steel rebars. Preparation of concrete samples (unreinforced concrete, smooth GFRP reinforced concrete, sand coated GFRP reinforced concrete and steel reinforced concrete) with fixed ratio of ingredients (1:1.5:3) and 0.5 W/C ratio were performed at two curing ages (7 and 28) days in ambient temperature. The value of volume fraction of GFRP and steel rebars in the reinforced concrete was (5 vol. %) equally distributed with specified distances in the mold. The results show the tensile strength of GFRP rebar is 593 MPa and bend strength is 760 MPa. The compressive strength was within reasonable range of concrete is 25.67 MPa. The flexural strength of unreinforced concrete is 3 MPa and reinforced concrete with GFRP rebar, especially sand coated GFRP RC exhibit flexural strength is 13.5 MPa as a result to increase bonding with concrete and higher strain is 10.5 MPa at 28 days than that of steel reinforced concrete at the expense of flexural modulus.

Keywords: GFRP rebars; Steel rebars; Reinforced concrete; Mechanical properties

1. Introduction

The traditional strengthened concrete members such as beams are composed of concrete included Portland cement and steel rebars reinforcement. The function of concrete in these beams is the resistance to compressive loads. The tensile and shear loads will be resisted by steel rebars embedded in the concrete. Such structure is efficient where the concrete inseparable resistance to compressive loads, while the steel enhances tensile and partially shear strengths. However, the problem of corrosion associated with the steel rebars reduced its live time and the solutions such as the coating of the steel rebars are costly. Recent technologies have resulted in alternative reinforcing materials such as GFRP materials commercially available in the form of bars or sheets that can be bonded in concrete

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members to fulfill several desired properties. The most important is that the corrosion resistance feature of the polymer and the elongated strain to failure that give enough time to alert before failure takes place [1] (see Fig. 1).

Experimental researches on some of concrete structures reinforced with GFRP bars were done (5–8) years ago. The results have shown that GFRP rebars weren't subject to any degradation process in existence of the alkaline and corrosive environment [2].

The tensile and shear strengths of GFRP bars by using four various diameters (20, 22, 25, 28 mm) have been discussed by authors. The young's modulus of GFRP bars was equal (1–5) of young's modulus of steel. The GFRP bars exhibited brittle behavior and the relationship between stress and strain was linearly elastic up to failure. The GFRP bars were anisotropic and they were characterized by high tensile strength only in the direction of the reinforcing fibers. The cross section dimensions didn't affect the GFRP bar modulus. Variation of the shear strength of all GFRP bars diameters was little, but the higher load caused failure. The ranges of GFRP bars shear strength were 16%–20% lower than the longitudinal tensile strength [3].

Reinforced concrete beams with the Glass Fiber Reinforced Polymer (GFRP) as an alternative of traditional rebar and behavior of beam under bending were also studied. The results concluded that use of GFRP rebar in tensile loads direction of beam have displayed flexural properties similar to the steel rebar and GFRP reinforced concrete has offered high bending properties, besides acceptable shear properties [4].

Authors studied a bending method of ultra-high performance fiber-reinforced concrete beams reinforced with GFRP rebars in different ratios in the beams. The low elastic coefficient of GFRP means that high deflection and more cracks, but the presence of short fibers in concrete will improve the bending performance (less deformation, higher ductility and higher rigidity) due to strain hardening with multiple micro cracks and increased bending strength with the increased reinforcement ratio. All of the test results showed a lower deflection due to strain hardening at a certain level of service [5].

