BEAHVIOR OF HEAVY WEIGHT CONCRETE BEAMS REINFORCED WITH CGFRP BARS

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ABSTRACT

Concrete is a brittle material that has high compressive strength, but low tensile strength, thus, reinforcement of concrete is required to allow it to handle tensile stresses. The corrosion and rusting issue of steel bars and their propagation especially, inside areas with harsh environmental conditions, are extremely influenced by the safety and performance of the structures. Therefore, scientists are trying to discover new materials close to their properties and even better than reinforcing steel. Finally, they came up with fiber bars.
*The aim of this research is to study the possibility of replacing steel bars with locally manufactured glass fiber bars incorporating carbon tire material to have some properties of carbon fiber bars and conduct new fiber bars called carbon glass fiber bars and use it to reinforce heavy-weight concrete to avoid severe environmental conditions and reduce the weight of reinforced concrete structures. An experiential program was designed to cover research objectives using normal-weight concrete beams and heavy-weight concrete beams with dimensions 120*250*2000 mms. Normal and heavy-weight concrete beams were reinforced with steel bars and steel stirrups and compared with the same concrete beams but reinforced with carbon glass fiber bars and steel stirrups. The cracking loads, ultimate loads, and behavior of crack propagation, in addition to the presence of curves illustrating load-deflection, load-strain of reinforcing bars, and load-strain of concretes. The results of the present paper indicated that the use of C. GFRP with heavy-weight concrete and normal-weight concrete is very effective and will achieve structural safety and reduce the overall cost.*

Keyword: - *Heavyweight concrete, Fiber bars, GFRP, Carbon fiber bars, CFRP, Concrete beams, Cracks*

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1. INTRODUCTION

Concrete is the most widely used construction material. Basically because of its low cost, accessibility, durability, and ability to resist extreme climate environments [1]. Hence the importance of having different types of concrete that suit the intended purpose. One of the most popular types of concretes is heavyweight concrete which is mainly preferred in facilities that are exposed to radiation [2]. But the concerning issue with using reinforced heavyweight concrete in mega structures is the weight of the superstructure [3]. From here scientists begin to search for alternatives to steel bars to reduce the overall weight of the superstructure and avoid corrosion under harsh environmental conditions [4]. Many structural engineers currently encourage the use of Glass-Fiber Reinforced Polymer (GFRP) bars instead of steel in reinforcing concrete structures, especially for their lightness and non-corrosive properties [5]. Ductility can be defined as the ability of the material to undergo large deformations without rupture before failure [4]. An effective economic way to overcome the crack width and large deflection of Fiber Reinforced Polymer (FRP) is the addition of silica fume (SF) in the tension zone [7]. Electromagnetic shielding in concrete structures is important to reduce radiation hazard problems [8]. The protection of the sensitive environment is nowadays carried out by appropriate shielding rooms made of metallic walls [9]. Their adequacy is rectified by their heaviness, not adequate for the installation over existing building walls [10]. The utilization of concrete

composites filled with conductive components like graphene oxide represents a valid alternative to the metallic shielded room since they can be adjusted to directly construct up the building walls to easily plaster the existing walls [11]. A radiation dose above the maximum permissible limit (0 - 50) mSv is very dangerous for human beings [12]. Unfortunately, nuclear plants are established to fulfill the increasing energy need, and we are compulsorily faced with radiation-emitting devices to keep pace with evolving technology. Thus, we need to know the hazards of radiation and take precautions to be affected by these effects at a minimum level. Lead or heavy aggregates are generally used to protect from the hazardous effects of radiation [13]. As the negative effects of lead on human health because it is considered a toxic element, protective shields can be created by using elements such as barite, hematite, siderite, limonite, and ilmenite, which have high intensity. Overall, heavyweight concrete has been used where it is necessary to reduce the thickness of radiation shielding, generally due to space considerations [14].
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2. AIMS OF THE WORK

This work aims to replace steel bars with locally manufactured glass fiber reinforced polymer bars (GFRP) incorporated with carbon tire material to provide carbon glass fiber reinforced polymer bars (CGFRP) to achieve the most economic price and acceptable mechanical properties. In this regard, two concrete mixtures of NWC are used for both Fcu of 40 Mpa and 30 Mpa. In addition, two concrete mixtures of HWC with Fcu of 40 Mpa and 50 Mpa are embedded in a certain proportion of barite and ilmenite. These concrete mixtures are tested for their compressive strength, splitting tensile strength, and bond strength.

3. EXPERIMENTAL STUDY

3.1. MATERIALS

3.1.1. Cementitious Materials

The cementitious material used in all concrete mixtures is Ordinary Portland Cement (OPC) with (CEM I 42.5 N). It is produced by Tourah cement company in Egypt, which attains the requirements of E.S.S 4756-1/2013 [15] and E. 197-1/2011 [16]. The chemical composition of cementitious materials is presented in Table 1.
In addition, micro-silica (silica fume) produced in Egypt by SIKA company for chemical materials is used to improve strength in all the cone mixtures. The properties of silica fume follow the ASTM C 1240 [17], and it is as follows: appearance is solid and grey powder, particle size is 0.2 µm, the surface area is 14 m2/g, density is 20 KN/m3, and PH is between 6 and 8.

