# Experimental study of FRP reinforced concrete beams according to ACI

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## ABSTRACT

The paper presents the experimental analysis of static behavior of twelve simply supported beams reinforced with FRP (Fiber Reinforced Polymers) bars. The design procedures, cracks and deflection parameters were calculated according to American (ACI 440.1R-06) guidelines. All beams were reinforced with CFRP and GFRP bars with different diameters. The bars came from different manufactures. A total of twelve beams dimensions was 2200 mm x 130 mm x 220 mm and were tested up to failure under four-point bending. The main parameters, deflections and cracks were recorded. The results were used to evaluate SLS stage of RC with FRP bars.

*Keywords: GFRP, CFRP, Cracks, Deflections, Beams*

## INTRODUCTION

Steel bars have been used for many years in concrete structures. In addition to positive attribute, they also have some issues related to their lifespan such as corrosion. Looking at these problems during several years' researchers have started to explore new materials that could replace steel bars and their issues. So, it came to discovering the FRP bars that come as a result of a technological process. FRP bars by nature are isotropic and non-homogeneous because they consist of fibers and resin. Their non-corrosive properties and high tensile strength have made their use in different constructions not to be seen as "impossible". This work is based on the twelve experimental examination beams, the purpose of this examination is to evaluate the usefulness of these materials, namely their behavior at the SLS stage. Evaluation of this stage is made through the main parameters such as deflections and cracks which have been the main focus of this examination. Beams are reinforced with two types of CFRP and GFRP bars, both of which have different diameters because the change of bar diameters leads to different reinforcement ratio and so on different behavior during the apply loads. The surface of the bars has been two types, sand coated, and helically grooved. Special considerations should be made in the design of FRP reinforcing concrete members resulting from the low modulus of elasticity especially to GFRP bars. As a result, GFRP reinforced concrete members after cracking have relatively les stiffness. Examination was done with the four-point load method, with load increase up to failure in order to evaluate the type of failure.

## MATERIAL PROPERTIES

Concrete mixes design was prepared with requested class of concrete C 30/37. The different types of reinforced bars were used in our research, first step was determinations of mechanical properties of FRP bars. The results are presented in Table 1, based on the testing process according the Standard ASTM D 7205. In the edges of the bars were set metallic shells in order to avoid constriction of the FRP bars shown in Figure 1. The properties of conventional steel bars were used from known parameters based on the previous research works. FRP bars used in our research were two types: GFRP (helically grooved) and CFRP (sand-coated), shown in figure 1. The mechanical properties of testing GFRP and CFRP are presented in table 1.

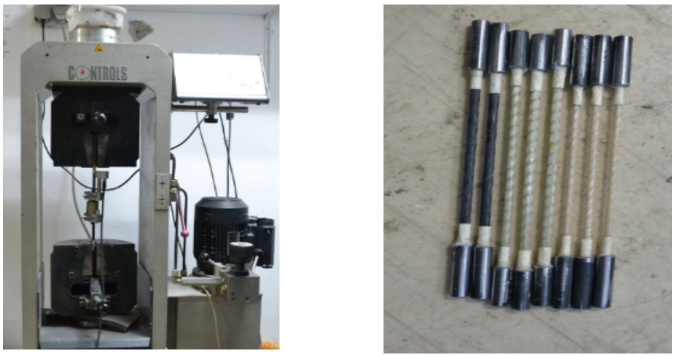

Figure 1. Testing the mechanical properties of Reinforced bars (GFRP CFRP)

Table 1. Mechanical properties of used GFRP and CFRP bars

| | GFRP | | | CFRP | |
|---|---|---|---|---|---|
| | Ø6 | Ø8 | Ø10 | Ø8 | Ø10 |
| Strain (‰) | 0.0204 | 0.0234 | 0.0256 | 0.0095 | 0.015 |
| Tensile (MPa) | 1022.10 | 1108.2 | 1194.3 | 1265.4 | 1420 |
| Elas. Mod. (GPa) | 55 | | | 155 | |


Figure 2: Testing the mechanical properties of concrete.