Other authors presented a properties of reinforcing bars (steel and GFRP) in the concrete beams were used. The GFRP surface finish was different (sand coating and helically grooved surface). The concrete beams were normal and high strength reinforced with steel and GFRP rebars. Steel reinforced concrete beam represents the reference sample. Bending test variables were type and reinforcement ratio, surface finish and rebar diameter. The results of the test showed that the cracks width in concrete was affected by the diameter of the reinforcement and the surface finish while the deflection was not affected by these parameters. All GFRP reinforced beams showed linear relation between stress and strain until failure. Normal strength concrete beams reinforced with GFRP have low strains compared with high strength concrete at the same level

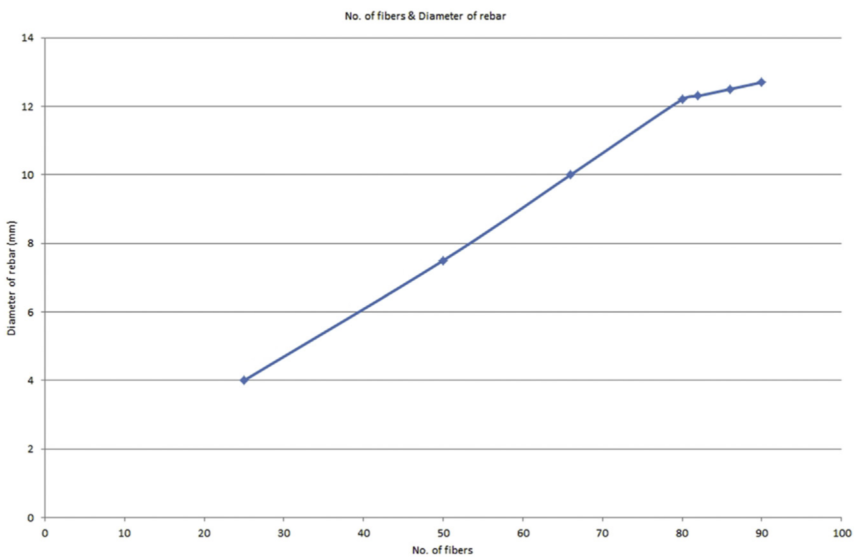

Fig. 1. Relationship between number of fibers and diameter of rebar.

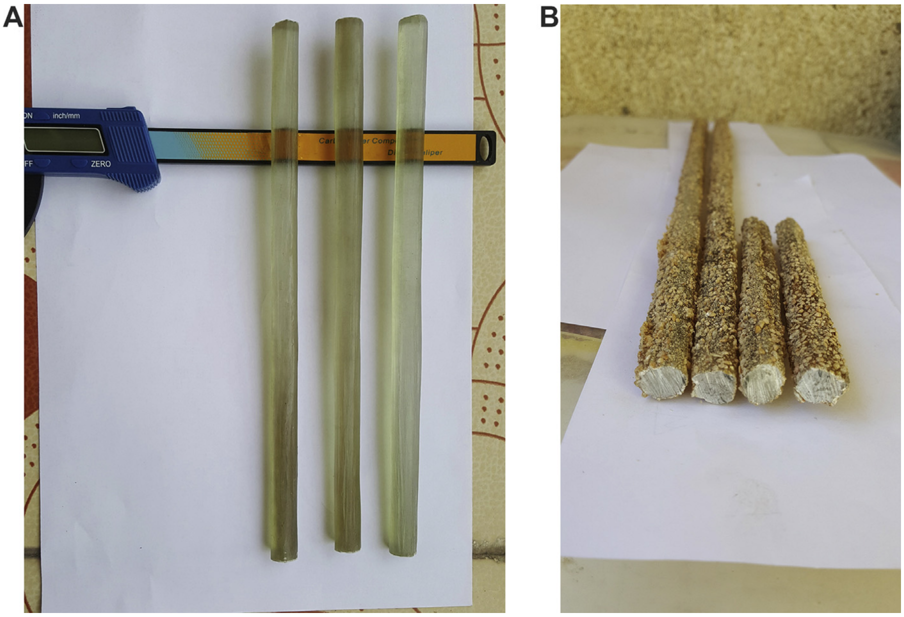

Fig. 2. GFRP specimens. (A) GFRP only, (B) Sand coated GFRP.

of load. Sand coated GFRP reinforced beams showed smaller cracks and reduced cracks width compared with helically grooved GFRP reinforced beams, which indicated better bond properties between concrete and GFRP [6].

