RESEARCH ARTICLE OPEN ACCESS

Enhancing flexural strength of reinforced concrete beams using carbon fiber reinforced polymers (CFRP)

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ABSTRACT: Structural repair and rehabilitation of reinforced concrete structures is becoming an increasing important option for all deteriorated/damaged structures to restore, enhance the load carrying capacity and increase the life span of the structure. Some of the main reasons of structural strengthening are increase in dead and live load material aging and corrosion, mechanical damage, design and construction failures, modification of structure scheme and natural disaster due to earthquake and hurricanes. In that way, the present study aims at presenting the main properties of this new material as well as the design routines for flexural strengthening of reinforced concrete beams. Finally, a package-software developed into the MATLAB platform is presented, intending to generate a simple tool for the design using fiber reinforced polymers.
Keywords: Carbon fiber reinforced polymers, Flexural strengthening, Reinforced concrete.

Date of Submission: 07-05-2018 Date of acceptance: 22-05-2018

I. INTRODUCTION

Following NBR6118,every concrete structure must meet requirement of strength (security against rupture) and performance in service (full conditions of use, without damages that partial or completely compromise its use or safety) and durability (resistance to environmental influences) during its construction in order to ensure security against rupture, resist to environmental influences.

Nevertheless, the load capacity of the structures predicted in the design can be affected by some of the following reasons can be considered while predicting load capacity of structure.

- some of the loads can be inadvertently underestimated, still in project stage;
- architectonic projects, with great heights and free spans create more difficulties for design of the structural elements and thus increase the chances of errors;
- the utilization of slender elements in the more varied ways and with excessive flexibility, based on the advancement of materials technology and the use of high strength concrete and steel with high mechanical strength;

The items previously cited compete to configure, in a time not so far, structures with strength lower than the ideal. In such condition, the structure's performance is only re established through the implementation of strengthening. This procedure can be seen as a response to the problems of deteriorating structures, inadequate projects, problems in the construction phase and also in anticipation to the placing of additional loads on the structure. And more recently the external bonding of Carbon Fiber Reinforced Polymers (CFRP) using structural epoxy resin (Figure 1).

Since 1940, the fiber based composites have been applied to perform important functions in the field of the military engineering, aerospace, naval, rail and automobile industry (JUVANDES et al., 1996). Due to its satisfactory performance, they have come to occupy a prominent place in buildings, as a viable alternative in the strengthening of structures by the combination of polymers with carbon fibers.

The CFRP are appropriate for structural strengthening of concrete elements due to the high mechanical performance of carbon fibers, ease to application, increase of strength, and maintenance of the original section of the reinforced part. Its use has been significant in several countries like Japan,especially in applications related to problems caused by earthquakes.

Figure 1. Flexural strengthening of reinforced concrete beams

1.1. Fiber reinforced polymer

Fiber reinforced polymer is a composite material consisting of different phases.There can be one or several discontinuous phases embedded in a continuous phase. The discontinuous phase is the reinforcement consisting of fibers, which are strong and/or stiff and will give the composite its strength. The fibers are embedded in a matrix (continuous phase), which transfers load and protect them. They are bonded together with an either strong or weak interface. Both the reinforcement and the matrix are typically lightweight. FRP can consist of both organic and inorganic fibers and the most common FRP in structural engineering is glass (GFRP), carbon (CFRP) and aramid (AFRP) together with a bonding there moset resin epoxy, vinylester or unsaturated polyester. The fiber part is the largest volume part with about 60-70% of the composite. This is due to the fibers being the main stress bearing component while the thermo set resin (matrix or binder) is transferring the stresses between the fibers and protecting them. FRP´s strength lies in the load-bearing capacity due to all small fibers working together and they are extremely defect free orientation and microstructure.

Since the matrix (binder) is the stress transferring part of the composite, it will allow a smooth load transfer between broken or damaged fibers and adjacent intact fibers, and also between intact fibers. The matrix system also leads to decreasing local stress concentration and an increase of the unidirectional composite strength. It also protects the fibers mechanical damage and effects from the environment (Zoghi, 2013).