## DESIGN GUIDELINES

The flexural capacity of an FRP reinforced flexural member is dependent on whether the failure is governed by concrete crushing or FRP rupture. The failure mode can be determined by comparing the FRP reinforcement ratio to the balanced reinforcement ratio (that is, a ratio where concrete crushing and FRP rupture occur simultaneously). Because FRP does not yield, the balanced ratio of FRP reinforcement is computed using its design tensile strength. However, once the beam cracked, the stiffness of the GFRP reinforced concrete beam decreased at a faster rate compared with the control beam. This resulted in a larger deflection of the GFRP reinforced concrete beam.

Due to the brittle nature of concrete and because of changing loading conditions and other factors which are not considered in the design (such as internal stresses resulting from casting), cracks in concrete infrastructures, can't completely be avoided in practice. Design-codes give guidelines for checking the amount of reinforcement that is required in a structure to keep the crack-width limited to a certain value at specified load-levels. Checks in design codes are mainly based on the forces and bending moments in the cross-section of the structure and are unreliable for relatively thin plate-shaped structures but are conservative for non-standard structures with more complex loading and support conditions. Analyzing the cracks is based on the basic parameters using in ACI 318, for cracking and deflections in concrete beams. The beams divided to four groups due to difference in the type of the reinforcement as mention in table (2). The expression and calculations procedure according to ACI codes is presented in table 2.

Table 2. Analyzing methods and theories of behavior the concrete beams

| Expression | Procedure |
|---|---|
| Cracking | |
| $w = 2.2k_b \cdot \beta \cdot \frac{f_f}{E_{frp}} \sqrt[3]{d_c \cdot A} \quad (MPa)$ | ACI 440.1R-06 & CSA. |
| Deflection | |
| $\Delta = \frac{P \cdot a}{24EI_e}(3L^2 - 4a^2)$ | ACI 318 |

## EXAMINATION

The beams were reinforcement with one layer of FRP reinforcement comprising two bars. The entire beams were reinforcement in compression with two 6mm steel bars, and shear failure was avoided by providing closely spaced steel stirrups (6mm spacing in the shear span. In addition, stirrups spaced at 12mm were placed in the constant moment zone to ensure the positions of longitudinal bars and minimize the confinement provided by the stirrups.

Figure 3 shows the geometry of the specimens. A linear variable differential transformer (LVDT) was used to measure the width of the first flexural crack right under the concentrated force. The beam was observed during the test until the first flexural crack appeared. As soon it appeared, the load was paused until the initial crack width was measured on the beam's side surface (at the reinforcement level).

During the test, crack formation on the side of each beam was marked and the corresponding loads were recorded Also compression concrete zone were instrumented with LVDT to measure the strain of concrete, and another LVDT was in mid-span of the beam to measure the deflection. All beam specimens were tested under four-point bending over a clean span of 200cm (Figure 4). The load was monotonically applied using 400 kN hydraulic actuator with a stroke-controlled rate of 300 N/s. The actuator, strain gauges, and LVDTs were connected to a data-acquisition unit to continuously record their readings.