The hybrid reinforcement (steel and GFRP) was discussed by authors for ultra-high performance fiber-reinforced concrete to improve the ductility and elasticity of FRP reinforced concrete. Bending test for high strength fiber-reinforced concrete reinforced with GFRP rebars (3 beams) and ultra-high performance fiber-reinforced concrete reinforced with steel (4 beams) at different reinforcement ratios was performed. Due to the strain hardening, all samples showed high stiffness after initial cracking. Increased GFRP ratio improved performance under bending test (ductility and stiffness). The hybrid reinforcement was by replacing part of the GFRP with steel rebars to improve stiffness before steel yielding which leads to less deformability [7].

A study simulates the flexural behavior of ultra-high performance fiber reinforced concrete beams reinforced with steel and GFRP was performed by authors. Finite element model was first carried out on the basis of single fiber pull-out method. Two different tension-softening curves (TSCs) with the assumptions of 2-dimensional (2D) and 3-dimensional (3D) random fiber orientations were obtained from the micromechanics-based modeling, and linear elastic compressive and tensile models before the occurrence of cracks were obtained from the mechanical tests and rule of mixture. Analytical results showed 2D random fiber orientation was suitable for ultra-high performance concrete beams non reinforced with rebar and 3D random fiber orientation was suitable for ultra-high performance concrete beams reinforced with steel and GFRP due to disorder alignment as a result of internal reinforcement [8].

The surface characteristics of FRP rebars were already discussed by authors. The rates of smooth FRP bond strength can be approximately comparable to that of steel distorted rebars. Modified FRP rebars with coarse sand can offer better bonding than smooth rebars. This is because the flexural modulus of the FRP bars are always less than steel reinforcing bars hence, the bond strength is extended at more slips [9].

The bond strength of fibers reinforced polymer (FRP) rebars in concrete with simple strength was studied. The pullout test was performed to measure the four various types of reinforcing bar: aramid FRP (AFRP), carbon FRP (CFRP), glass FRP (GFRP) and steel. The total samples were 151 including rebars with diameters (6, 8, 10, 16 and 19 mm) embedded in the concrete samples (203 mm cube). The results concluded that the effective mean of surface deformation applied to improve the bond between concrete and bars were similar to the ones on steel, other means of surface deformation were by making an external helicoid strand and deep dents (groves) which are acceptable means of bond improvement. One of the easier means of surface deformation was by sand coating for obtaining bond strength better than that of those with smooth surface [10].

2. Aims of the work

Glass fiber reinforced polymer (GFRP) was used as an alternative material to the steel rebar. It is light-weight, no-corrosion, superior tensile strength, and high mechanical performance. Installation of the GFRP rebar is similar to steel rebar, but with less handling, transporting and storage problems. In this work, the unsaturated polyester resin and E-glass fibers are used to synthesis GFRP rebars of 1.25 cm diameter to simulate the dimensions of steel rebars. Their surfaces are modified by the inclusion of coarse sand to avoid slipping in stress conditions. Then, the mechanical characterizations of reinforced concrete with GFRP rebars are applied and compared with that of steel rebars.

3. Materials and methods

3.1. Materials used

The Materials used in this research and their characteristics are: Glass fibers in the form of a mat "JIASHAN FIBERGLASS WEAVING FACTORY ZHEJIANG, China" Weighing 600 g$\diagdown$m^2 and a length of 1250 mm. The fibers are pulled from the mat and utilized to synthesis rebars. It is found that 86 fibers and the added resin are required to produce a rebar of 1.25 cm diameter. Unsaturated polyester resin "FARAPOL Company, Iran" and Hardener (Methyl ethyl ketone peroxide) "akpakimya company, Turkey". Ordinary Portland cement manufactured by (Mass-Bazian) was used, conformed to the Iraqi standard [11]. Al-Ukhaydir natural sand as fine aggregate and the gradation and selected chemical and physical properties were within limits of the Iraqi standard [12]. Gravel of (5–19 mm) gradation was utilized as a coarse aggregate from north of Baghdad (Al-Nabaai) and the sieve analysis, specific gravity, density and sulfate contents are within Iraqi standard No.45/1984 [12]. Tap water was used.

