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Concrete beams Flexural under sustained loading

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Abstract: *Steel reinforced concrete structures are susceptible to corrosion in severe environments. Corrosion limits the service life of structures, and results in expensive maintenance costs. GFRP composite bars are excellent alternative to steel bars for reinforcing concrete structures in severe environments. However, there is limited experience with the design and construction of GFRP reinforced concrete structures. This report investigates some parameters used in design of GFRP reinforced concrete members following the Eurocode 2 recommendations. A ratio of Agfrp bar reinforcement equal to 2% is recommended to a stabilization of the constraint in the bar. The compressed part of the concrete must be limited and does not exceed 40% useful height of the beam.*

Keywords: *GFRP Bar reinforcement, failure, Flexural design, Sustained loading*

K	Coefficient in consideration of non –linear stress distribution
$f_{ct.eff}$	Effective tensile just before cracking
fe	Allowable stress immediately after cracking
σ_{gfrp}	Characteristic constraint
ULS	Ultimate Limit State
SLS	Serviceability Limit State
γ_g	Regulatory safety coefficient
ε_g	GFRP bar deformation
ε_{gl}	Limit GFRP bar deformation
b	Width of concrete beam
d	Effective depth of cross section
h	Depth of the concrete beam
E	Modulus of elasticity of GFRP bar
M_{rc}	Resistant Moment concrete
M_{uls}	Moment with the Ultimate Limit State
μ	Reduced moment
N_c	Compressive force in the concrete
N_{gfrp}	GFRP bar traction effort
f_c	Stresses in the concrete
y_{ul}	Position of the neutral axis

I. Introduction

When considering a design utilizing GFRP Rebar, the differences in physical properties and performance characteristics must be taken into account. Of chief importance to the designer is the fact that all FRP's are linear elastic up to failure and exhibit no ductility or yielding. In traditional steel reinforced concrete design, a maximum amount of steel reinforcing has been specified so that the steel is the weak link in a structure. When weakened, the steel rebars stretch or yield and give a warning of pending failure of the concrete member. When using GFRP Rebars, ACI committee 440's design guidelines recommend a minimum amount of GFRP rebar rather than a maximum. If a member fails, the concrete will be the weak link and will crush in compression. The crushing concrete will serve as the warning of failure and there will still be ample reserve tensile capacity in the GFRP reinforcing. Another major difference is that serviceability will be more of a design limitation in GFRP reinforced members than in steel reinforced members. Due to its lower modulus of elasticity, deflection and crack width will affect the design. Deflection and crack width serviceability requirements will provide additional warning of failure prior to compression failure of the concrete. In many instances, deflection and crack width will control design. Detailed design guidance can be found in the American Concrete Institute publication "Guide for the Design and Construction of Concrete Reinforced with FRP Bars". Design Guidelines for GFRP Reinforced Concrete have been published [1,2,3,4].

Since the structural failure due to FRP reinforcing bar rupture is rather catastrophic, the over-reinforced design concept that ensures that compressive failure of concrete takes place prior to the tensile failure of FRP has been accepted [5,6,7].Nanni pointed out that, for FRP reinforced concrete beams, the balanced reinforced ratio, which is defined as the reinforcement ratio producing a condition for simultaneous failure of the concrete and the FRP reinforcing bar, is much lower than the practically adopted reinforcement ratio if the concrete is confined [8]. The modulus of elasticity of most available FRP materials is only 1/5 to 1/3 that of steel, which results in larger deflections as well as larger crack widths under service loads in comparison with those of its counterpart steel-reinforced concrete element for a given reinforcement ratio [9,10,11,12].

Strength and stiffness of a composite material are defined by the type, amount and orientation of the strengthening fibers. The fibers of Schock Combar are oriented linearly, resulting in the highest possible axial tensile strength, thus these GFRP bars remains linearly elastic up to failure. When the tensile strength of the material is exceeded, yielding does not occur. However, GFRP shows relatively low tensile and compressive strength perpendicular to the fibers [13].

Much research showed that same the decreases of 30% of the GFRP bars bond strength compared to steel does not affect the correct operation of the reinforced concrete [14,15]. Active efforts are also underway for a European Euro code 2 [16], under the efforts of FIB Task Group 9.3 "FRP (Fibre Reinforced Polymer) Reinforcement for Concrete Structures. The use of competent experienced engineering personnel should always be employed in the design and construction of concrete reinforced structures.