Table 1: Chemical composition of cementitious materials

%	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3
OPC	19.8	5.5	63	1.18	3.39
SF	92	0.2	0.3	---	0.4
%	Na_2O	K_2O	SO_3	Loss of Ignition (LOI)	
OPC	0.46	0.16	3.01	5.2	
SF	---	---	0.1	2	

3.1.2. Aggregates

The used aggregate is a mix of coarse aggregate (i.e., dolomite - barite) and fine aggregate (i.e., sand - ilmenite). In NWC mixtures, the crushed stone (dolomite) was used as a coarse aggregate with a specific gravity of 2.7 while natural sand was used as a fine aggregate with a specific gravity of 2.53. The physical properties of the natural sand are shown in Table 2. The HWC mixtures consist of normal weight aggregate (dolomite and sand) in addition to heavyweight aggregate (barite) as a coarse aggregate and (ilmenite) as a fine aggregate, with a specific gravity of 4.48 and 4.8, respectively.

The maximum coarse aggregate size in NWC and HWC was 9.5 mm. The sieve analysis results of coarse and fine aggregates are displayed in Fig. 1, following the American Society for Testing and Materials (ASTM). The two figures show that both coarse and fine aggregates used in NWC and HWC are within the limit of sieve analysis of ASTM C 33 [18].

Table 2: Physical properties of fine aggregate (sand)

Property	Value	Limits *
Specific gravity (SSD)	2.53	__
Unit weight (KN/m3)	15.3	__
Fineness modulus	2.5	__
Clay and other fine materials (%)	1.5	≤ 3 %

*According to ASTM C 117

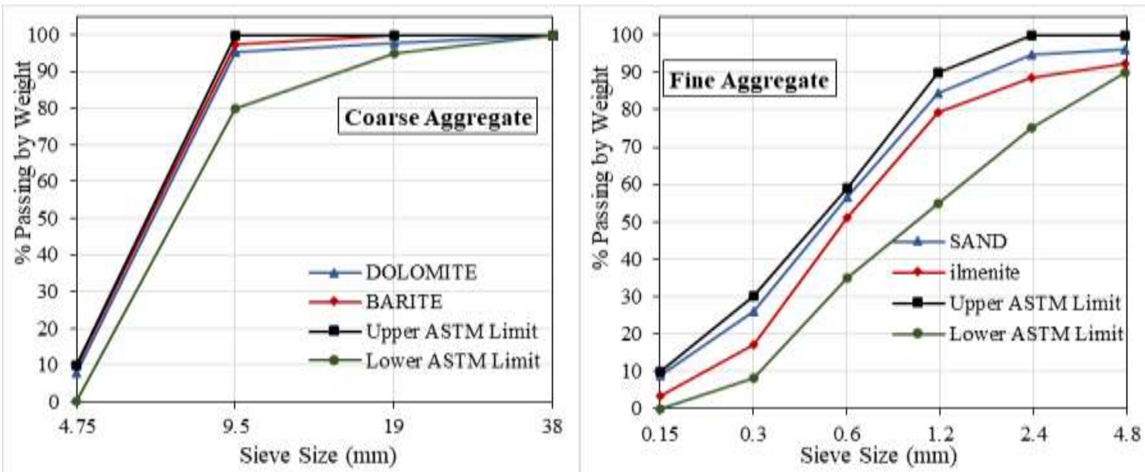

Fig. 1: Sieve analysis of coarse and fine aggregates

*According to ASTM C 33 [18]

3.1.3. Super-Plasticizer

The Sikament-NN was used as a super-plasticizer that complies with ASTM C494 Type (F) [19] and BS 5075 Part3 [20]. The properties of Sikament -NN are shown in Table 3.

Table 3: Properties of Superplasticizer (Sikament -NN)

Base	Naphthalene Formaldehyde Sulphonate
Appearance	Brown liquid
Density (KN/m^3)	12
Chloride content	Zero
Air entrainment	Approximately zero
Compatibility	All types of Portland cement

*According to ASTM C 494 Type F and BS 5075 Part 3 Reinforcement Bars

3.1.4. Reinforcement bars

The reinforcement bars used in this study include steel bars and Carbon Glass Fiber Reinforced Polymer (CGFRP) bars. The steel bars are high tensile steel with grade 52. Their mechanical properties are as follows: the diameter is 12 mm, the yield stress is 411 MPa, ultimate stress is 628 MPa, the weight per meter is 8.88 N, density is 78 KN/m3, and elongation is 17.7%. The Carbon Glass Fiber Reinforced Polymer bars are formed with a density of 1.764 KN/m3 by adding Carbon tire 330 powder to the manufactured Glass fiber and following the ASTM Vol. 09.01 [21]. The glass fiber is produced by CAMELYAF company in Turkey with a specific gravity of 2.54, a TAX of 2400 (TAX= weight in grams of 1 Km length of roving), a tensile strength of 3250 MPa, elongation of 4.5%, and diameter of 12 mm. as shown in Fig 2. Polyester resin used is TOPAZ 2200 NT from ICR company in addition to peroxide.