3.2. GFRP rebar

Synthesis of GFRP rebar from glass fibers and unsaturated polyester resin was produced by immersing the fibers longitudinally in the unsaturated polyester resin with (1%) of its hardener and then the excess polymer is removed. That was without the utilization of a mold, because in case of using a mold, the matrix will fail before fibers resistance when subjected to the forces of tension. Several efforts were made to fulfill the required diameter of bar by using different number of fibers and measuring diameter every time as shown in Fig (1). Finally a bar of diameter 12.5 mm was obtained which is common in construction applications. The resulting bar has fibers volume fraction of 80% and polyester volume fraction of 20%.

After obtaining GFRP as shown in Fig (2A), tensile and bend strengths were measured and compared with normal reinforcement bar. There are many ways to increase bonding between reinforcement and the concrete such as coating of GFRP bars with coarse sand of above 300 μm as shown in Fig (2B).

3.3. Mixing method

The used mixing proportion was (1:1.5:3). The dry materials (cement and sand) were thoroughly mixed per ASTMC-192 in a pan and then the gravel was combined and mixed with the entire batch by shovel until the gravel is uniformly distributed throughout the batch. Then the water was poured and blended with the dry materials for specific duration until the concrete is homogenous in appearance and has the desired consistency. The mixing process was paused and then returned for a few minutes and the open end or top of the pan was covered to prevent evaporation during the rest period. This step was repeated in two cycles to insure the homogeneity for mixture. The total mixing time was about 15 min [13] (see Fig. 2).

3.4. Molds used

Wooden mold for compressive strength and flexural strength was used throughout this investigation. Cubic shapes (edge length of 100 mm) of molds were used to prepare specimens for compressive strength and prismatic specimens of 100 × 100 × 400 mm for flexural strength. The molds were softly coated with Vaseline oil before use, per ASTMC-192 concrete casting was performed in different layers, each layer of 50 mm. Each layer was compacted by using Tamping Rods until no air bubbles emerged in the concrete, and the surface of concrete was leveled off fully to the upper of the molds by using steel trowel. Concrete is reinforced by 5 vol. % GFRP and steel bars evenly distributed with specific distance in the mold. Polyethylene sheets are utilized as