II. Experimental Study

2.1 Beam description

A total of six RC beam specimens of dimensions, 150 mm x 200 mm x 2000 mm, were fabricated with concrete cover of 20 mm. For the tensile reinforcement, two 12 mm diameter were used, and for the compressive reinforcement, two 8 mm diameter. Properties of the GFRP and steel bars used in this study and the details of beam cross-section are shown in table 1[17], and Figure 1.

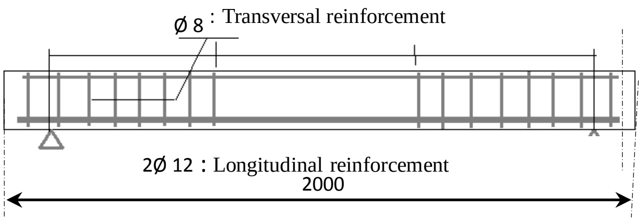

Fig. 1 GFRP bars reinforcement and Beam

2.2 Test set-up and instrumentation

The beams were subjected to sustained loads for a period of 30 days to compare under sustained loading the deflection of the beams reinforced with GFRP and steel bars in ambient laboratory condition. To simulate the sustained loading, beams were placed at one-four points us shown in Fig 2.

Fig. 2 Beam test instrumentation

The mid-span deflection was monitored by a Linear Variable Displacement Transducer (LVDT) with accuracy equal to 0.001mm, placed underneath the center of the beam. All the beams were tested simply supported at the age of 28 days under four-point loading.

Pure bending is a condition of stress where a bending moment is applied to a beam without the simultaneous application of axial, shear, or torsional forces. Pure bending is the flexure (bending) of a beam under a constant bending moment (M) therefore pure bending only occurs when the shear force (V) is equal to zero, since dM/dx= V

The schematic diagram of the testing arrangement of the beam is shown in Figure 3.

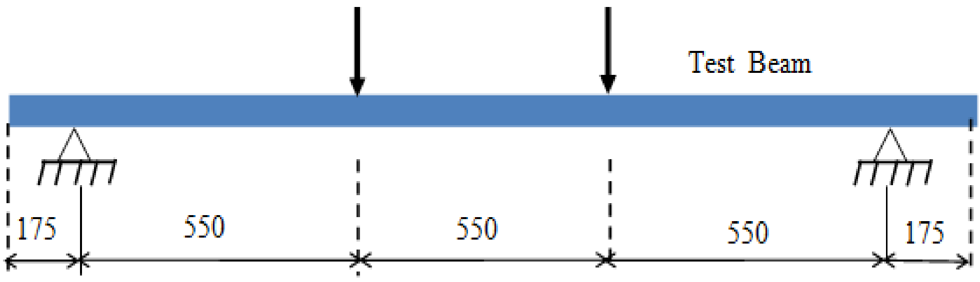

Fig.3 Schematic diagram of testing arrangement

III. Analytical Investigation

In this section we will investigate some critical parameters of EC2 code such as bending moment capacity, GFRP reinforcement ratio and internal strength in GFRP bars. These parameters are important in beam reinforced with GFRP bars because they have an important impact and directly effect serviceability behavior.

3.1 Regular design

The safety concept follows the rules of EC2 in line with concrete reinforcing steel, is based in the comparison between external load as a result of a certain stress and the resistance of a structural member. Both load and resistance are multiplied with different safety factors in order to determine the bearing capacity in the ultimate limit state (ULS) as well as in the serviceability limit state (SLS). An action “F” is subdivided into loads (G), live loads (Q), extraordinary loads (A) and temporary loads (e.g. during construction or installation). For the design application, the following values are distinguished: characteristic loads (Fk), representative loads (Frep) and design loads (Fd). The serviceability limit stat is determined by the characteristic or the representative loads respectively. Hence, the partial safety factors is $\gamma F = 1$.