Fig.2: carbon glass fiber reinforced polymer bars (CGFRP)

3.2. MIX DESIGN

Four trail mixes were designed to give compressive strength of 40 MPa. The first two mixes are for NWC and designed according to ACI 211.1-91 [22] with a unit weight of 24 KN/m3. The last two mixes are for HWC and designed according to ACI 304.3R-96 [23] with a unit weight of 38 KN/m3. The material quantities for the concrete mixtures are listed in Table 4.

Table 4: Material quantities for the four concrete mixtures

Mixture ID	Mixture code	W/C	Concrete Ingredients (Kg/m^3)							
			Cement	Water	Coarse aggregate		Fine aggregate		Silica fume	Plasticizer
					Dolomite	Barite	Sand	ilmenite		
M-1	NWC	0.47	375	175	960	-	680	-	35	7
M-2	NWC	0.50	350	175	960	-	680	-	35	-
M-3	HWC	0.47	375	175	350	850	560	340	35	7
M-4	HWC	0.0	350	175	350	850	560	340	35	7

3.3. CASTING AND CURING OF TEST SPECIMENS

All the concrete mixtures in this study were mixed and cast in the laboratory of the Faculty of Engineering-Materia, Helwan University, and for each concrete mixture, fifteen standard cubes (150 mm x 150 mm x 150 mm) were cast to determine the compressive strength at 7 days, 28 days, and 365 days. An additional three cubes for each mix were cast to determine the water absorption percentage at 28 days. Further, twelve standard cylinders with dimensions (150 mm diameter x 300 mm height) were cast for each concrete mixture to determine the splitting tensile strength at 28 days and 365 days. Another twelve standard cylinders were also cast for each concrete mixture to obtain the bond strength between concrete mixtures and reinforcement bars. Among these specimens, three were reinforced with steel bars, and the other three were reinforced with carbon glass fiber bars.

Four reinforced beams with dimensions of 125 mm width, 250 mm height, and 2000 mm length were cast with compressive strength of 400 N/mm2, two of the four beams were for normal weight concrete (M-1), and the other two beams were for heavyweight concrete (M-4), for each mix one beam was reinforced with steel reinforcement and steel stirrups as shown in Fig.3, and the other one was reinforced with carbon glass fiber bars (CGFRP) and steel stirrups as shown in Fig.4.All beams were simply supported with a clear span of 1800 mm, the bottom and top longitudinal reinforcement were 2 bars with a diameter of 12 mm and 2 bars with a diameter of 10 mm respectively. The steel stirrups were 10ø8/m, as illustrated in Fig.5.

Note that after casting all specimens, they were molded and immersed in a saturated water curing tank at 25◦ C until reaching the age of testing. Fig. 6a shows specimens preparation for the pull-out test where the test was conducted at the age of 365 days, while Fig.6b shows a part of standard cubes and cylinders after curing.

Fig.3: Steel reinforcement for beams

Fig.4: CGFRP reinforcement for beams

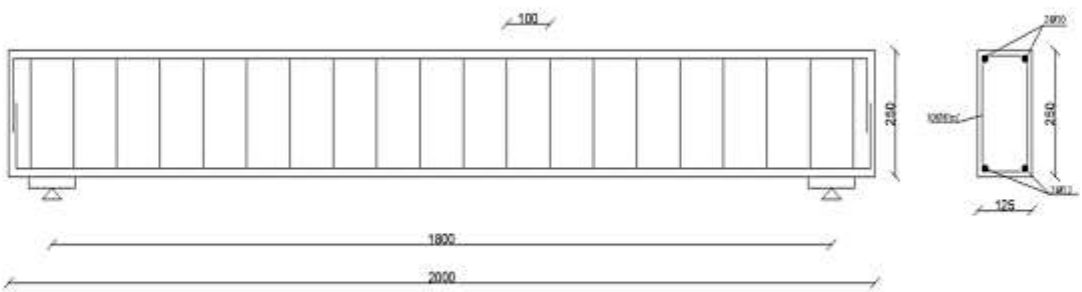

Fig.5: Beam dimensions and reinforcement details

3.4. TESTING METHODOLOGY

In this section, all tests completed on fresh concrete, hardened concrete, and reinforcement bars are described. Fresh and hardened concrete tests were carried out at the laboratory of the Faculty of Engineering-Materia, Helwan University. While the tensile test for steel and fiber bars was tested at Housing and Building National Research Center (HBRC).

3.4.1. Determination of fresh concrete properties

The slump test is used to measure the workability and consistency of fresh concrete mixtures instantly after mixing, according to BS EN 12350-2:2009 [24].

a) Pull-out test specimens' preparation b) Part of standard cubes and cylinders after curing

Fig. 6: samples of the standard cubes and cylinders used in the experimental tests

3.4.2. Determination of Hardened concrete properties

3.4.2.1. Density and compressive strength tests

The density test is used to ascertain the bulk density of concrete. The compressive strength test is a mechanical test for measuring the maximum compressive load that the concrete can bear before fracturing. The tests were carried out on the concrete specimens (i.e., standard cubes 150 mm x 150 mm x 150 mm) according to BS EN 12390-3:2009 [25]. The specimens were submerged in water until the time of the test. The compressive strength was determined at 7 days, 28 days, and 365 days.