Table 3. Characteristics and reinforced of different sets of concrete beams

| | Beam | Reinforcement in upper zone | Reinforcement in down zone | Bending Moment $M_{max}$ [kNm] | Percent of reinforcement $\rho_b$[%] |
|---|---|---|---|---|---|
| Set 1 | B1 | Ø6 Steel | Ø6 GFRP | 8.60 | 0.00501 |
| | B2 | Ø6 Steel | Ø8 GFRP | 8.60 | 0.00415 |
| | B3 | Ø6 Steel | Ø10 GFRP | 16.34 | 0.00353 |
| Set 2 | B1 | Ø6 Steel | Ø6 GFRP | 16.34 | 0.00501 |
| | B2 | Ø6 Steel | Ø8 GFRP | 27.00 | 0.00415 |
| | B3 | Ø6 Steel | Ø10 GFRP | 27.00 | 0.00353 |
| Set 3 | B1 | Ø6 Steel | Ø8 CFRP | 17.90 | 0.00737 |
| | B2 | Ø6 Steel | Ø8 CFRP | 17.90 | 0.00737 |
| | B3 | Ø6 Steel | Ø8 CFRP | 17.90 | 0.00737 |
| Set 4 | B1 | Ø6 Steel | Ø10 CFRP | 42.88 | 0.00329 |
| | B2 | Ø6 Steel | Ø10 CFRP | 42.88 | 0.00329 |
| | B3 | Ø6 Steel | Ø10 CFRP | 42.88 | 0.00329 |

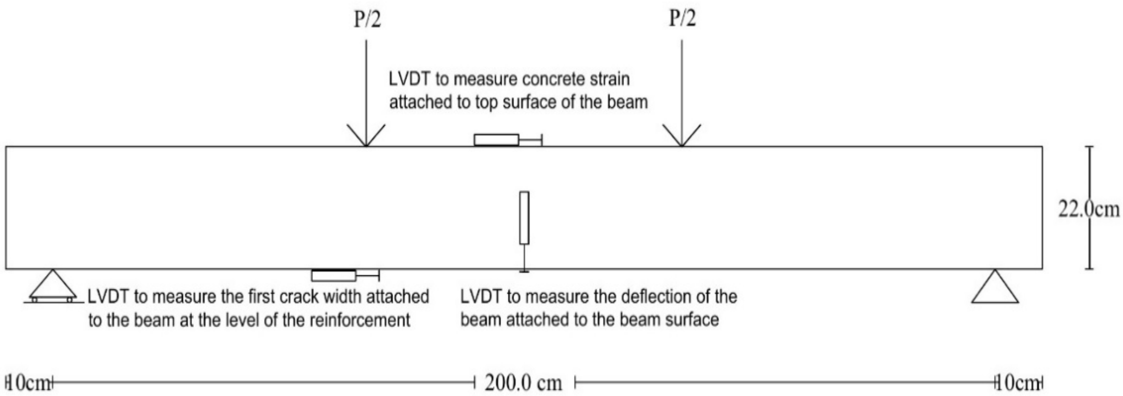


Figure 3: Beam measuring instruments position

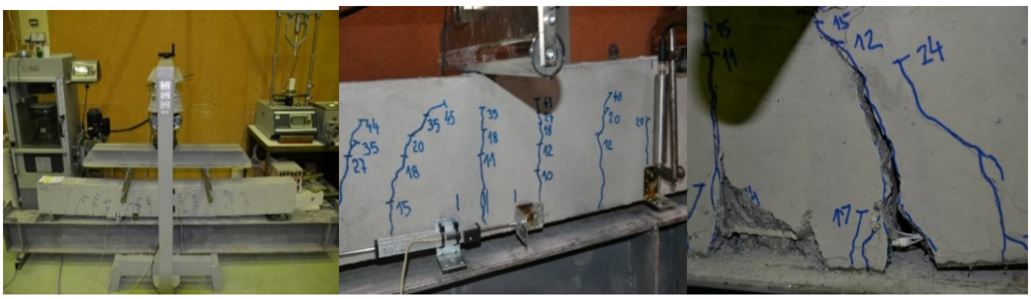

Figure 4: Beams during examination

## ANALYSIS OF RESULTS

As can be seen from the results in the table 4, the maximum strength of GFRP and CFRP reinforced bars is very high, but their serviceability limit state stage ends very quickly. GFRP reinforced bars are characterized by deep cracks that occur rapidly in the direction of the forces line, a phenomenon that is not emphasized at this level in reinforced concrete slabs with conventional steel bars. This condition is due to the low modulus of elasticity of the GFRP bars while the CFRP bars are seen to be a greater percentage of the use since the CFRP bars have a module of elasticity about three times greater than the GFRP bars but the CFRP bars are limited due to of their poor bond with the concrete resulting from their smooth surface.