3.2 Calculation in not very prejudicial cracking

We will study in this section the calculation of the longitudinal reinforcements which take again the traction effort in the tended zone. For the member subjected to the pure bending of rectangular section, the EC2 code envisages two justifications in two different states:

- A justification with the ultimate limit state (ULS)
- A justification with the serviceability limit state (SLS)

When cracking is considered to be prejudicial or very prejudicial, dimensioning will be with the SLS (Fig 4)

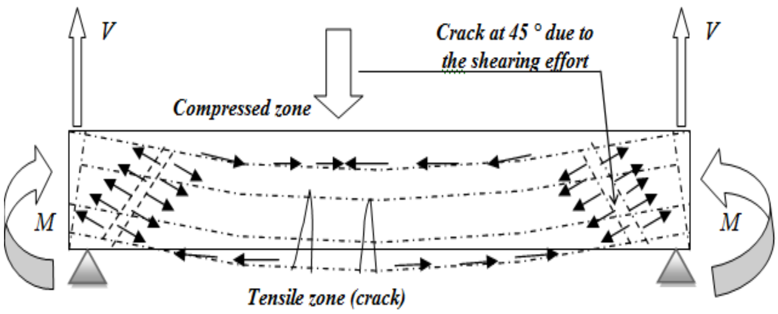

Fig. 4 Schematic of beam cracking

After loading until cracking we can observed that:

- The average fiber takes a form curves
- The deflection is maximum in the middle of the beam
- The top fiber shortened (compression)
- The bottom fiber lengthened (traction)

The bending moment causes cracks due to traction in the lower part of the beam. The shearing action causes cracks on the level of the supports. For that we must put in this beam longitudinal reinforcement which take again the traction effort in the tended zone, and transversal reinforcement which take again the sharp effort.

The dimensioning of the sections with respect to pure bending is carried out with the ultimate limit state by applying the diagram of the limiting deformations with the following assumptions:

- The cross-sections remain plane after deformation.
- There is no relative slip between the reinforcements and the concrete.
- The traction strength of the concrete is neglected because of concrete cracking.
- The diagram stress-strains of the concrete is defined with 3.5 ‰ like unit limit of shortening of the concrete.
- The diagram stress-strains of GFRP bars is defined with 15 ‰ like unit strain limit of GFRP bars.
- Distribution of the constraints in the concrete compressed according to the diagram simplified
- The compression or tensile stress of GFRP bars is such as:

$$\sigma_{gfrp} = \frac{f_e}{\gamma_g} \quad \text{if} \quad \varepsilon_g \leq 15 ‰$$

$$\sigma_{gfrp} = E_g \times \varepsilon_g \quad \text{if} \quad \varepsilon_g < \varepsilon_{gl}$$

For sections with a rectangular compression zone, design aids such as diagrams and monograms are commonly used. Corresponding values for designing with GFRP are available using the parabolic-rectangular diagram for concrete. The strain at any particular point in the section is linearly proportional to its perpendicular distance from the neutral axis. The strength of concrete is neglected and the compressive strength in concrete is accommodate to the corresponding σ-ε .Diagram.

That is to say a rectangular section width b_w, depth h , reinforced with a section A_{gfrp} of GFRP bars and subjected to an ultimate moment M_{uls} (Fig.5)

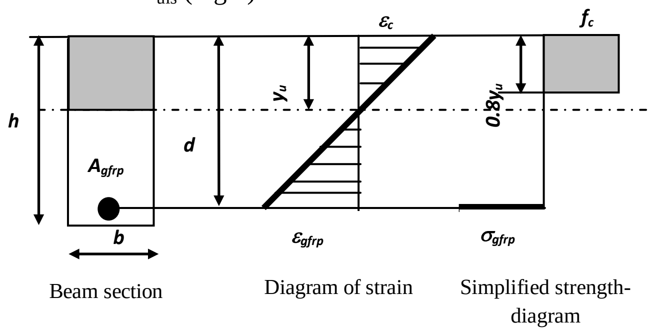

Fig. 5 Beam section and diagrams representation

The equilibrium equations give successively:

$$N_c = N_{gfrp} \quad \Leftrightarrow \quad 0.8 y_u \times b_w \times f_c = A_{gfrp} \times \sigma_{gfrp}$$

We posed yu = α.d $\Rightarrow$ z = d-0.4 α.d = d(1-0.4α).