3.4.2.2. Water absorption

This property is evaluated for the concrete specimens according to BS 1881-122:2011+A1:2020 [26]. It measures the amount of water maintained in the pores using Equation 1. The WD represents the weight of the oven-dry cube specimen, and WS represents the weight of the saturated cube specimen.

$$[(WS-WD)] / WS \qquad (1)$$

3.4.2.3. Splitting tensile test

It was performed according to BS EN 12390-6-2009 [27] at 28 days and 365 days using standard cylinders (150 mm diameter x 300 mm height). The splitting tensile strength of concrete (ft) was calculated using Equation 2; where P is the maximum applied load indicated by the testing machine, d is the diameter of the specimen, and L is the length of the specimen.

$$f_t = {}_{2\,p\,/}\,\pi . d . L \qquad (2)$$

3.4.2.4. Pull-out test

It was conducted to determine the bond strength between concrete and embedded steel or fiber rebars at 365 days, according to ASTM C882-99 [28]. The selected specimens were concrete cylinders (150 mm x 300 mm), where each cylinder has full-height embedded rebar with a 400 mm free end to apply the test.

3.4.2.5. Flexure strength of concrete beams

The test was carried out under a controlled load of four-point loading up to failure using a manual hydraulic jack of 1000 KN capacity as shown in Fig. 7. The load increment was constant for beam specimens at 5KN. Two concentrated loads at 300 mm from the mid-span were applied on the beam using a distributing steel I-beam, supported on two steel rods, and rested on neoprene pads as illustrated in Fig. 8. During testing, the loading was paused at different load levels to visually inspect the beam. Crack propagation was visually observed, and the cracks were marked on the surface of the tested specimen.

3.4.3. Determination of tensile strength: steel and CGFRP bars

The tensile strength test was performed using a single-purpose testing machine according to ASTM A370 [29]. The CGFRP bars have a special setup to apply tension tests to avoid destroying the bars' tip from the grip of the machine, hence, an epoxy resin was used to assemble steel pipes with the end of fiber bars.

Fig. 7: Controlled four-point load compression machine.

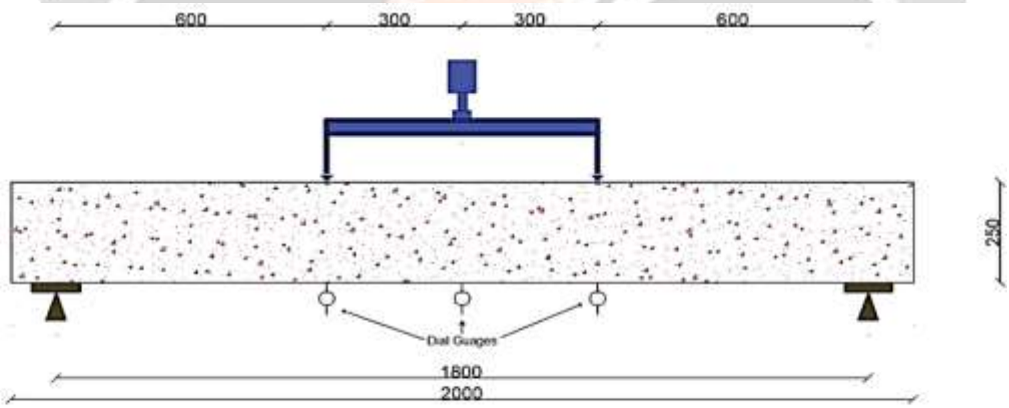

Fig. 8: Applied loads location

4. EXPERIMENTAL RESULTS AND DISCUSSION

It comprises the fresh and mechanical concrete properties of the four concrete mixtures. It includes the slump test results, density, water absorption, comprehensive strength, and splitting tensile strength. The results represent the average of measurements according to the number of specimens in each test.

4.1. Slump, density, and water absorption

The concrete slump test results are 9 mm for M-1, M-2, M-3, and 10 mm for M-4. The density varies among the concrete mixtures where M-3 has the highest density with 3110 kg/m3. The density of the HWC (i.e., M-3 and M-4) is higher than the NWC (i.e., M-1 and M-2), as shown in Fig. 9. That, in turn, will lead to more efficiency of shielding when using the HWC. The water absorption of the M-1, M-2, M-3, and M-4 is 5.21%, 5.39%, 4.41%, and 4.47%, respectively. That indicates the high absorption of the NWC compared to the HWC.

