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Research Paper

Reinforcement of concrete using Glass Fiber Reinforced Polymer

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The use of composite materials such as fiber reinforced polymers in strengthening and repairing of structural elements, particularly those made of reinforced concrete, is widely spreading. Among the fiber reinforced polymers (FRP) used for concrete strengthening, GFRP because they are more ductile and cheaper than carbon fibers and can be considered as an alternative solution to repair and strengthen concrete elements. The GFRP enhance significantly the ductility and strength of concrete by forming perfect adhesive bond between the wrapping material and concrete. Present study mainly emphasizes on effectiveness of external GFRP strengthening for concrete beams and columns. Total five circular concrete columns of 320 mm in height and 160 mm in diameter, and 30 concrete rectangular beams with a section of 40 mmx40 mm and 160 mm in length. Two columns were control and the rest three columns were strengthened with three types of GFRP. For beams, fifteen of them was control and the others were strengthened by GFRP with U-shape. All the test specimens were loaded to fail in axial compression and strain for columns, and under three-point bending for beams. The test results clearly demonstrated that compared with the ordinary concrete, the axial load carrying capacity and flexural strength increase for the reinforced concrete no matter the kind of the GFRP used even if it was in different storage condition.

1 Introduction

In the twenty-first century, among problems and challenges facing countries is the premature deterioration and functional deficiency of existing civil infrastructure. In the United Kingdom, over 10.000 bridges of concrete need structural attention. Nearly 11% of the nation's highway bridges in the United States are presently deficient structurally, and 19% are functionally obsolete [1]. In Japan, at 1995 Kobe earthquake, more than 120.000 structures were damaged and more than half of which were fully collapsed. Concerning the deterioration of structures, there can be many reasons; it can be due to inadequacy of current design codes, environmental influences, changes in the seismic hazard levels, need for structural upgradation (increase in applied load), deterioration due to corrosion in steel caused by exposure to an aggressive environment, poor concrete

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quality, design methods, and serviceability requirements. As a result, many existing structures have yet to be retrofitted in order to remain reasonably safe during pulse-type ground motions or other disaster than those they have been designed for [2].

For these purposes, different strengthening technique have been developed to repair and retrofit existing and aged structures and the technique which emerges in recent years is using FRP as external reinforcement. To be kept in mind the materials chosen for structural strengthening must, in addition to improving or increasing the various properties of the structures, fulfil some criterion, for the cause of sustainability and a better quality. Fibre reinforced polymer (FRP) have been introduced as the advanced materials for retrofitting/strengthening the aging structures or the structures having changed functionality, due to their broad range of properties such as high strength-to-weight ratios, stiffness-to-weight ratios, outstanding durability in a variety of environments, ease and speed of installation, flexibility, and application techniques, high resistance to corrosion and outstanding fatigue characteristics [3, 4]. Currently, the widely used fibre materials for FRPs are glass and carbon (GFRP and CFRP). Comparing the GFRP and CFRP, the GFRP have lower tensile modulus and strength as well as much lower material cost than those of CFRP, however the GFRP are more ductile and have better impact resistant properties. In practice, FRPs as external reinforcement have been used to provide confinement to reinforced concrete (RC) columns to enhance their load-carrying capacity, ductility and their lateral displacement capacity, and to improve shear and flexural strength capacities of reinforced concrete (RC) beams. The Direction for FRP wrapping for RC columns is in horizontal direction to the length of the column. The Flexural strengthening of reinforced concrete (RC) beams is achieved by attaching a bonded strip of FRP to the tension face of a flexural member to increase the effective tensile force resultant in the member and thereby increase the moment capacity of the member.