1.1.1. Review of literature

Externally bonded, FRP sheets are currently being studied and applied around the world for the repair and strengthening of structural concrete members.FRP composite materials are of great interest to the civil engineering community because of their superior properties such as high stiffness and strength as well as ease of installation when compared to other repair materials. Also, the non-corrosive and nonmagnetic nature of the materials along with its resistance to chemicals made FRP an excellent option for external reinforcement.

Research on FRP material for use in concrete structures began in Europe in the mid 1950's by Rubinsky and Rubinsky, 1954 and Wines, J. C. et al., 1966. The pioneering work of bonded FRP system can be credited to Meier (Meier 1987); this work led to the first on-site repair by bonded FRP in Switzerland (Meier and Kaiser 1991).Japan developed its first FRP applications for repair of concrete chimneys in the early 1980s (ACI 440 1996).By 1997 more than 1500 concrete structures worldwide had been strengthened with externally bonded FRP materials. Thereafter, many FRP materials with different types of fibres have been developed. FRP products can take the form of bars, cables, 2-D and 3-D grids, sheet materials and laminates.

With the increasing usage of new materials of FRP composites, many research works, on FRPs improvements of processing technology and other different aspects have been performed. Though several researchers have been engaged in the investigation of the strengthened concrete structures with externally bonded FRP sheets/laminates/fabrics, no country yet has national design code on design guidelines for the concrete structures retrofitted using FRP composites. However, several national guidelines (The Concrete Society, UK: 2004; ACI 440:2002; FIB: 2001; ISIS Canada: 2001; JBDPA: 1999) offer the state of the art in selection of FRP systems and design and detailing of structures incorporating FRP reinforcement. On the contrary, there exists a divergence of opinion about certain aspects of the design and detailing guidelines. This is to be expected as the use of the relatively new material develops worldwide. Much research is being carried out at institutions around the world and it is expected that design criteria will continue to be enhanced as the results of this research become know in the coming years.

Several investigators like Saadatmanesh et al., (1994); Shahawy, (2000) took up FRP strengthened circular or rectangular columns studying enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these columns.

Saadatmanesh et al. (1994) studied the strength and ductility of concrete columns externally reinforced with fibre composite strap. Chaallal and Shahawy (2000) reported the experimental investigation of fiber reinforced polymer-wrapped reinforced concrete column under combined axial-flexural loading. Obaidat et al (2010) studied the Retrofitting of reinforced concrete beams using composite laminates and the main variables considered are the internal reinforcement ratio, position of retrofitting and the length of CFRP.

Naaman et al. (2001)studied parameters influencing flexural response of RC beams strengthened using CFRP sheets. **Duthinh et al. (2002)**studied strength & ductility of RC beams wrapped with CFRP.

Referring to work carried out by **Naaman et al. (2001)**study was carried out. From the test results, it was observed that Carbon FRP plates are very effective for flexural strengthening of RC beams, provided proper anchorage of FRP is ensured.

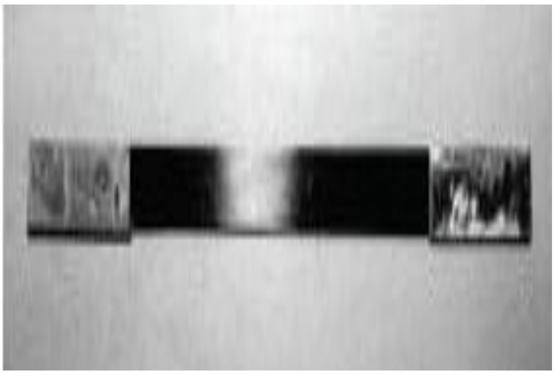
II. METHODOLOGY

2.1. Flexural strengthening using fiber reinforced polymers

The aim of the present study is to present the main mechanical properties of the carbon fiber reinforced polymers.The calculation routines needed for the design of flexural strengthening of concrete beams using the referred material are also presented, in order to demystify this process. At last, we also present a computer program conceived within the MATLAB platform, which aims to be a versatile tool for design the flexural strengthening of reinforced concrete beams by using the CFRP.