Table 4. Behavior the testing beams for different type of reinforcement

| Type of bars | Bar diameter (mm) | Limit of strength between SLS & ULS [kN] | Maximum strength [kN] | Serviceability limit state [%] |
|---|---|---|---|---|
| GFRP | 6 | 8.21 | 29.24 | 28.0 |
| GFRP | 6 | 9.59 | 35.00 | 27.4 |
| GFRP | 8 | 9.54 | 37.00 | 25.7 |
| GFRP | 8 | 10.57 | 43.00 | 24.5 |
| GFRP | 10 | 15.43 | 70.00 | 22.0 |
| GFRP | 10 | 15.69 | 72.11 | 21.7 |
| CFRP | 8 | 23.74 | 59.00 | 40.2 |
| CFRP | 8 | 20.98 | 72.00 | 29.1 |
| CFRP | 8 | 23.39 | 72.90 | 32.0 |
| CFRP | 10 | 29.18 | 80.00 | 36.4 |
| CFRP | 10 | 27.81 | 85.00 | 32.7 |
| CFRP | 10 | 28.30 | 84.00 | 33.7 |

### Cracks and Deflection parameters in testing beams

The balanced reinforcement ratio and the nominal flexural strength defined in the presented sections can be obtained by using a sectional analysis in different stages of SLS theory, including the percent of ratio "Moment-M/$M_u$"

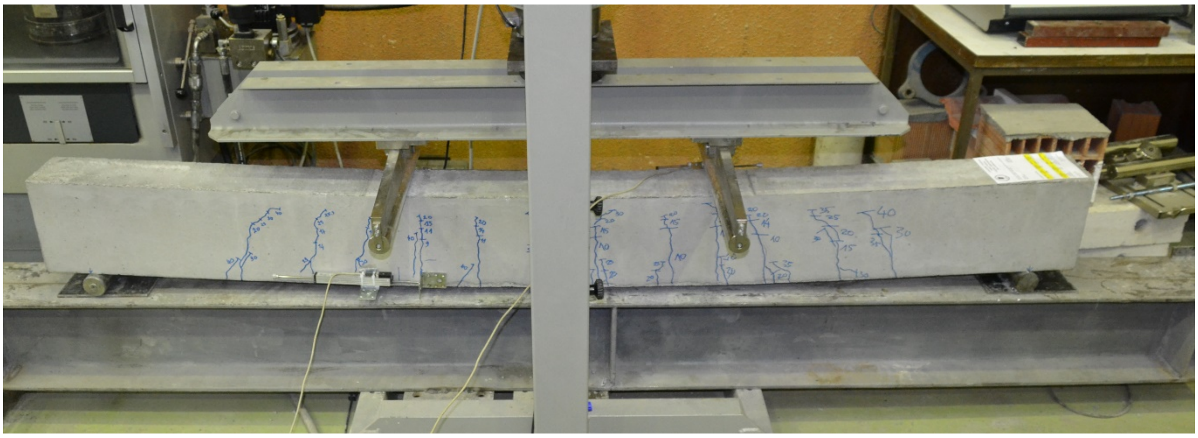

Figure 5: Four-point load.