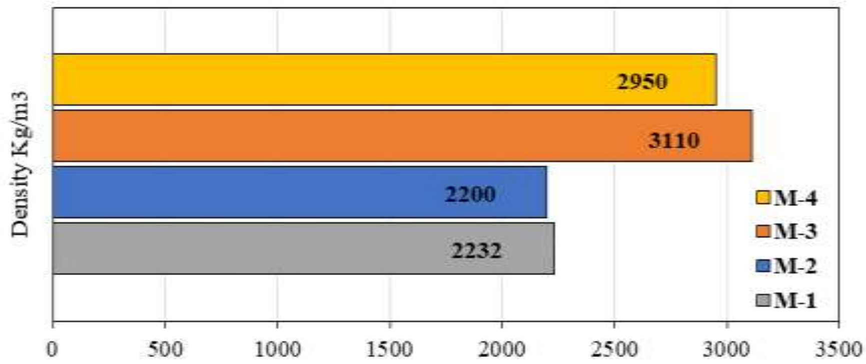

Fig. 9: Variation of density between NWC and HWC mixtures.

4.2. Compressive strength of concrete (F_{cu})

The comprehensive strength (F_{cu}) results are shown in Fig.10 for all the concrete mixtures. Concerning the NWC, the M-1 mixture achieves a compressive strength (F_{cu}) of 40 MPa after 28 days, which increases to 45 MPa after 365 days. The M-2 mixture achieves compressive strength (F_{cu}) of 31 MPa after 28 days and improves to 35 MPa after 365 days. Regarding the HWC, the M-3 and M-4 mixtures reach the F_{cu} of 50 MPa and 40 MPa respectively, after 28 days. Though, after 365 days, F_{cu} increased for both mixtures to 55 MPa and 45 Mpa.

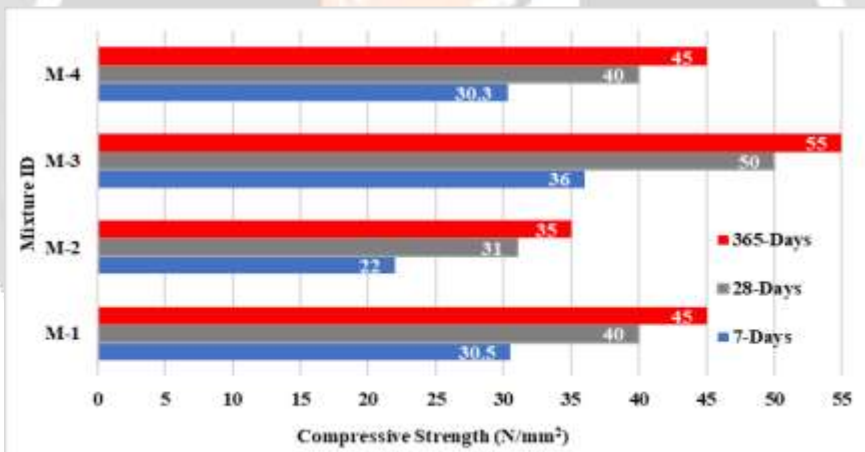

Fig.10: Compressive strength results for all concrete mixtures

4.3. Splitting tensile strength results

The splitting tensile strength at 28 days is comparable to the NWC mixtures of M-1 and M-2 (2.07 N/mm2 and 2.06 N/mm2, respectively). It increases to reach 2.35 N/mm2 and 2.33 N/mm2 after 365 days. Concerning the HWC, the splitting tensile strength of the M-3 mixture increases from 2.1 N/mm2 at 28 days to 2.41 N/mm2 at 365 days. Similarly, the M-4 mixture increases from 2.08 N/mm2 (28 days) to 2.39 N/mm2 (365 days). Fig.11 indicates that for the same compressive strength (as M-1 and M-4 with 40 Mpa), HWC gave slightly more splitting tensile strength than NWC by 0.5 % and 1.7 % after 28 days and 365 days respectively. And on that choosing to use NWC or HWC for the same compressive strength will not affect the results of splitting tensile strength by more than 1.7%.

4.4. Pull-out test results

The pull-out test was carried out for concrete cylinders after 365 days for all concrete mixtures of NWC and HWC to compare the usage of steel and carbon glass fiber-reinforced polymer bars in the reinforcement of both NWC and HWC. It was concluded from the test results in Table 5, that using steel bars enhances the bond strength by 19% more than using carbon glass fiber-reinforced polymer for the same mixture of NWC or HWC.
Concerning steel reinforcement for the same compressive strength of HWC and NWC, it was found that the reinforcement of HWC with steel bars gave slightly high bond strength than using NWC by 0.4%. While using Carbon Glass Fiber Reinforced Polymer (CGFRP) bars in HWC increased the bond strength by 0.7% more than using NWC. The results reveal that the bond strength for HWC is slightly high than NWC and steel bars have higher resistance toward the bond strength than CGFRP in both NWC and HWC.