2.2. Strengthening system with CFRP and its mechanical properties

The carbon fiber composites to be used in buildings as a way of structural reinforcement of concrete elements can be found in two distinct forms of systems pre-fabricated and molded in loco. The pre-fabricated systems (Figure 2) are made by continuous layers of unidirectional fibers impregnated by resins, through a pultrusion process, controlling the thickness and width.



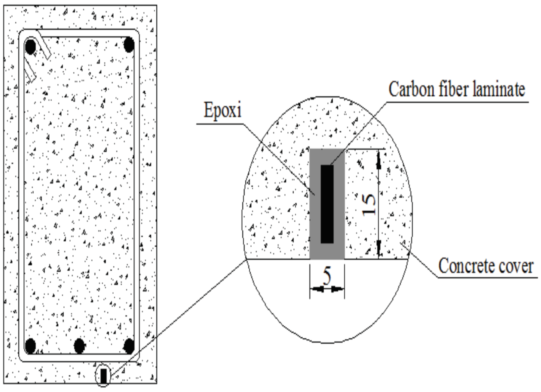
a) carbon fiber laminate

b) application of the laminate

Figure 2. Appearance and application of the carbon fiber laminate.

With rare exceptions, there is an omission as for the information about the average or expected mechanical properties of the composites. In most cases, it is only showed the presentation of the carbon fiber properties. Below are some properties of the pultruded composite, according to the manufacturer Sika Brasil S/A, listed in the technical catalog:

- Tensile strenght: 2,400 MPa;
- Modulus of elasticity: 155 GPa;
- Maximum deformation: 19‰;
- Thickness: 1.2 mm;
- Width: 50 mm;
- Cross section: 60 mm2;
- Density: 1,600 kg m-3;
- Usually applied in a single layer and on flat surfaces through thixotropic adhesives.



a) strengthening of beams

b) strengthening of corbels

Figure 3. Near-surface mounting fiber-reinforced polymer (a) of beams and (b) short corbels.

The blankets and tissues have been developed in the early 90's and in general have tensile strength and modulus of elasticity higher than the laminate at raw state, i.e., when not impregnated with epoxy adhesive. They also have advantages of being flexible, and can be applied involving structural elements. The blanket has carbon fibers in just one direction (unidirectional), while in the

tissue, the fibers are arranged in more than one direction. More recently, it has emerged another way of using the CFRP laminate for strengthening of beams; consisting in its insertion into slots made in the concrete cover as shown in Figure 3. The system uses carbon fiber laminates with small dimensions (about 10 mm width and 1.4 mm thickness) and it is known as the technique of polymer (FRP) bars/strips .

The technique is interesting to increase the resistant capacity of structural elements subjected to bending. The authors, on the other hand, have obtained a good performance of the technique on the strengthening of short corbels, where the shear is predominant ('D Regions').

The technique of inserting laminates into slots on concrete cover has been studied by some researchers with the purpose to improve the effectiveness in the use of laminate. The results so far have shown that this technique presents excellent behavior in relation to the resistant capacity, thermal effect, and especially as for the rupture mode, preventing the peeling-off effect.

2.3. Formulating the design for flexural strengthening

Afterwards, it is presented the main steps needed for flexural strengthening of reinforced concrete beams using CFRP, observing that future studies will

approach the reinforcements for other situations such as shear and torsion. Further information about strengthening using CFRP is found in Machado (2002), FIB (2000), ACI (1996, 2001a and b).

2.4. Flexural strengthening using fiber reinforced polymers

Initially, to decide on the need of strengthening, one should respond which is the maximum load that can be absorbed by reinforced concrete beam with its initial characteristics. Once observed the necessity of strengthening for the structural element to bending, i.e., if the ultimate bending of the beam is lower than the new demanded ultimate bending, then it is carried out the calculation of the required strengthening using carbon fibers, whether in the form of blankets or rigid bars.

The procedure for determining the maximum bending supported by the reinforced concrete beam is based on the use of simplified rectangular diagram for concrete and also considers the fundamental principles of strain compatibility, equilibrium and constitutive relations of materials (steel and concrete). The formulation described below is primarily based on the recommendations of NBR6118 (ABNT, 2003) and Hulse and Mosley (1986).