Table 5. The load deflection behavior for all the beams

| Beams | | Codes | SLS % | "SLS" | | 75%-Ratio | | 100%-Ratio | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Cracks | Deflection | Cracks | Deflection | Crack | Deflection |
| S1 | Ø6 GFRP | ACI | 27.4 | 0.89 | 8.68 | 2.44 | 38.13 | 3.25 | 51.76 |
| | | CSA | | 0.89 | 11.16 | 2.44 | 38.17 | 3.25 | 51.58 |
| | | EC2 | | 1.33 | 6.12 | 4.06 | 35.86 | 5.45 | 49.82 |
| | | Exp. | | 0.73 | 7.57 | 2.91 | 44.8 | 3.81 | 44.90 |
| | | Exp2 | | 0.69 | 1.7 | 2.25 | 36.29 | 2.98 | 49.61 |
| S2 | Ø8 GFRP | ACI | 24.5 | 0.89 | 5.28 | 2.44 | 27.25 | 3.25 | 36.87 |
| | | CSA | | 0.89 | 7.4 | 2.44 | 27.38 | 3.25 | 36.84 |
| | | EC2 | | 0.69 | 4.5 | 2.33 | 26.22 | 3.12 | 35.96 |
| | | Exp. | | 0.71 | 8.29 | 2.91 | 43.25 | 3.81 | 48.31 |
| | | Exp2 | | 0.68 | 4.10 | 2.80 | 23.11 | 3.90 | 31.53 |
| S3 | Ø10 GFRP | ACI | 21.7 | 0.58 | 6.89 | 1.99 | 31.21 | 2.66 | 41.81 |
| | | CSA | | 0.58 | 8.31 | 1.99 | 31.22 | 2.66 | 41.77 |
| | | EC2 | | 0.61 | 6.75 | 2.2 | 30.73 | 2.94 | 41.4 |
| | | Exp. | | 0.31 | 8.30 | 1.54 | 39.87 | 2.04 | 46.61 |
| | | Exp2 | | 0.34 | 6.69 | 1.69 | 30.33 | 2.49 | 40.64 |
| S4 | Ø8 CFRP | ACI | 31.3 | 0.38 | 6.64 | 0.92 | 15.78 | 1.23 | 21.04 |
| | | CSA | | 0.38 | 6.23 | 0.92 | 15.63 | 1.23 | 20.92 |
| | | EC2 | | 0.49 | 5.52 | 1.20 | 15.31 | 1.61 | 20.68 |
| | | Exp. | | 0.70 | 8.06 | 1.86 | 22.50 | 2.59 | 32.22 |
| | | Exp. | | 0.38 | 8.30 | 0.60 | 18.50 | 0.79 | 28.43 |
| | | Exp. | | 0.34 | 8.29 | 0.87 | 22.80 | 1.27 | 33.42 |
| S5 | Ø10 CFRP | ACI | 33.7 | 0.35 | 3.98 | 0.78 | 8.92 | 1.05 | 11.89 |
| | | CSA | | 0.35 | 3.90 | 0.78 | 8.87 | 1.05 | 11.86 |
| | | EC2 | | 0.37 | 3.69 | 0.85 | 3.76 | 1.14 | 11.77 |
| | | Exp1 | | 0.29 | 8.29 | 0.76 | 21.06 | 1.07 | 30.19 |
| | | Exp2 | | 0.46 | 4.11 | 1.20 | 8.49 | 1.62 | 11.33 |
| | | Exp3 | | 0.30 | 3.91 | 0.70 | 9.02 | 0.93 | 12.03 |

## CONCLUSION

- At RC beams with GFRP bars is noticed that with increasing bar diameter, increases their bearing capacity and decreases their SLS, vice-versa at RC beams with CFRP bars is noticed that, with increasing bar diameter increases their bearing capacity and value of SLS
- The use of GFRP bars in the construction nowadays is difficult to achieve as a replacement of steel bars, due to the low modulus of elasticity and characterized by great deformations.
- The use of CFRP bars as a direct replacement of steel bars is difficult to achieve because of poor bonding with concrete. with the improvement of adhesive properties of concrete bars, from different manufacturers, the use of these bars can be increased because they have a relatively elastic modulus of steel
- The use of these bars at this stage is limited due to some properties that may be improved in the future by different manufacturers. These types of bars in general at this stage can be used for constructions that do not have rigorous SLS condition criteria. especially their full use instead of steel bars in skimmers subject to aggressive ambient conditions, such as salt water and so on.

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