Moment : $M_u = N_c \times Z$

When we substitute Nc and z we obtain

$$M_u = 0.8.\alpha.(1-0.4\alpha).b.d^2.f_c$$

We called reduced moment $\mu = 0.8\alpha \ (1-0.4\alpha)$

That implies $\mu = \dfrac{M_u}{f_c bd^2}$ and $\alpha = 1.25(1-\sqrt{1-2\mu})$ (1)

The rules of the limiting deformations imposed that the ultimate limit state is obtained either by excessive lengthening of GFRP bars (ε_{gfrp}=15 ‰) or by excessive shortening of the concrete ε_{bc}=3.5 ‰ (Fig.6)

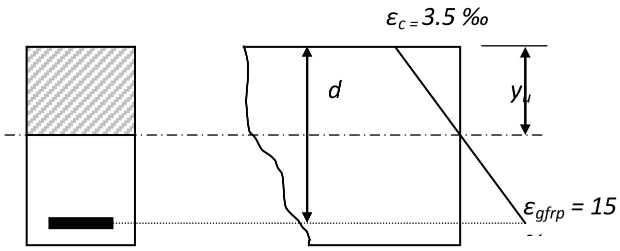

Fig.6 Beam section and diagram deformation

If we substitute yu = α.d, which gives α = 0.259 and consequently

$$\mu = 0.8\alpha\ (1 - 0.4\alpha) = 0.186$$

For α_{AB} =0.259 and μ_{AB} =0.186 the line of deformation passes by the points A and B.
Pivot A is reached for the values of $\mu \leq 0.186$

Situation 1 : $\mu \leq 0.186$
The rupture appears by excessive lengthening of the GFRP bars

$\varepsilon_{gfrp} = 15\ ‰$ σ_{gfrp}=fe/γs and $\varepsilon_c \leq 3.5\ ‰$

$\alpha = 1.25\,(1 - \sqrt{1 - 2\mu})$; $Z_b = d\,(1 - 0.4\alpha)$

and finally $A_{gfrp} = \dfrac{M_{uls}}{Z_b \times \sigma_{gfrp}}$ (2)

Situation 2 : $\mu > 0.186$

In this case, the concrete is used to the maximum, steel is under employee i.e., it works with less than 15 ‰. One will have to thus stick so that ε_{gfrp} lies between ε_e and 15 ‰.

The experiment shows that if GFRP bars works at a rate equal to or higher than 5.25 ‰. , the section of GFRP bars calculated with the ultimate limit state (ULS) does not require a checking with the serviceability limit state (SLS). In this case, the concrete is used to the maximum, GFRP bars is under employee i.e., it works with less than 15 ‰. One will have to thus stick so that ε_{gfrp} lies between ε_{gfrp} and 15 ‰.

The neutral axis yu is that whose deformation is zero.

The equation of the static moment is established compared to the neutral axis y_u . The solution of this equation gives the position of the neutral axis yu .

$$\frac{b.y^2}{2} + n.A's(y - d') - nAs\,(d - y) = 0 \qquad (3)$$

For this reason the majority of the reinforced concrete code recommends to limit the compressed part of the concrete in such way that the neutral axis y_{ul} does not exceed 40% useful height of the beam

$$\frac{3{,}5}{y_u} = \frac{5{,}25}{d - y_u} \Rightarrow y_u = \frac{3{,}5}{8{,}75}.d \qquad y_u = 0{,}4\,d$$

d = 0.9 h; yu ≤ 0.4 d ; $\frac{yu}{d} \leq \frac{0.4\ d}{d} = 0{,}4 = \alpha_{\text{limit}}$

μ_{limit} = 0.8. α_{limit}. (1-0.4 α_{limit})= 0,8.0,4.(1-0,4.0,4) =0.269

Thus we retains the limiting value of the moment reduces the value μ_{limit} = 0.269

Situation 3 : $0.186 < \mu \leq \mu$limit = 0. 269

In this case, it is not necessary to add compressed reinforcements.

The rupture appears by supercharging of the concrete.

$5.25\ ‰ \leq \varepsilon_s \leq 15\ ‰$; σ_{gfrp}=fe/γg and $\varepsilon_c = 3.5\ ‰$

Situation 4 : $\mu > \mu_{limit}$ = 0. 269

This calculation is to be carried out when it is impossible to increase the geometrical section of the beam

Dimensioning in prejudicial cracking

The dimensioning of the sections with respect to the inflection in the event of cracking prejudicial or very prejudicial is carried out with the serviceability limit state (SLS) by applying the following assumptions:

The cross-sections remain plane after deformation

There is no relative slip between steel and the concrete

Tensile stresses neglected in the concrete: only the steel which takes again the traction effort

We does not take account of the problem of the withdrawal and of creep, the concrete and steel are regarded as linearly elastic materials, which makes it possible to apply the forced relations deformations

We apply in calculations of steels the general method of the RDM: The beam is supposed in the elastic range. The reinforced concrete is not homogeneous; to use the resistance of materials, the diagram of the constraints must be linear. One will homogenize the section of the reinforced concrete beam:

We counts 15 times the GFRP section

$\varepsilon_{gfrp} = \varepsilon_c$ (not of relative slip)

Evolution of internal strength in GFRP bars versus GFRP reinforcement ratio

The internal strength GFRP bars is given by the follow equation:

$$\sigma_{gfrp} = \frac{0.8 \cdot f_c \cdot y_{ul}}{A_{gfrp}} \qquad (4)$$

With f_c Stresses in the concrete, y_{ul} the position of the neutral axis and A_{gfrp} reinforcement section

IV. Test Results And Discussion

4.1. Proportionality load/deflection

We took a series of measurement flexions for all six beams charged reinforced by steel and GFRP bars. We can notice for values weak of loading a linear variation load/deflection. The groups of dots as well as the linear behavior are represented by the figure 7.

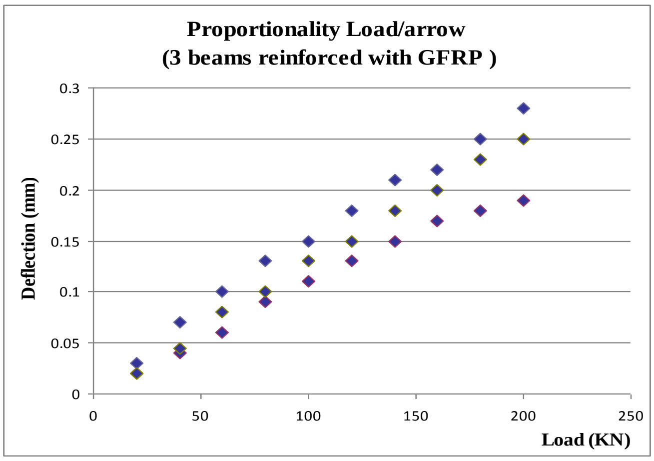

Fig. 7 Deflection versus load

4.2 Deflection variation versus time

We maintained loads constant for 30 days for both beams reinforced with steel and GFRP bars. We can notice that during 30 days, deflection of the two beams of steel and GFRP increases slightly in time. The beams reinforced with GFRP are less marked of creep phenomenon, since under a constant loading these beams present a variation of deflection less marked than those reinforced with steel bars. Figure 8

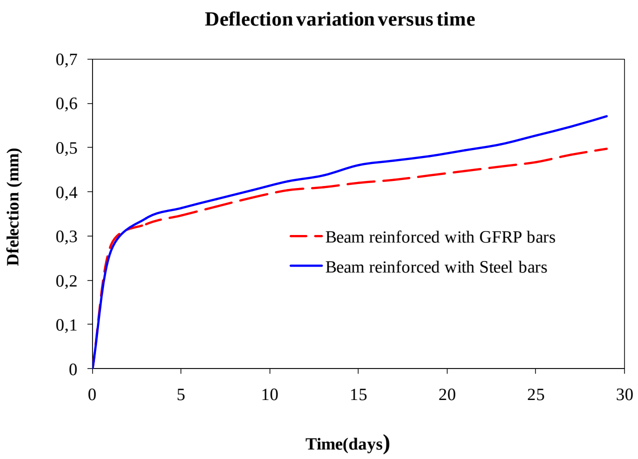

Fig. 8 Deflection variation versus time

4.3 Live load according to Mrc and the deflection

In comparison with the steel bars, the GFRP bars have a weaker modulus of elasticity, which leads to a larger deflection, with equal load and span. Consequently, in much of case, the serviceability limit state (the deflection) could control the dimensioning of a beam in bending. The live load was calculated in two manners. The first process was to calculate Q according to Resistant Moment concrete Mrc calculation and the second according to the deflection.

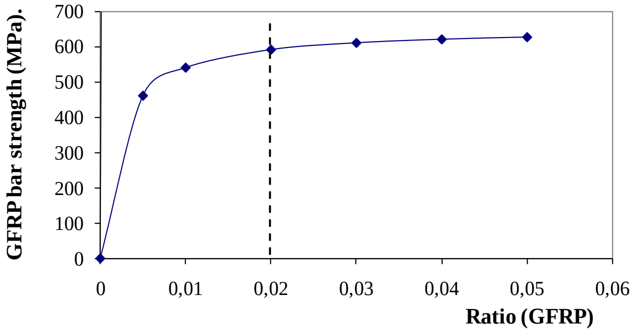

Fig. 9 : Evolution of the constraint versus GFP ratio

We can notice according to figure 9, that in two situations the deflection does not control dimensioning in bending. In the range of value of A_{gfrp} recommended (between A_{gfrp} and 1.2* A_{gfrp}). This value recommended (economic) corresponds to a stabilization of the constraint in the bar (0.02).