2.5. Maximum Bending Absorbed by the Reinforced Concrete Beam

The input parameters required for executing the proposed routine are: negative reinforcement (A's),positive reinforcement (As), effective height of negative reinforcement (d'), effective height of positive reinforcement (d); beam height (h); beam width (b); concrete characteristic strength to compression (fck), characteristic strength of steel to yielding (fyk), modulus of elasticity of the steel (Es),ultimate bending of strengthening (Muk). Once the input data are defined, then the routine can be conducted for determining the ultimate bending(Mud) supported by the beam.

a) Initially it is assumed a value for the neutral axis depth x, which should vary incrementally from the effective height of the negative reinforcement (d') up to the effective height of the positive reinforcement (d).
b) From the value specified for x, it is possible to calculate the strains in the compressed reinforcement (ε sc), in the tensile reinforcement (εst), and in the compressed concrete (εcu), as illustrated in Figure 4 and following expressions that consider the strains prescribed in NBR6118 S(ABNT, 2003):

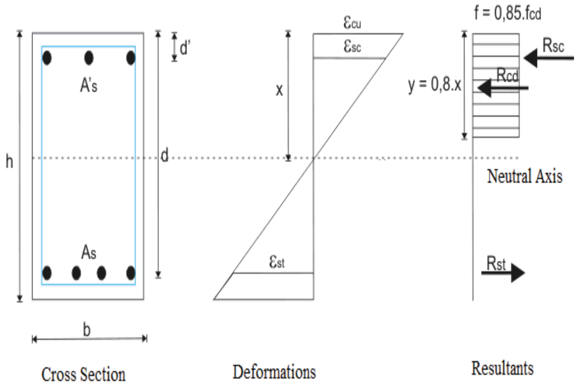


Figure 4. Compatibility of strains and resultants of stresses in reinforced concrete beams

If x ≤ 0.259.d →Ultimate Limit State in domain2(1)

$\varepsilon cu = 0.010x/(d-x) \leq 0.0035$ (1.a)

$\varepsilon sc = (x-d').0.010/(d-x)$ (1.b)

$\varepsilon st = 0.010$ (1.c)

If 0.259.d < x ≤0.628.d → ultimate limit state in domain 3 (2)

$\varepsilon cu = 0.0035$ (2.1)

$\varepsilon sc = (x-d').0.0035/x$ (2.2)

$0.00207 < \varepsilon st = 0.0035/x \leq 0.010$ (2.3)

If $x > 0.628.d$ → ultimate limit state in domain 4 (3)

$\varepsilon cu = 0.0035$ (3.1)

$\varepsilon sc = (x-d').0.0035/x$ (3.2)

$\varepsilon st = 0.0035(d-x)/x < 0.00207$ (3.3)

c) From the stress-strain diagram of the steel, it is possible to determine the stresses acting on the compressed (σ sc) and tensile reinforcement (σst),according to the following expressions: (4)

$\sigma sc = Es.\varepsilon sc \;\; for \;\; \varepsilon sc \leq \varepsilon yd = fyd/Es$ (4.1)

$\sigma sc = fyk/\gamma s = fyd \; for \; \varepsilon sc > \varepsilon yd$ (4.2)

$\sigma st = Es.\varepsilon sc \; for \; \varepsilon sc \leq \varepsilon yd = fyd/Es$ (5.1)

$\sigma st = fyk/\gamma s = fyd \; for \; \varepsilon sc > \varepsilon yd$ (5.2)

d) according to above stresses, it is calculated the resultant of compressed concrete (Rct) above the neutral axis depth, as well as the resultant of tensile steel (Rst), below the neutral axis, as the following expressions:

Rct= $Rcd + Rsc$ (6)

Rcd $= 0.85fcd.b.0.8.x = 0.68.fcd.b.x$ (7)

Rsc= $A's.\sigma sc$ (8)

Rst= $Rsd = As.\sigma st$ (9)

e) If the resultants of concrete compression (Rct) and tensile steel (Rst) are not equal, admitting a certain level of tolerance (error), then we return to step (a), and the process is repeated until obtaining the equality in these resultants. When achieved this equality, we proceed to step (f);

f) The ultimate bending of the beam (Mud) is obtained by taking the moment resultants around the tensile reinforcement, as the following expression:

Mud =0.68.fcd.b.x(d -0.4.x) +A’s.$\sigma sc.(d-d')$ (10)

g) If the ultimate bending of the calculation obtained (Mud) is higher than the bending for which is questioned the reinforcement (Mur), the beam does not need flexural strengthening. Otherwise, the beam needs flexural strengthening it is necessary to follow the routine described in details in the next section.