Most of the experimental works were carried out on CFRP laminates/ sheets/fabrics in strengthening of RC structures which showed that the use of this technique of reinforcement increase the strength in bending, reduce the deflections as well as crack width of the RC beams in comparison to other types of FRPs [5-19]. There are also some notable studies related to the application of externally wrapped GFRP composites for strengthening the RC beams, which showed that U wrapping of GFRP sheet is an effective way to enhance the flexural capacity of RC beams [20-29]. Triantafillou and Plevris [30], show that bonding GFRP or Aramid FRP fabrics or sheets, to the sides of the beams improve significantly their ductility and shear strength. Priastiwi et al. [31] investigated the influence of the hoop confinement at the concrete compression zone of the RC beams. They conclude that compared with RC beams without confinement at concrete compression zone, there was a significant increase in the load capacity and concrete strain and for RC beams with the confinement at the compression zone. Ameli et al. [32] studied experimentally and numerically the behaviour of twelve rectangular RC beams reinforced by CFRP / GFRP wrap with different configuration. Results showed a significant improvement in ductility GFRP wrapping as compared to CFRP wrapping. For the RC columns, Hadi [33] wrapped it with FRP straps both in horizontal and vertical directions and tested them under axial and eccentric loading. He concluded that the performance of CFRP straps was more effective compared to GFRP and conventional steel reinforcement. According to Sezen [34] who evaluated the axial behaviour of strengthened circular RC columns with FRP and steel jackets, the FRP wraps increased the axial strength of the RC columns by up to 140%. However, after the maximum axial capacity was reached, the two methods resulted in a brittle failure immediately. R. Kumutha et al. [35] studied the influence of the number of layers of the GFRP on the behaviour of RC rectangular columns with different ratios (h/b) where h and b are respectively, the longer and shorter sides of column cross-section, h/b = 1.0, h/b = 1.25, and h/b = 1.66. Nine specimens were subjected to axial compression. Reinforcement by GFRP showed an improving on the compressive strength. However, more the number of layers of GFRP increase better confinement is achieved, resulting in enhanced load carrying capacity of the column, in addition to the improvement of the ductility. Lau and Zhou investigated the behaviour of FRP wrapped concrete cylinders with different wrapping materials and bonding dimensions using finite element (FEM) and analytical methods [36]. They found that, the load carrying capacity of the wrapped concrete structure is governed by the mechanical properties such as modulus and Poisson's ratio, of the wrapping sheet.

The scope of work includes evaluation of the effectiveness of external strengthening by GFRP on the behaviour of five concrete columns and thirty beams in the present investigation. The flexural reinforcement was in the form of U-shape for beams, and columns was fully wrapped by GFRP. The experimental variables considered were the types of GFRP and the conditions of conservation of the strengthened concrete specimen.

2 Experimental program

2.1 Test Specimen

Totally five circular concrete columns were tested under concentric compression in testing frame and thirty concrete beams under flexural load. All columns had the same dimension with a height of L=160 mm and a diameter of D=320 mm as can be seen in fig 1. The rectangular beam specimens had 400 mm in height and 400 mm in and an overall length of 160 mm with a span length of 100 as can be seen in fig 2. The columns were fully wrapped by GFRP, while the beams were subjected to U-wrapping. They were three types of GFRP and we used the same section of each element in order to study the influence of the variation of types of GFRP reinforcement on the behaviour of each element. Each column has been reinforced by type of GFRP and the last two was served as control columns. The thirty beams were made in five stages, in each step six beams are made, three of them are considered as controls beams and for the three other beams, each one was reinforced by a type of GFRP. Schematic identification and representation of specimen with wrapping configurations using different type of GFRP are shown in fig 3.