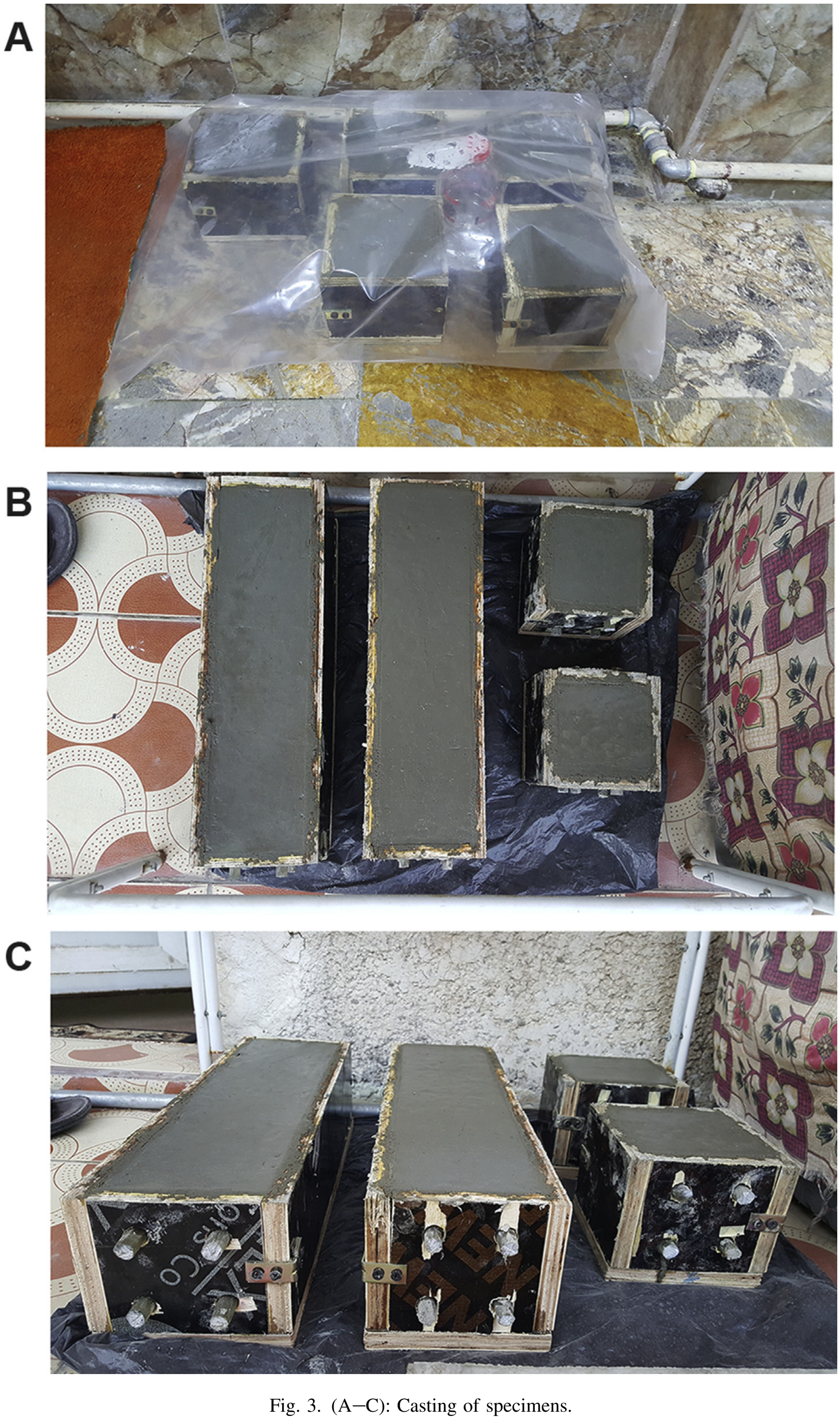

Fig. 3. (A−C): Casting of specimens.

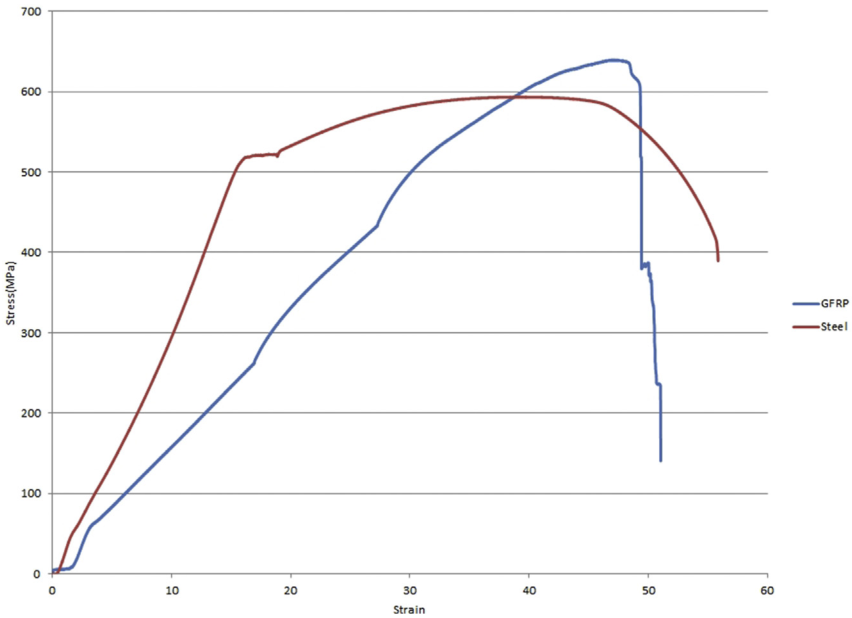

Fig. 4. Tensile curves of rebars.

covers for specimens after their casted for 24 h in room temperature (24 ± 2) °C to inhibit moisture content from evaporation as shown in Fig. 3 [13].