2.6. Design of the flexural strengthening with CFRP

Once confirmed the need of flexural strengthening, then it is necessary to define the type of strengthening will be adopted, i.e., blanket or bars of CFRP. In this way, one can define the limit strains for the fibers (□εf,limite), as well as the modulus of elasticity of the used material (Ef),needed to determine the reinforcement area. Besides that, it is necessary to inform the characteristic maximum bending due to the self weight of the beam (Mgk), since there will be necessary to subtract it from the fiber total strain the specific strain caused by the load when applying the reinforcement.

The methodology proposed is basically a hybrid formulation between the proposals of Machado (2002) and GangaRao et al. (2006), always aiming at obtaining a reinforcement of minimum area that lead to a situation of ductility at ultimate limit state, i.e., rupture of the concrete simultaneously with the yielding of the reinforcements and suitable level of strain for the carbon fiber. The procedure is described below and the equations of equilibrium and compatibility are obtained from the Figure 6:

a) Initially one must calculate the height of the neutral axis depth (xg) for the isolated action of the maximum bending caused by permanent loading (Mgk), as follow :

$$xg = 1.25.d\left[1 - \sqrt{1 - \frac{\gamma_f.M_{gk}}{0.425.b.\gamma_C}}\right] \quad (11)$$

with $\gamma_f = \gamma c = 1.4$

b) Once calculated the height of the neutral axis for permanent loading, the strain in the tensile reinforcement (ε_{stg}), in the compressed concrete (ε_{cg}), in the tensile carbon fiber (ε_{fg}) and in the compressed reinforcement (εscg) are determined, as follows:

$$z = d - 0.4.x_g \quad (12)$$

$$Fs = Mgk/z \quad (13)$$

$$\sigma st = Fs/As \quad (14)$$

$$\varepsilon_{stg} = \sigma st/Es \quad (15)$$

$$\varepsilon_{cg} = (\varepsilon_{stg}.xg)/(d - xg) \quad (16)$$

$$\varepsilon fg = (\varepsilon cg/xg).(h - xg) \quad (17)$$

$$\varepsilon_{scg} = ((xg - d')/xg).\varepsilon_{cg} \quad (18)$$

c) It is assumed a value for the neutral axis depth x, which should vary incrementally from the limit of the domains 3 and 4 (x34 = 0.628.d) to the limit of the domains 2 and 3 (x23 = 0.259.d), since it is intended to obtain a balanced reinforcement. In this way, it is possible to obtain an economic design for the ultimate limit state, with the yielding of tensile reinforcements and the rupture of the compressed concrete;

d) Then, regarding the assumed value of x, it is calculated the strains, the stresses and the resultants for both concrete and reinforcements employing all the expressions in the interval from (1) to (9);

e) In the sequence, it is calculated the maximum stress allowed for the carbon fiber (σuf) based on the specification of the limit stress of the composite material (ε f,limite). Regarding the stresses calculated in the section (d), one should calculate the active stress (εff) and effective stress on the carbon fiber, taking into account the initial stress due to its self weight (εfg). Finally, it is calculated the stress acting on the carbon fiber (σfe):

$$\sigma_{fu} = E_F.\varepsilon_{f,limite} \quad (19)$$

$$\varepsilon_{ff} = (\varepsilon_{cu}/x).(h-x) \quad (20)$$

$$\varepsilon_{fe} = (\varepsilon_{ff} - \varepsilon_{fg}) \quad (21)$$

$$\sigma_{fe} = E_f.\varepsilon_{fe} \quad (22)$$

f) After that, are calculated the resultant forces on the carbon fiber, considering the sum of moments around the positive reinforcement, around the negative reinforcement and around the resultant of compressed concrete. The tensile force in the carbon fiber (Rfc) is taken as being the highest value among the three previous resultants, as follows:

Rf1 = (Mur - (Rsc.(d – d') +Rcd.(d – 0,4.x)))/(h – d)

Rf2 = (Mur - (Rst.(d – d') – Rcd.(0,4.x – d')))/(h – d')

Rf3 = (Mur - (Rsc.(0.4.x – d') + Rst.(d – 0.4.x)))/(h – 0.4.x)

$$Rf \geq \begin{cases} Rf1 \\ Rf2 \\ Rf3 \end{cases}$$

g) Once known the resultant force in the carbon fiber (Rf) it is possible to calculate the amount of fiber required for the reinforcement (Af):

$$Af = (Rf / \sigma fe) \quad (23)$$

h) When the reinforcement area is determined, it is calculated the final position of the neutral axis depth (xnew), as follows. If the new value of x coincides with the value of x specified in item (a), considering a certain tolerance, the process can be ended, and the reinforcement area is determined. Otherwise, the process should be repeated from the item (a), taking as a value of x in the section (a) the height of the neutral line found in the item (xnex). The process is iterative and usually has rapid convergence.

$$x_{new} = ((As.\sigma st) + (Af.\sigma fe) - (A's.\sigma sc)) / (0.68.b.fcd) \quad (24)$$

If $x = x_{new}$ ⟶ The process converged

If $x \neq \neq x_{new}$ → → $x = x_{new}$ Back to item (a) for a new iteration

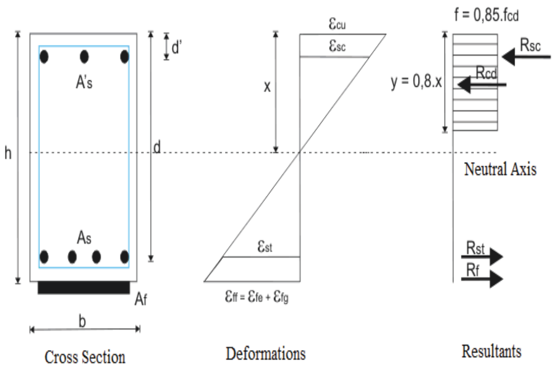


Figure 5- Compatibility of strains and resultants of stress in reinforced concrete beam strengthened with CFRP.

III. VALIDATION

Validation of the results of the present investigation has been made with that of the research results of the flexural strengthened beam by Machado (2002) and results obtained using the program developed in MATLAB.

3.1. Validation results

Table.1: Input Data

Input Data	
Beam height, h	69.00cm
Beam width, b	20.00cm
Negative reinforcement A's	1.60 cm2
Effective height of –ve reinforcement d'	2.50cm
+ve reinforcement As	9.45cm2
Effective height of +ve reinforcement, d	65.00cm
Fck	2.00Kn/cm2
Fyk	50.00Kn/cm2
Modulus of elasticity of steel Es	21,000Kn/cm2
Modulus of elasticity of fibre Ef	22,800Kn/cm2
Limit strain for carbon fibre εf, lim	14.00
Mgk	29.00Knm
Mur	206.00Knm

Table.2: Resultant Forces

Resultant Forces	Values(kn)
Positive reinforcement	410.8
Negative reinforcement	69.21
Compressed concrete	428.11

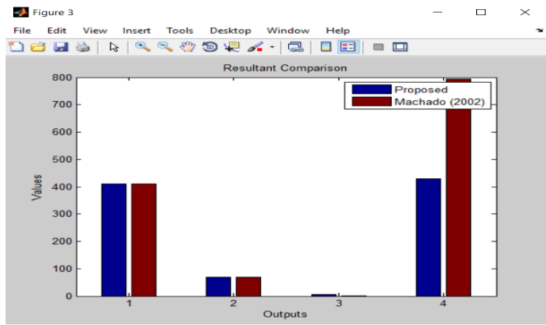


Fig.6-Resultant force comparison, Obtained resultant forces for positive reinforcement, negative reinforcement and compressed concrete are 410.8, 69.21, 428.11 respectively as shown in blue bar