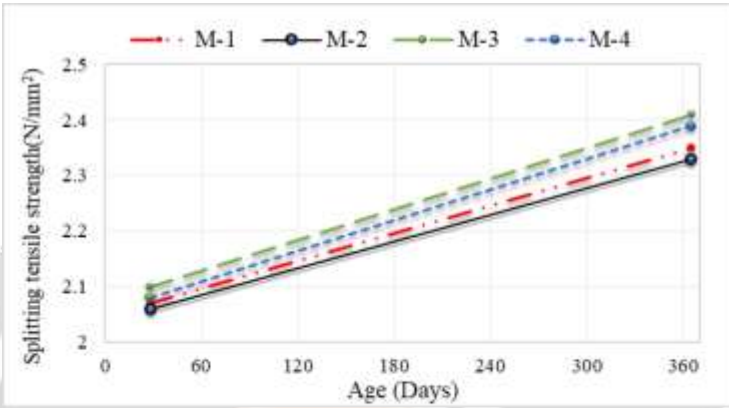

Fig. 11: Splitting tensile strength for normal weight and heavyweight concrete.

Table 5: Bond strength for steel and Carbon Glass Fiber Reinforced Polymer (CGFRP) bars

Mixture ID	Mix code	F_{cu} (MPa)	*Bond strength (MPa)	
			Steel bars	(CGFRP) (MPa)
M-1	NWC	40	7.49	6.04
M-2	NWC	30	7.41	5.94
M-3	HWC	50	7.56	6.12
M-4	HWC	40	7.52	6.08

* Bar diameter is 12 mm, and the embedded length is 300 mm for both steel bars and CGFRP bars.

4.5. Tensile strength of reinforcement bars

The tensile strength for steel and CGFRP bars was measured according to ASTM A496-02 [30] and ASTM D7205-06 [31] respectively. The results of the tensile strength of steel and CGFRP bars show a significant increase in the ultimate strength of steel by 24% than CGFRP bars. From the elongation results, it can be indicated that the behavior of failure for steel was ductile while the failure for CGFRP bars was brittle.

Table.6: Tensile strength of steel bars and carbon glass fiber bars

Specimen* (Bar)	Ultimate strength (Mpa)	Proof strength (Mpa)	Elongation (%)
Steel	628	411	17.3
CGFRP	478	-	4.8

*Specimen of 500 mm length and 12 mm diameter.

4.6. Flexure strength of concrete beams

According to the behavior failure of steel and carbon glass fiber reinforced polymer bars, it could be expected the failure modes for both NWC, and HWC beams reinforced with steel or CGFRP bars. It was seen from Fig. 12 and Fig.13 that when using steel bars in the reinforcement of both NWC and HWC beams the failure mode will be a ductile failure. While the failure was brittle for both NWC and HWC beams reinforced with CGFRP bars This confirms that CGFRP bars are brittle material and do not exhibit any plastic behavior (yielding) before rupture [32]. Table 7 summarized all specimens' results of failure loads (Pu), vertical deflections (Δu), maximum concrete strain (εc), maximum bars strain at failure (εr), first crack load (Pcr), and failure mode.

a) Reinforced with steel bars

b) Reinforced with CGFRP bars

Fig.12: Crack pattern for normal weight concrete beams.

Table 7: Flexure strength results of concrete beams

Model*	P_u (KN)	Δ_u (mm)	ε_c max	ε_r max	P_{cr} (KN)	Failure modes
N. S	88.4	17.3	0.0017	0.0197	9	Ductile
N. F	64.5	25.7	0.0022	0.0150	13	Brittle
H. S	92.4	13.4	0.0018	0.0172	10	Ductile
H. F	80.2	22.2	0.0013	0.0111	12	Brittle

*Where: N: NWC. - H: HWC -S: Steel bar reinforcement -F: CGFRP bars reinforcement.

a) Reinforced with steel bars.

a) Reinforced with CGFRP bars.

Fig.13: Crack pattern for heavyweight concrete beams

4.7. Load – Midspan deflection behavior

To understand the unique flexural behavior of NWC and HWC beams reinforced with steel and CGFRP bars, the typical load, and mid-span deflection curves were analyzed as shown in Fig.14 and Fig.15.By studying Figs 12 to 15 and the results summarized in Table 12, it was concluded that the first crack was observed in the beams reinforced with steel early than those reinforced by CGFRP. And it is noticed that there was no significant decrease in the stiffness even though several micro-cracks formed. This is mainly resulting in a strain-hardening response [33]. Then the flexural stiffness gradually decreased with an increase in the number of micro-cracks until the beams reached the peak load then the capacity decreased suddenly for beams reinforced with CGFRP because of its brittle behavior and low elastic modulus of CGFRP rebars. It concluded also that the failure load in the beams that were reinforced with steel was higher than those reinforced by CGFRP for both NWC and HWC. This was attributed to the higher elastic modulus of steel rebars. These conclusions were in good agreement with the previous researchers [34-36].

4.8. Main Reinforcement Strain

Strains measured at the center of longitudinal steel and CGFRP rebars as shown in figures 16, and 17. it's observed that normal weight concrete and heavyweight concrete beams have similar behavior. The strain of CGFRP was seen as almost linear up to the failure without yielding behavior, whereas the strain in steel shows yield behavior before failing. The strain in CGFRP bars was lower than those of steel bars not only due to the brittleness of CGFRP but also due to the higher elastic modulus of steel rebars than that of CGFRP rebars, which led to a higher longitudinal rigidity. The results are in good agreement with Antino and Pisani [37]. They reported that in the case of conventional concrete and FRC beams, the strains in the FRP rebars increased almost linearly with the applied load after cracking.