3.5. The effective curing in first ages is essential for the gain of durability, strength and stability of volume

The basic conditions that must be supplied to continue a reaction is the appropriate temperature, and adequate moisture. The green concrete contains enough water to complete the hydration process of cement, but in most conditions a large quantity of water is evaporated by heat. Moisture curing method was utilized to compensate for the water that evaporates during the casting process [14]. Specimens were completely submersed in water tanks at 21 ± 2 °C until the time of measurements (7 or 28 days) as a curing age.

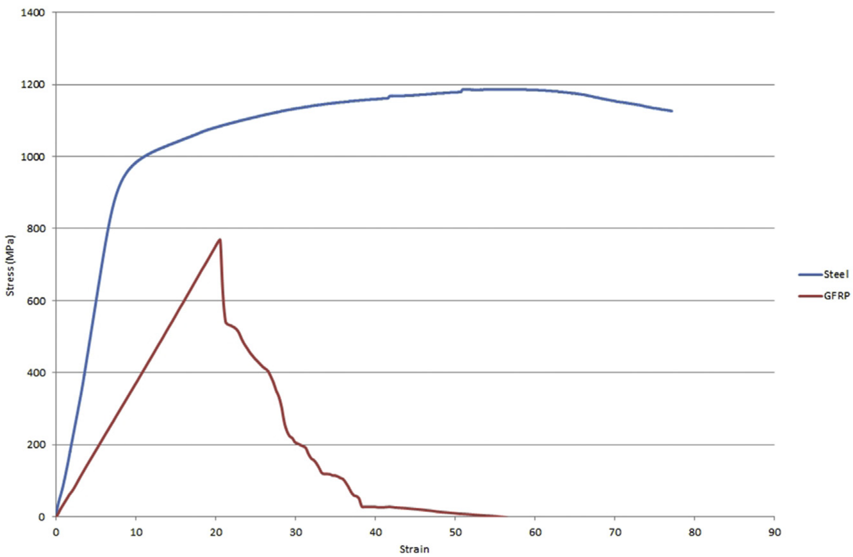

Fig. 5. Bending curves of GFRP and steel.

Table 1
Tensile strength of rebars.

Property	Samples	
	Steel	GFRP
Yield strength (MPa)	520	593
Yield strain	17	40

Table 2
Results of bending measurement of rebars.

Property	Samples	
	Steel	GFRP
Yield strength (MPa)	1050	760
Yield strain	16	20

Table 3
Compressive strength results of concrete.

Sample type	Compressive strength (MPa)	
	7 days	28 days
Unreinforced concrete	20.41	25.67

4. Results and discussion

4.1. Characterization of rebar

4.1.1. Tensile strength

The tensile strength was measured according to ASTM D7205-06 for GFRP rebar and ASTM A496-02 for steel rebars using specimen of 25 ± 5 cm length, 1.25 cm diameter [15,15a].

The concrete will be bonded with reinforcing bars, so that the extra tensile stresses, which can't be resisted by concrete, will be transported to the reinforcing bars therefore, the rebars must have a relatively high tensile strength (see Fig. 5).

Tensile measurement results are offered in Fig. 4 and Table 1).

The curves have shown that GFRP has higher yield strength than traditional steel rebar due to unique anisotropic property of composites makes them strong in tension. The yield strain of GFRP is higher than steel rebar; this will give the engineer premature warning of the failure Table 2.

4.1.2. Bending strength

Bending strength is measured per ASTM D790 for GFRP and steel rebar using specimen of 25 ± 5 cm length, 1.25 cm diameter [16]. This measurement is performed to determine an approximate values of the bending (strength and strain) of a bare GFRP reinforcing bar and it's compared with bare steel reinforcing bar. The results of bending measurements are shown in Fig (5) and Table (2).