Table.3:Calculated strains

Strains	Values
Total strain in concrete	3.55
Strain in negative reinforcement	3.16
Strain in positive reinforcement	6.79
Maximum allowed strain	14

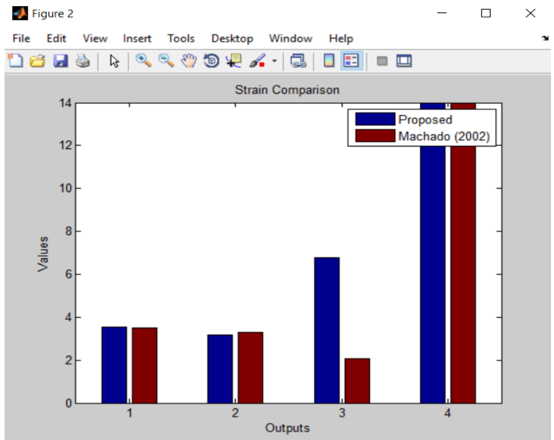


Fig.7-Strain comparison

Strain in concrete, strain in negative reinforcement, strain in positive reinforcement, maximum strain allowed for fibre obtained from MATLAB code are 3.55, 3.16, 6.79, 14 respectively.

Table.4: Different outputs of designed methodology

Output	Values
fibre reinforcement area	0.55cm2
no of iterations	11
estimated height of neutral axis	31cm
total strain in carbon fibre	7.82
effective strain in carbon fibre	7.28

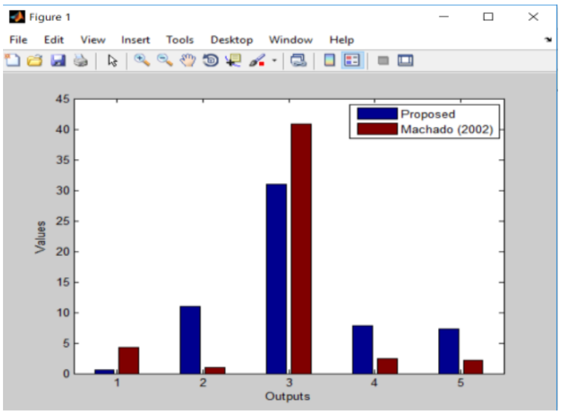


Fig.8- Different parameter comparison, Calculated fibre reinforcement area, no of iterations, estimated height of neutral axis, total strain in carbon fibre and effective strain in carbon fibre are 0.55cm2, 11, 31, 7.82, 7.28

Basically the calculation routines presented in the previous sections have been programmed into a M-file, in order to achieve greater productivity in the iterative process, needed for determining the areaof carbon fiber reinforcement for reinforced concrete beam with flexural deficiency.

As one can see by the processing, the area of reinforcement required provided by the programcreated is 0.55 cm2, while the amount specified by Machado (2002) was 0.58 cm2. In this way, it is observed a good performance of the program created, with the advantage that the process is faster, accurate and provides all the information necessary about the forces and strains acting on the materials.

IV. ANALYSIS OF RESULT

Table.5: Second Input Data

Beam height, h	70.00cm
Beam width,b	20.00cm
d'	2.50cm
As	10 cm^2
A's	2.00cm^2
D	66cm
Fck	2.5Kn/cm^2
Fyk	50Kn/cm^2
Es	21,000Kn/cm^2
Ef	22,800Kn/cm^2
Limit strain for CFRP	14
Mur	206.00Knm
Mgk	31knm

Table.6: Resultant forces

Resultant Forces	Values(kn)
Positive reinforcement	408.5
Negative reinforcement	67.11
Compressed concrete	426.23

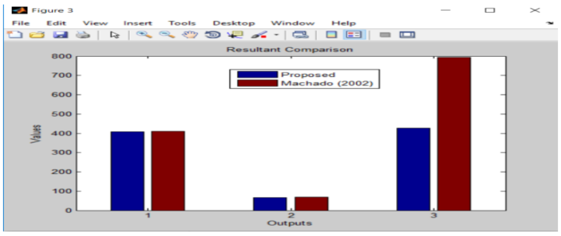


Fig.9- Resultant force comparison

Obtained resultant forces for positive reinforcement, negative reinforcement and compressed concrete are 408.5, 67.11, 426.23 respectively as shown in blue bar.