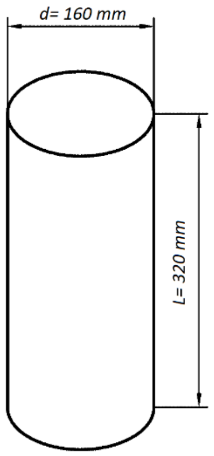


Fig. 1 – Concrete column dimensions

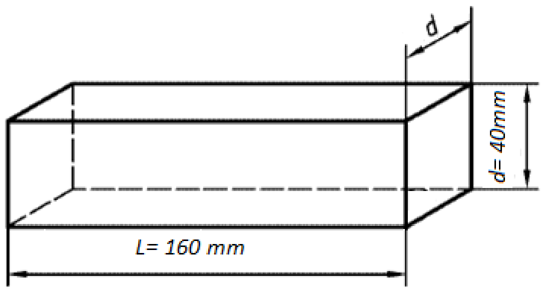


Fig. 2 – Concrete beam dimensions

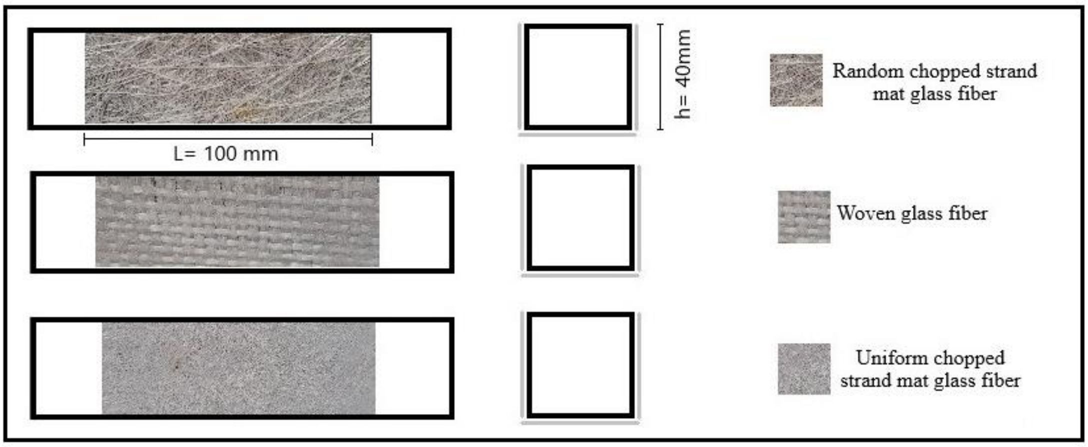


Fig. 3 – Strengthening disposition on beams

2.2 Materials properties

2.2.1 Concrete

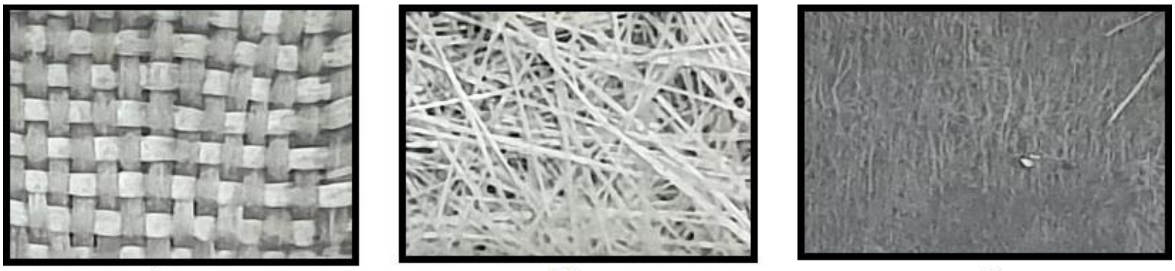
Concrete is a construction material of water and Portland cement combined with gravel, sand, crushed stone, or other inert material such as vermiculite or expanded slag. The water and cement form a paste that hardens by chemical reaction into a strong, stone- like mass. The character of the concrete is determinate by the quality of the paste formed by the water and cement largely determines. In our experimental study, ordinary locally available Portland cement with a strength of 45 MPa (CPJ45) was made use of, in the casting of the to the requirements of water for concreting and curing as NM 10.1.353 was used throughout. The average standard 28-days compressive strength of concrete cylinder was 25 MPa with specimens. Crushed sand with a granular class 0/5 was used. Two kind of gravel was used in our concrete formulation, the first one had a granular class of 6.3/10 and 10/14 for the second type. Water conforming mix ratio of cement: sand: gravel: water 1: 2.29: 2.65: 0.54. The table below shows the quantities of ingredients used in the concrete mix.

Table 1 – Proportion of ingredients used for concrete mix (1 m^3)

Ingredient	Granular Class	Quantity
Gravel 1	10/14	568.1 kg/m^3
Gravel 2	6.3/10	358.7 kg/m^3
Sand	0/5	800.9 kg/m^3
Cement	CPJ 45	350 kg/m^3
Water	-	191 kg/m^3

2.2.2 GFRP Sheets

There were three types of glass fibre sheets used in this present investigation, were woven glass fibre, uniform and random chopped strand mat glass fibre as shown in fig. 4. The properties of GFRP sheet are presented in Table 3. The resin system used to bond the glass fibre sheets over the reinforced element (columns and beams) was an epoxy resin made of two parts, resin and hardener. As known the epoxy resins are relatively low molecular weight pre-polymers able of being processed under different conditions. The important advantage is that they can be partially cured and stored in that state and they exhibit low shrinkage during curing. The epoxy used in this study was Sika CarboDur 31 Colle M with a compressive strength between 70/80 MPa and a tensile strength varies between 20/30 MPa.



a) b) c)

Fig. 4 – Glass fiber types

Table 2 – Glass fiber properties

Fiber type	Woven Glass Fiber	Random Chopped Strand Mat Glass Fiber	Uniform Chopped Strand Mat Glass Fiber
Young Modulus (GPa)	76	45	61

2.3 GFRP Wrapping

Before bonding the composite fabric, the concrete surface needed to be cleaned with wire brush to remove all dirt and debris. Girding machine was used for smooth even surface as can be seen on fig5. Once the surface of specimen was prepared to the required standard, the epoxy resin was mixed. Sika CarboDur M is made from two different part; component A (resin with a white color) and component B (Hardner with a black color) with a mix ratio of A: B 3: 1. Mixing was carried out in a plastic container and was continued until the mixture was in uniform color (Grey) as shown on fig 6. The epoxy was applied over the surface with spatula. Then, wrapping of GFRP is done layer-wise and pressed with a roller to remove air void. GFRP wrapping procedure is presented in fig. 7.