The curves have shown the basic difference between GFRP and steel rebars. The results for the bending strength of GFRP showed that highest point of stress involve the stress which creates at the crack, after that the stress will decrease but the crack will grow until the failure. The initial failure of the steel rebar at strain 16.21%, while the initial failure of the GFRP starts at strain 20.23%. Thus, the use of the

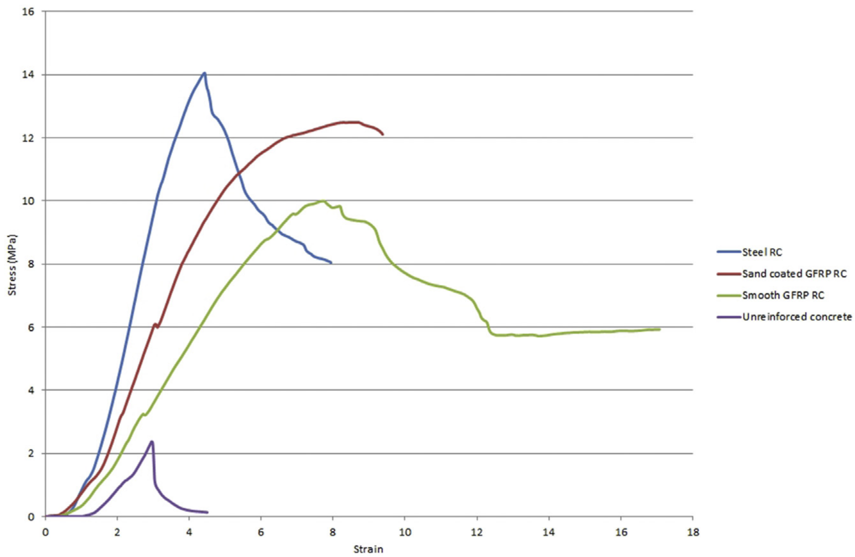

Fig. 6. Flexural curves of unreinforced and reinforced concrete at 7 curing age.

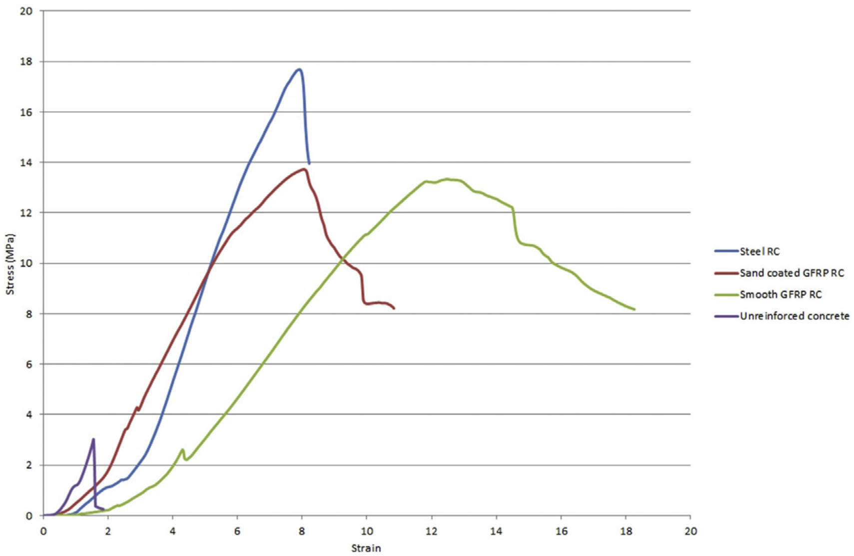

Fig. 7. Flexural curves of unreinforced and reinforced concrete at 28 curing age.

GFRP rebars shows more deflection before starting to fail. This can give more chance to be alerted before failure takes place.

4.2. Characterization of reinforced concrete

4.2.1. Compressive strength

The compressive strength is measured BS1881: part 116 [17]. The test samples were 100 mm cubes and the results are shown in Table 3. The sufficient compressive strength will be provided by concrete. The foundation is example of construction applications that require compressive strength according to mixing proportions used.

The results showed the compressive strength of unreinforced samples at 28 days is good for foundations application. The compressive loads will resist by concrete only as a result powdered ingredients of concrete.

4.2.2. Flexural strength

Measurement of flexural properties was done according to ASTMC-293 [18]. The test samples were 100 × 100 × 400 mm prisms and tested via three points loading. The specimens were measured after (7, 28) days of immersion in water.