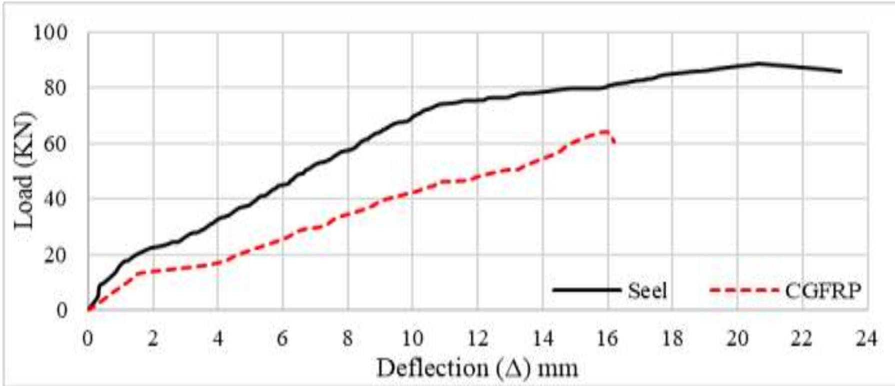

Fig.14: Load -Midspan deflection for normal weight concrete beams

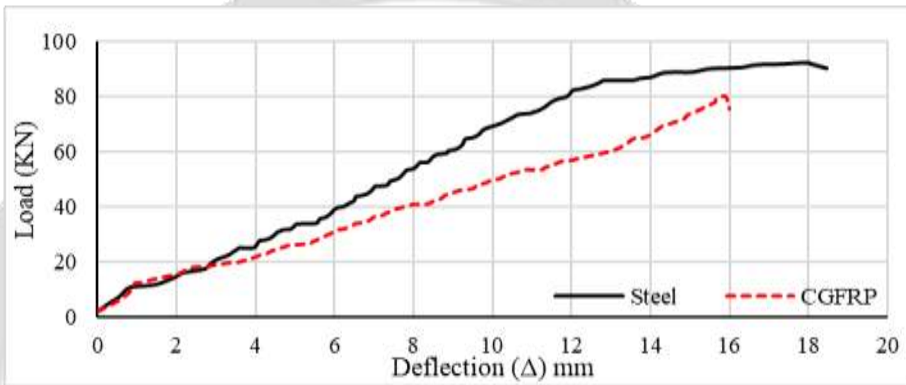

Fig.15: Load -Midspan deflection for heavyweight concrete beams.