V. Conclusions

From the analytical and experimental investigation carried out, the following conclusions can be drawn:

- For values weak of loading, there is a linear variation load/deflection.
- Deflection of the two beams of steel and GFRP increases slightly in time.
- Beams reinforced with GFRP are less marked of creep phenomenon.
- The effect of sustained loading is more detrimental in beams reinforced with steel bars than in those with GFRP bars
- Deflection does not control dimensioning in bending. In the range of value of A_{gfrp} recommended (between A_{gfrp} and 1.2* A_{gfrp}). This recommended value (economic) corresponds to a stabilization of the constraint in the bar (Ratio = 0.02).
- The compressed part of the concrete in such way that the neutral axis yul must be limited and does not exceed 40% useful height of the beam

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References

[1] Design Guidelines for GFRP Reinforced Concrete (1997) published by the ASCE Journal of Composites for Construction (Aug 1997 Vol.1 No 3 ISSN 1090-0268 Coden: JCCOF2).

[2] ACI Committee 4401R-06, "Guide for the Design and Construction of Concrete Reinforced with FRP Bars, American Concrete Institute, Farmington Hills. Branson, , McGraw-Hill, New York, 1977, 546pp

[3] ACI Committee 435, “State-of-the-Art Report, Deflection of Two Way Reinforced

[4] Concrete Floor Systems,” ACI SP 43-3, Deflections of Concrete Structures, 1974, pp. 55- 8182/23. Berkeley: EERC. University of California, CA., USA

[5] Sonobe, Y et al, Design Guidelines for GFRP Reinforced Concrete building Structures (1997) Journal of Composite for construction , V 1 No 3 Aug pp. 90-113

[6] Theriault et al. (1198), Effect of FRP reinforcement ratio and concrete strength on flexural behaviour on flexural of concrete beams. Journal of Composite for construction , V 2 No 1 Feb. pp. 7-15

[7] Nanni.A (1993) Flexural behaviour and design of RC members using FRP reinforcement Journal of structural engineering V.119 No 11 Nov 1993 pp. 3344-339

[8] Nawy, E et al.(1971). Fiberglass reinforced concrete slabs and beams ASCE journal of the structural division V.97. N° ST9 pp. 2203-2215

[9] Nawy, E et al.(1997). Fiber glass reinforced concrete slabs and beams ASCE journal of the structural division V.103. N° ST2 pp. 421-428

[10] Faza, S et al (1993) Theoretical and experimental correlation of behavior of concrete beams reinforced with fiber reinforced plastic rebars. Proceeding of international symposium SP 138. A Nanni and C.W. Dolan. eds. American concrete institute Famington Hills, Mich, 1993, pp. 599-614

[11] Benmokrane et al. (1996) Flexural response of concrete beams reinforced with FRP Reinforceing bars ACI Structural Journal V.93 N°.1 1996, pp46-55

[12] Aboutaha R (2004) Recommended Design for the GFRP Rebar Combar®, Syracuse University, Department of Civil and Environmental Engineering, Technical report, sponsored by Schok Bauteile GmbH ,U SA

[13] Masmoudi A., (2010), Effet de la température et de l'eau sur les propriétés d'adhérence des barres polymères renforcées de fibre de verre avec le béton, Thèse de Doctorat ENIT Université Tunis el Manar, 176p

[14] ACI Committee 435, "Allowable Deflections", ACI Journal, Proceedings V. 65, No. 6, 1968, pp. 433-444.

[15] Bank L. et al. (2003). A Model Specification for Composites for Civil Engineering Structures. Construction and Building Materials,vol. 17(6-7), pp.405-437.

[16] EC2, Norme Européenne, Eurocode 2, (2008), Calcul des structures en béton, Partie1: règles générales et règles pour les bâtiments

[17] Schock Bauteil GmbH Combar (2006) Design Guideline for Concrete Structures Reinforced with Glass Fiber Reinforced Polymer following the Requirements of DIN 1045-1and EC2 Issued Germany.26p