Fig. 5 – Grinding of specimen

Fig. 6 – Epoxy used in our study

Fig. 7 – GFRP wrapping

Fig. 8 – Reinforced and unreinforced Concrete columns

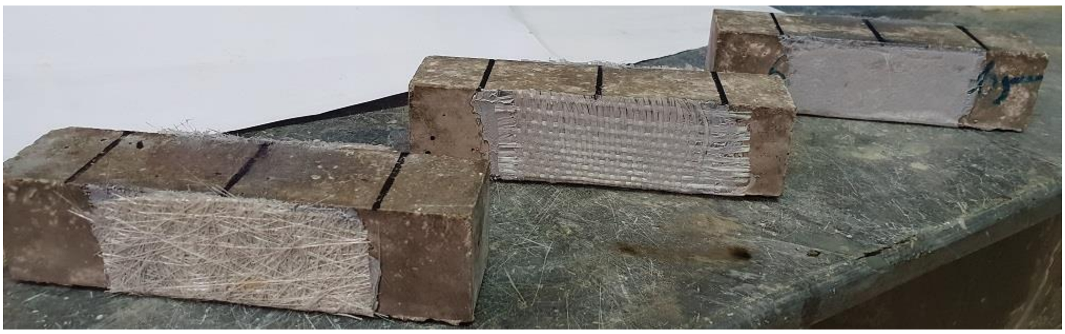
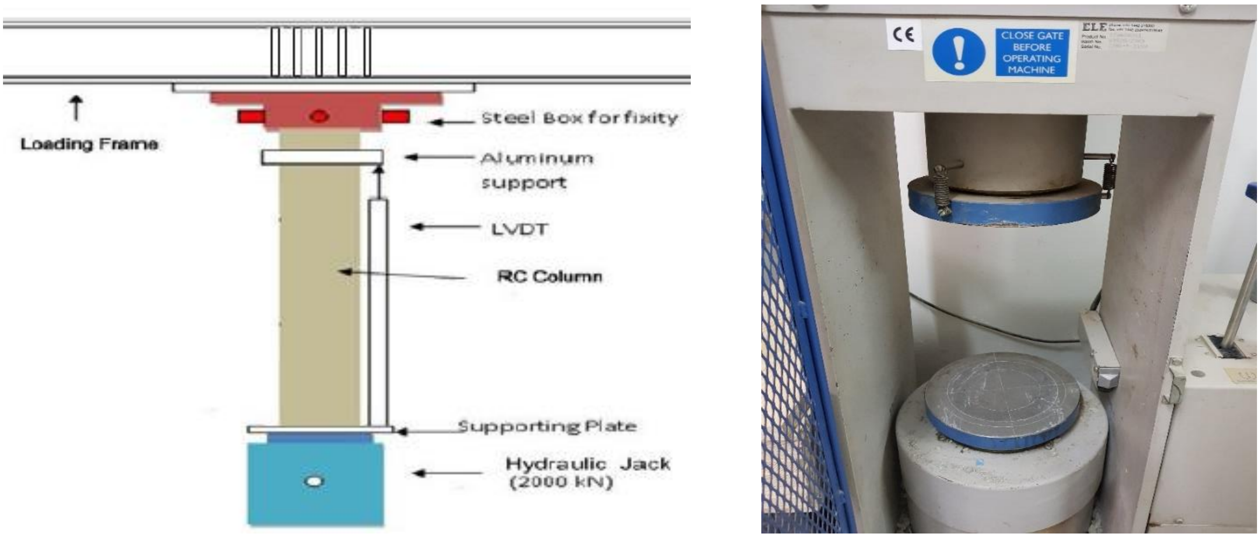