Table 4
Average flexural characteristics values of samples (7 days curing).

Property	Samples			
	Unreinforced concrete	Smooth GFRP reinforced concrete	Sand coated GFRP reinforced concrete	Steel reinforced concrete
Flexural strength (MPa)	2	10.5	11.5	14
Strain	4.5	17	11	8
Modulus of elasticity (MPa)	500	500	1000	2000

Table 5
Average flexural characteristics values of samples (28 days curing).

Property	Samples			
	Unreinforced concrete	Smooth GFRP reinforced concrete	Sand coated GFRP reinforced concrete	Steel reinforced concrete
Flexural strength (MPa)	3	12.5	13.5	17.5
Strain	2	16	10.5	9
Modulus of elasticity (MPa)	1000	500	1000	1500

Fig. 8. (A, B): typical fracture of unreinforced concrete.

Fig. 9. (A, B): typical fracture of smooth GFRP RC.

This measurement was performed to determine ability of sand coated GFRP reinforced concrete to withstand flexural loads and to compare it with unreinforced concrete and other reinforced concrete samples.

The results of flexural tests are shown in Figs 6 and 7 and Tables 4 and 5.

The curves showed ductile behavior of GFRP reinforced concrete at 7&28 curing ages which gives more chance to alert before the failure. The results showed flexural strength of the unreinforced concrete is low and it's significantly improved by reinforcement. The flexural strength of the sand coated GFRP reinforced concrete is high and it's close to steel reinforced concrete. This is because it has higher strain than the steel reinforced concrete at the expense of the flexural modulus.

The strength of Smooth GFRP reinforced concrete is lower than the sand coated GFRP reinforced concrete, as a result of low flexural modulus. Sand grains cause an increase in brittleness of the GFRP rebars, this lead to increased strength at the expense of the flexural strain.

4.2.3. Comparison between the fractures of the different samples

In the case of the unreinforced concrete, the brittle fracture is very clear as shown in Fig. 8A, B. While, the smooth GFRP reinforced concrete also show multiple fracture line, but without complete fragmentation as shown in Fig. 9A, B. On the other hand, the sand coated GFRP reinforced concrete is shown in Fig. 10A, B. The fragmentation after fracture is lower than that

Fig. 10. (A, B): typical fracture of sand coated GFRP RC.

Fig. 11. (A, B): typical fracture of steel RC.

of the smooth GFRP reinforcement. The concrete is still in one piece which may be helpful in reducing damaged after failure. The appearance of the fractures of the sand coated GFRP reinforced concrete is comparable to that of the steel reinforced concrete Fig. 11A, B.

5. Conclusions

From this work, the following conclusions are withdrawn:

1. In general: GFRP reinforcing bar has higher tensile strength and higher corrosion resistance than steel rebar in addition, moderate flexural strength, these properties make GFRP is good alternative of steel in foundations application.
2. According to the results, the mechanical characteristics can be concluded as the following:
   a. Tensile strength of bare GFRP bar is high, because they are anisotropic composite materials, GFRP rebar achieved yield tensile strength about 13% higher than that the steel rebar, while yield strain of GFRP is higher than steel about 58%.
   b. Bend strength of bare GFRP bar is good; where yield strength of GFRP rebar achieved 72% of steel rebar strength while yield strain of GFRP is higher than steel about 20%.
   c. Compressive strength of unreinforced concrete is 25.67 MPa; this value is acceptable according to British Standard specification.
   d. Flexural strength is good of sand coated GFRP RC at all curing ages. Increase of smooth GFRP

RC flexural strength was about 76—81% and sand coated GFRP RC about 78—83% as compared with unreinforced concrete strength. However, strength of smooth GFRP achieved 71—75%, while sand coated strength achieved 77—82% of steel RC flexural strength. Decrease of flexural modulus of smooth GFRP RC around 66% and sand coated GFRP RC around 33% compared with steel RC. The flexural strain of Smooth GFRP RC is increased around 44% and sand coated GFRP around 14% as compared with steel RC at 28 day curing age.

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