Table.7:Calculated strains

Strains	Values
Total strain in concrete	4.15
Strain in negative reinforcement	3.86
Strain in positive reinforcement	5.49
Maximum allowed strain	14

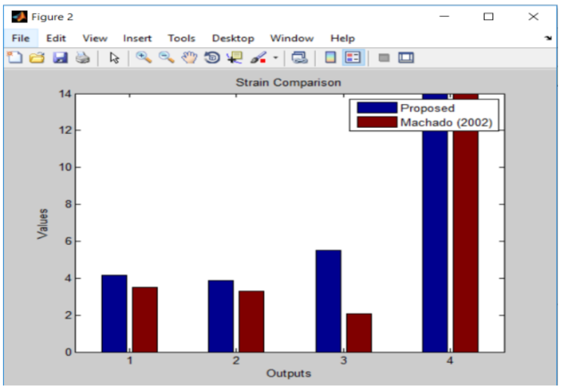


Fig.10. Strain comparison

Strain in concrete, strain in negative reinforcement, strain in positive reinforcement, maximum strain allowed for fibre obtained from MATLAB code are 4.15, 3.86, 5.49, 14 respectively.

Table.8: Different outputs of designed methodology

Output	Values
fibre reinforcement area	0.58cm2
no of iterations	11

estimated height of neutral axis	35
total strain in carbon fibre	8.2
effective strain in carbon fibre	7.00

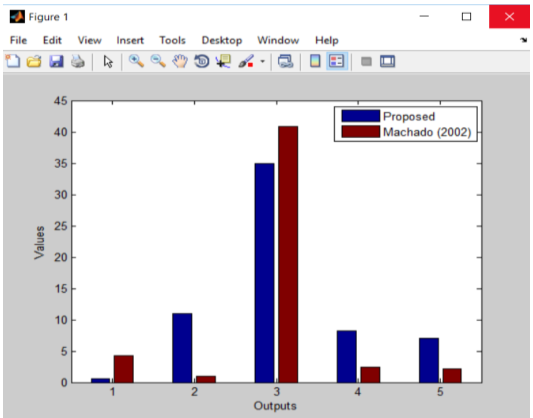


Fig.11- Different parameter comparison and again to analyse the effectiveness of the methodology the developed MATLAB code has been tested for another input data. And the area of reinforcement provided by the programme is0.58cm^2.

Calculated no of iterations, estimated height of neutral axis, total strain in carbon fibre and effective strain in carbon fibre are 11, 35, 8.2, 7.00.

Basically the calculation routines presented in the previous sections have been programmed into a M-file, in order to achieve greater productivity in the iterative process, needed for determining the area of carbon fiber reinforcement for reinforced concrete beam with flexural deficiency.

As one can see by the processing, the area of reinforcement required provided by the program created is 0.55 cm2, while the amount specified by Machado (2002) was 0.58 cm2 . In this way, it is observed a good performance of the program created, with the advantage that the process is faster, accurate and provides all the information necessary about the forces and strains acting on the materials

V. CONCLUSION

The FRP have become an optimal alternative for the strengthening of structural elements undergoing resistance deficiencies. When compared with other options for strenghtening, such as addition of bars or plates of steel, the carbon fibers present several advantages like economy, ease of application, lower weight and higher durability. Nevertheless, there is some difficulty on the required procedures for using this material.

The present study aimed to present the main characteristics of the carbon fiber and the process of design of the reinforcement using this material for reinforced concrete beams with flexural deficiency. In addition, an specific program implemented in the MATLAB package has been developed in order to optimize the iterative processes usually required for this type of analysis.

The initial results are very encouraging, regarding the obtaining of a tool versatile and simple to use, attractive to increase the use of carbon fibers as an alternative of strenghtening.

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Himanshu S. Panda "Enhancing flexural strength of reinforced concrete beams using carbon fiber reinforced polymers (CFRP)"International Journal of Engineering Research and Applications (IJERA) , vol. 8, no.5, 2018, pp.35-44