Fig. 9 – Reinforced concrete beams

2.4 Test Setup and Instrumentation

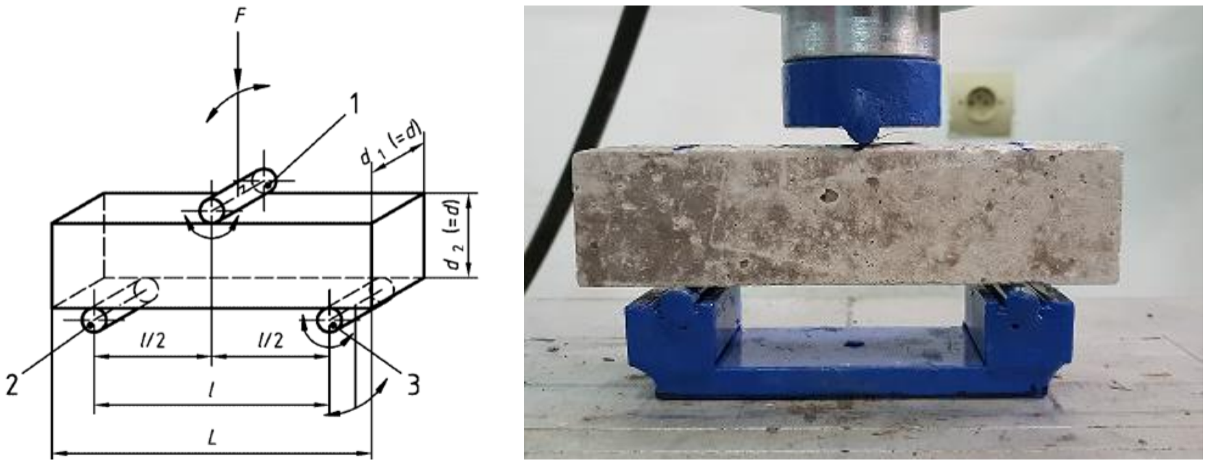
Test of the circular columns was carried out on loading frame in laboratory called “Labo Proctor”. The load was applied using hydraulic jack of capacity 1500 kN. The concrete columns were tested on the loading frame under axial compressive loading. General arrangement of test setup is shown in fig. 10. To ensure parallel surface and to put the columns under a uniform load to reduce eccentricity, all columns were capped with steel plate. The loading arrangement for evaluating the compressive strength of the concrete columns was followed in accordance to NM 10.01.051.



(a) *(b)*

Fig. 10 – (a) schematic diagram of compressive test [37], (b) Compressive testing machine

All the beams were tested under three-point bending until failure. The length of beams was 160 mm and its clear span was 100 mm. The loading velocity was 50N/s. The representative schema of experimental test setup is shown in Fig. 11.a. and the laboratory test setup is shown in Fig. 11.b. The loading arrangement for evaluating the flexural strength of the concrete beam was followed in accordance to NF EN 12390-5.



(a) *(b)*

Fig. 11 – (a)The schematic diagram of experimental test, (b) – Three-point bending for beams testing machine

3 Result and Discussion

3.1 Columns

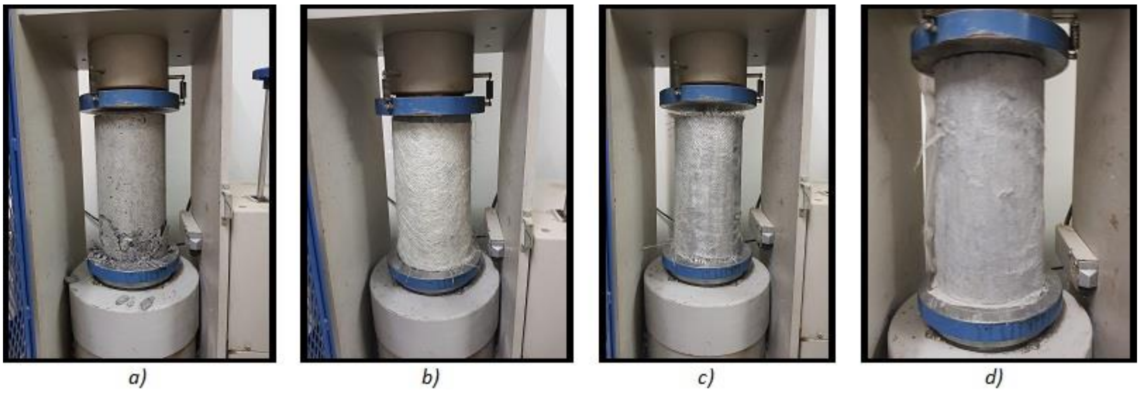


Fig. 12 – Reinforced and unreinforced columns under compressive loading

Table 3 – Compressive test result

Specimen number	Type of specimen	Compressive Strength	Gain
Specimen 1&2	Control	25	-
Specimen 3	Reinf. By random chopped strand mat glass fiber	27.37	9.5 %
Specimen 4	Reinf. By uniform chopped strand mat glass fiber	32.12	29 %
Specimen 5	Reinf. By woven glass fiber	34.37	37.5 %