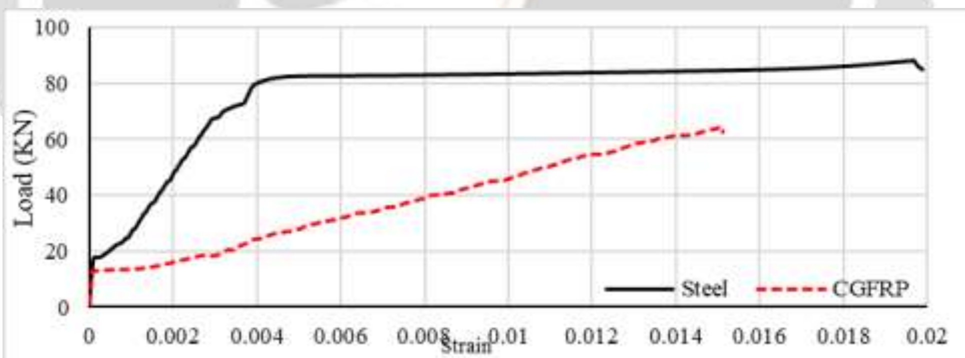

Fig.16: Load -reinforcement strain for normal weight concrete beams

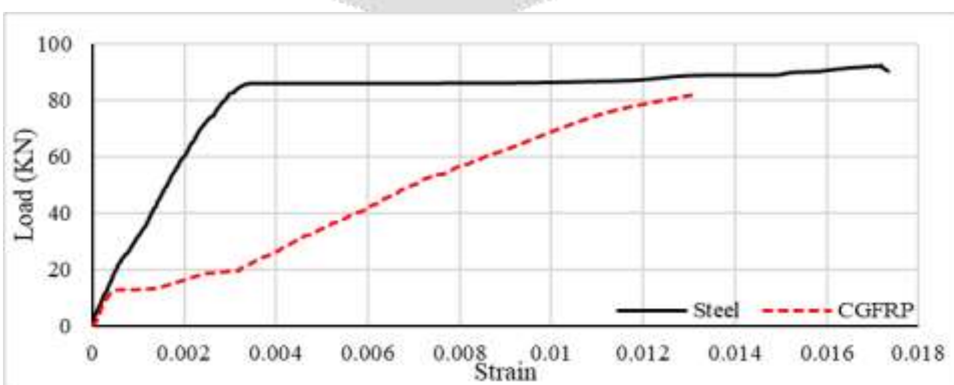

Fig.17: Load - reinforcement strain for heavyweight concrete beams

4.9. Compression concrete Strain

Figures18, and 19 show the relation between the load and the concrete strain at top of the beam measured at mid-span for both normal weight concrete and heavyweight concrete reinforced with steel bars and CGFRP bars. The concrete strain in the beams reinforced with CGFRP bars is greater than the concrete strain in beams reinforced with steel bars in normal weight concrete beams, while the concrete strain in the beams reinforced with CGFRP bars is less than the concrete strain in beams reinforced with steel bars in heavyweight concrete beams. the concrete strain is negligible at the beginning before cracking until the first crack, then the concrete strain increases considerably.

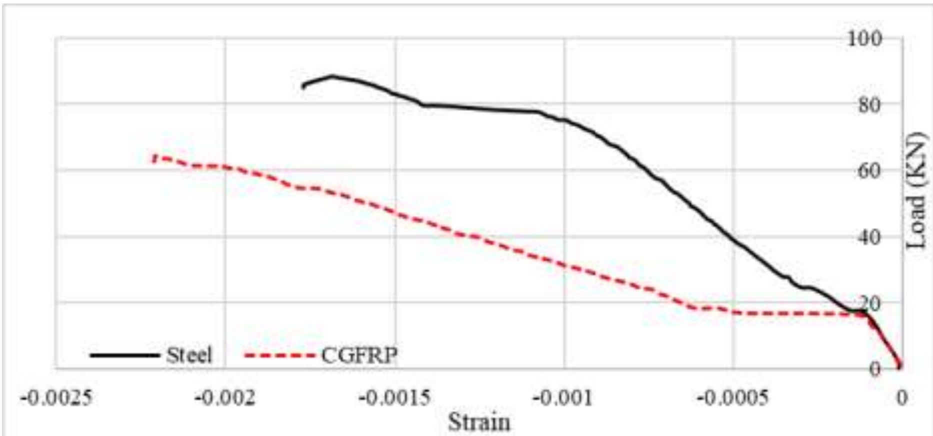

Fig.18: Load - concrete strain for normal weight concrete beams

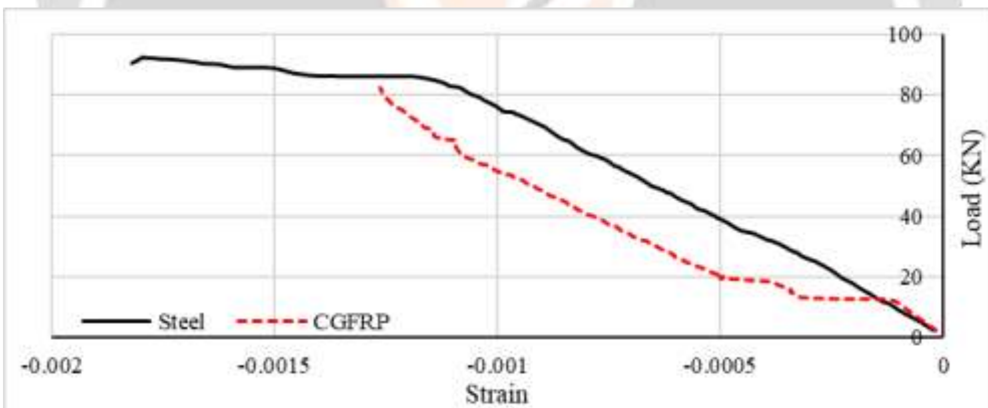

Fig.19: Load - concrete strain for heavyweight concrete beams

5. CONCLUSION

In this research, the behavior of normal weight concrete and heavyweight concrete beams reinforced with steel bars and carbon glass fiber bars subjected to flexure was studied using an experimental study.

The conclusions can be summarized in the following points:

1- The bond strength of CGFRP bars is less than the bond strength of steel bars by 19%.
2- Ultimate strength of CGFRP bars is less than steel bars by 23% due to manually manufacturing.
3- Ultimate load for normal weight concrete beams reinforced with CGFRP is less than normal weight concrete beams reinforced with steel bars by 27%.
4- Ultimate load for heavyweight concrete beams reinforced with CGFRP is less than normal weight concrete beams reinforced with steel bars by 13%.
5- The deflection of a normal weight concrete beam reinforced with CGFRP is less than a normal weight concrete beam reinforced with steel bars by 38%.

6- Deflection of heavyweight concrete beam reinforced with CGFRP is less than normal weight concrete beam reinforced with steel bars by 16%.
7- Stress-straining relationship of reinforcement bars in both normal weight concrete and heavyweight concrete reinforced with steel bars and CGFRP bars is almost the same, where the normal weight beams reinforced with CGFRP bars are less than normal weight beams reinforced with steel bars by 25%, while heavyweight beams reinforced with CGFRP bars is less than normal weight beams reinforced with steel bars by 23%.

6. CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

7. ACKNOWLEDGEMENT

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