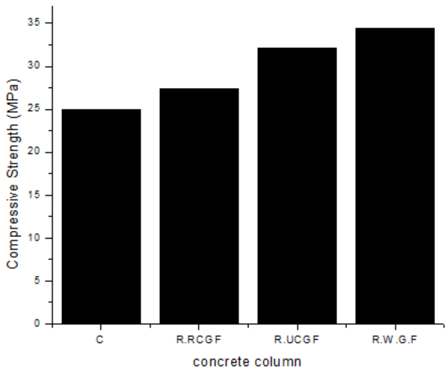


Fig. 13 – Compressive strength of reinforced and reinforced columns

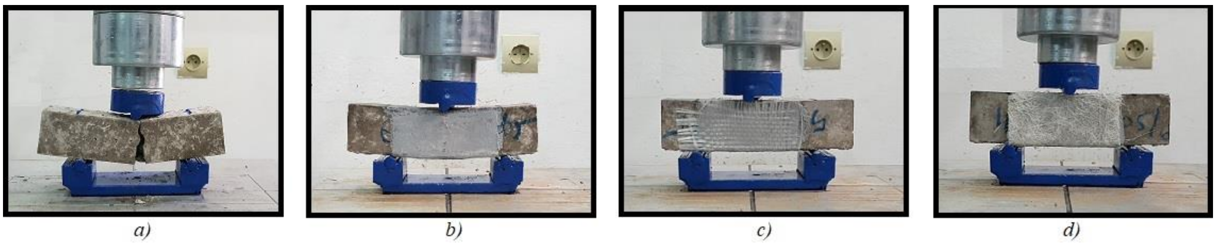


Fig. 14 – Reinforced and unreinforced beams under flexural loading

Figure 13 shows the compressive strength for each specimen. According to this figure, the compressive strength of unreinforced concrete is 25 MPa while for a reinforced concrete, the resistance is 34.37 MPa for a concrete strengthened by woven glass fibre (W.G.F), 32.12 MPa for the one strengthened by uniform chopped strand mat glass fibre (U.C.G.F) and

27.37 MPa for random chopped strand mat glass fibre (R.C.G.F). Based on the results above, we can note a 37.50% increase for reinforced concrete by W.G.F, 29% for the one reinforced by U.C.G.F and 9.5% for R.C.G.F. reinforced concrete. We can also notice that no matter the type of glass fibre used we will have an increase in compressive strength. However, this increase varies from 9.5% to 37.5% depending on the type of fibre used, which shows the effectiveness of this technique, except that to have a better result the W.G.F has shown its efficiency with a gain of 37.5% in compressive strength.

From these results we can conclude that the variation of the resistance depends on the type of fibre used because even if they are from the same base (glass fibre) the increase varied from 9.5% to 37.5% which means that the arrangement, distribution, direction and orientation of the fibres clearly affects the compressive strength of the concrete.

3.2 Beams

The figures and tables below show the flexural strength of the reinforced and unreinforced concrete according to different storage conditions of the specimens and using different type of glass fibre.

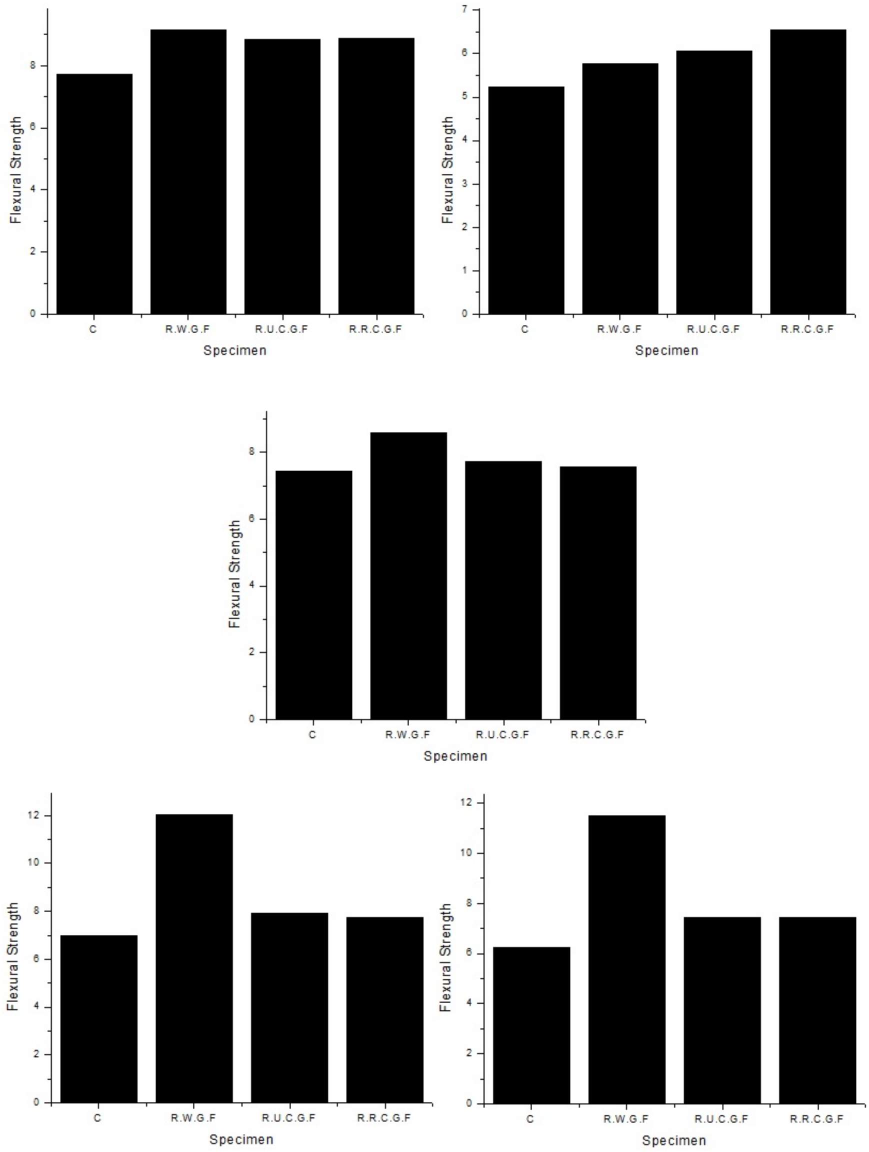


Fig. 15 – Flexural strength of reinforced and unreinforced beams in different storage condition

From the table above the bending strength for an unreinforced concrete varies from 5.23 MPa to 7.71 MPa, while for a concrete strengthened by U.C.G.F the value varies from 6.05 MPa to 8.84 MPa, for a strengthened concrete by R.C.G.F the resistance is the value is from 6.54 MPa to 8.88 MPa. The high value was noted for a concrete reinforced by W.G.F and it rises to 12.02 MPa.

Table 4 – Flexural test result

Bonding Time	Temp.	N° of specimen	Type of specimen	Maximal load (kN)	Flexural strength (MPa)	Gain
2 h	24,6°C	1	Control	3,29	7.71	-
		2				
		3				
		4	R. By woven glass fiber	3,90	9,14	19%
		5	R. By uniform chopped strand mat glass fiber	3,77	8,84	15%
		6	R. By random chopped strand mat glass fiber	3,79	8,88	15%
2 h	25°C	1	Control	2,23	5.23	-
		2				
		3				
		4	R. By woven glass fiber	2,46	5,77	10%
		5	R. By uniform chopped strand mat glass fiber	2,58	6,05	16%
		6	R. By random chopped strand mat glass fiber	2,79	6,54	25%
5 h	29°C	1	Control	3.17	7.43	-
		2				
		3				
		4	R. By woven glass fiber	3,66	8,57	15%
		5	R. By uniform chopped strand mat glass fiber	3,30	7,73	4%
		6	R. By random chopped strand mat glass fiber	3,22	7,55	2%
24 h	20°C	1	Control	2.98	6.98	-
		2				
		3				
		4	R. By woven glass fiber	5,13	12,02	72%
		5	R. By uniform chopped strand mat glass fiber	3,39	7,94	14%
		6	R. By random chopped strand mat glass fiber	3,30	7,73	11%
24 h	22°C	1	Control	2.66	6,23	-
		2				
		3				
		4	R. By woven glass fiber	4,90	11,48	84%
		5	R. By uniform chopped strand mat glass fiber	3,18	7,45	20%
		6	R. By random chopped strand mat glass fiber	3,17	7,43	19%

The first test is carried out in a room with a temperature of 24.6 °C, the duration of epoxy application was 2h as indicated on the instructions of the pot. The flexural strength found for unreinforced concrete was 7.71 MPa, 8.84 MPa for U.C.G.F reinforced concrete, 8.88 MPa for R.C.G.F reinforced concrete and 9.14 MPa for W.G.F. The results obtained showed a gain of 15% for reinforced concrete by U.C.G.F and R.C.G.F, and 19% for concrete reinforced by W.G.F. The second test had a similar epoxy application duration of the first test. The difference between the two was that the conservation of the specimen. It was under the sunrays in order to raise the temperature of the specimens to have a good hardening of epoxy. The reason behind this was that the hardening time varies depending temperature, because the higher the temperature, the shorter the hardening time, from 2h for a temperature of 10 ° C to 30 min for a temperature of 30 ° C.

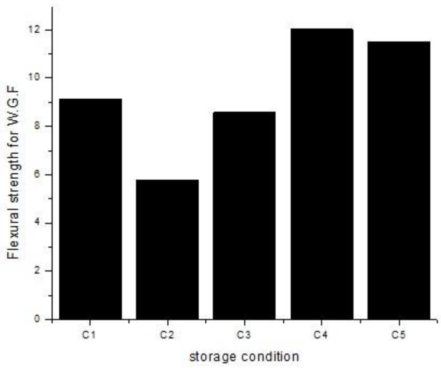


Fig. 16 – Flexural strength of reinforced beams using W.G.F in different Storage conditions

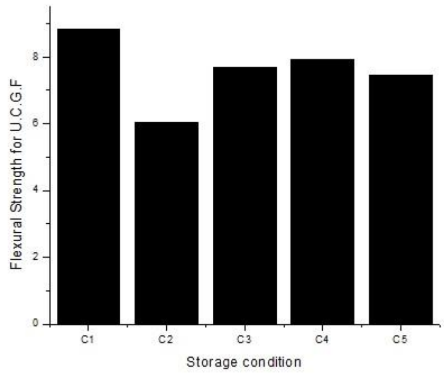


Fig. 17 – Flexural strength of reinforced beams using U.C.G.F in different Storage conditions

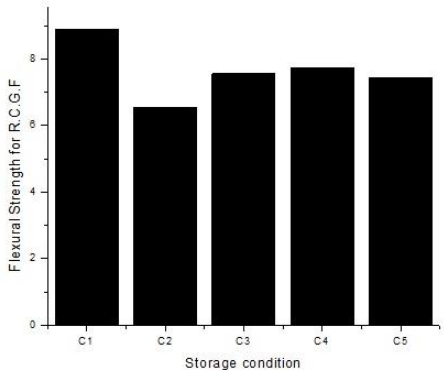


Fig. 18 – Flexural strength of reinforced beams using R.C.G.F in different Storage conditions

The first thing to notice is that the strength of the unreinforced concrete is lower than the first test. which shows that the temperature and humidity of the specimen play an important role in the characteristics of the concrete. Even if the flexural strength for unreinforced concrete in the second test is lower than the first one, the reinforcement has shown its effectiveness, except that this time the best value was noted for a concrete reinforced by R.C.G.F for a gain of 25%. The difference in the third test was the epoxy application time that is 5h, with a temperature ambient of 27 ° C. In this test, the reinforcement efficiency decreased for the U.C.G.F and R.C.G.F because the gain for these two types reinforcement was 2% and 4%, while the highest value was from W.G.F that equals 8.57 MPa equivalent to a gain of 15%. According to this test, it is possible to notice the influence of the conservation of the specimens at a high temperature on the strengthening efficiency. The specimen of the fourth and fifth test were kept in a storage room at a temperature of 22 °C / 20 °C and a humidity of 93/95, the epoxy duration this time was 24 hours. The results were surprising this time, because with the same reinforcement section used in the previous tests it was possible for us to go from a value of 6.98 MPa for an unreinforced concrete to a value of 12.02MPa for a concrete reinforced by W.G.F. A gain of 72% was achieved for the fourth test and 84% for the fifth, which illustrates very clearly the effect of the epoxy application time and the storage conditions of the specimens; temperature and humidity.

Based on these results, we cannot deny the efficiency of the technique of external concrete reinforcement using bonding GFRP sheets, however this improvement in the concrete properties vary according to different criteria, be it the conditions of storage, the duration of resin application and not forgetting the type of GFRP used woven, Uniform or random chopped strand mat GFRP.

Finally, it is very clear that the woven glass fibre reinforcement is the best solution comparing with the other types used in this study, because the greatest value was from this type of fibre and it was 12.02 MPa. This type of fibre is woven in the form of mesh, which means there are fibre s parallel to the beam axis and other perpendicular to the latter and this is where lies the strong point of this type of glass fibre because the fibre s parallel to the main beam axis supports the bending forces while the perpendicular fibre s takes care of the shear forces the thing that explains the high gain of these fibres.

4 Conclusion

By way of conclusion, according to this study:

- The external reinforcement by GFRP has demonstrated a remarkable increase in load carrying capacity, compressive and flexural strength.
- The best gain has been noted for woven glass fibre, which means that the orientation and arrangement of the fibres plays an important role and clearly influences the behaviour of the concrete.
- The temperature and humidity play a major role on the change of the properties of the concrete and we can also notice a change in the flexural strength even if we are using the same type of glass fibre.
- The best results of reinforcement were noted for woven glass fibres in a temperature of 20 ° C and a humidity of 95% with an epoxy application time of 24 hours.

However, this study needs another complementary and more detailed study in order to more investigate the influence of the storage conditions (for example a temperature greater than 30 °C) and the duration of resin application (a duration greater than 24 hours).

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