Use of carbon fibbers for strengthening of the reinforced concrete structures

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ABSTRACT

The need for structural rehabilitation of concrete structures all over the world is a well known problem and a great amount of research is going on in this field. There can be many reasons for strengthening such as increased loads, design and construction faults, change of structural system, and so on. Economic comparison between the cost of a full or partial replacing to a building and the intervention of a localized reinforcening makes us give the priority to the second solution, for reasons like the urban connections, the architectural effects, the natural landscapes etc. All these reasons, have pushed the world of technological research to establish new technics for reinforcening the structures with new composite materials, mainly reinforced with fibers of different nature.

Composite materials heard otherwise with the abbreviation FRP consist in continued fibers enclosed in a matrix (adhesive substances) of polymers origin. Carbon fibers represent a resistant element toward external loads and actions, while the polymer composition has the mission to transfer constraints in fibers and between fibers and also protects them from the surrounding environment. The use of CFRP is a competitive method both regarding structural performance and economical aspects which refers to the bonding of a thin carbon fiber laminate or sheet to the surface of the structure in order to act as an outer reinforcement layer.

Mechanical properties of composites depend on several different factors like the mechanical properties of the carbon fibers themselves, their nature and the technic used to manufacture them.

Composite materials provide high resistance to traction, excellent resistance to corrosion and a low specific weight so for they are widely used in the construction field, on reinforced concrete elements, masonry, wood, steel.

In this study article will be also shown a numerical implementation of designing a beam in flexing, reinforced with carbon fibers.

INTRODUCTION

Concrete is a building material with a high compressive strength and a poor tensile strength. A structure without any form of reinforcement will crack and fail when subjected to a relatively small load. The failure occurs in most cases suddenly and in a brittle manner. To increase a structure load carrying capacity and ductility it needs to be reinforced. This is tradicionaly done by reinforcing with steel bars that are placed in the structure before the concrete is cast. Since a concrete structure usually has a very long life the demands on the structure will normally change over time. The structures may have to carry larger loads at a later date or meet new standards, in extreme cases a structure may need to be repaired due to accidents, other reason includes errors made during the design or construction phase so that the structure needs to be strengthened before it can be used.

As we move into the twenty-first century, the renewal of our lifelines becomes a critical issue. To keep a structure at the same performance level it needs to be maintained at predestined time intervals. If lack of maintenance has lowered the performance level of the structure, need for repairing up to the original performance level may be required. In cases when higher performance levels are needed, upgrading can be necessary.

Performance level means load carrying capacity, durability, function or aesthetic appearance. Upgrading refers to strengthening, increased durability and change of function or improved aesthetic appearance.

In this paper, we will mainly base in strengthening discussion, because maintenance, repair and strengthening of old concrete structures are becoming increasingly common. If one considers the capital that has been invested in existing infrastructures, then it is not always economically viable to replace an existing structure with a new one. The challenge must be taken to develop relatively simple measures to keep or increase a structure performance level through its life. There are difficulties in identifying the most suitable method for an actual subject and because of this, it is important to analyse the problem to thoroughly be able to select the most suitable method. The choice of an inappropriate repair or strengthening method can even worsen the structure's function. In comparison to building a new structure, strengthening an existing one is often more complicated since the structural conditions are already set. Traditional methods such as different kinds of reinforced overlays, shotcrete or post tensioned cables placed on the outside of the structure normally need much space. In recent years the development of the composite materials repairation techniques, as above mentioned, has been shown to be applicable to many existing strengthening problems in the buildings, industry etc. The carbon fiber technique may be defined as one in which composite sheets, strips or plates of relatively small thickness are bonded with an adhesive (epoxy) to a concrete structure to improve its structural behaviour and strength. The sheets or plates do not require much space and give a composite action between the adherents. The old structure and the new bonded-on material create a new structural element that has a higher strength and stiffness than the original one.

The basic ideas related to the use of CFRPs (Carbon Fibre Reinforced Polymers) for structural strengthening, along with examples of application, have been presented by Triantafillou, since 1998. The most common way to strengthen structures method is to place sheets or laminates on the damaged surface of the structure and most of the researches has been undertaken to study flexural strengthening and confinement but also in these last years presented tests are furthermore a contribution on concrete members strengthened for increased shear capacity.

1.What are carbon fibre and why are they so firm ?

Basically they are lamineas (or yarns) composed by fibres of carbon which cling to structure with a special adhesive material (matrix/resin). As the name shows Carbon is the main component in carbon fibre. It has many states of aggregation, among others soft graphite and the world's hardest material, diamond, where each atom is tightly linked with four surrounding atoms. Owing to carbon's hexagonal crystalline structure carbon fibre's carbon molecules are attached to each other with strong covalent bonding during the manufacturing process, thus forming solid atomic levels.

Lamineas (yarns) have e thickness of *1.2-1.4 mm* and a tensile resistance over *28000* daN/cm^2 ,working mostly in the elastic phase and having a fragile type (not ductile) degradation. The ultimate deformation at the time of destruction is about *1.8%*.

Carbon fibers can be available as cables or flat ribbons/strips (*Figure 1;3a;3b)* with parallel fibers (the number of every single filaments in the cable is approximately 1000-2000), or as in the form of unidirectional sheet (*Figure 2)* .

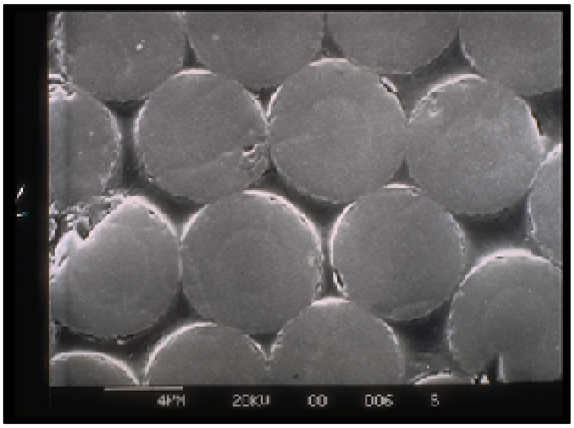

Figure 1

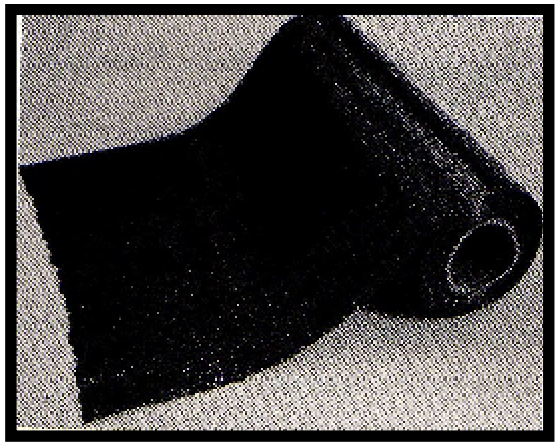

Figure 2

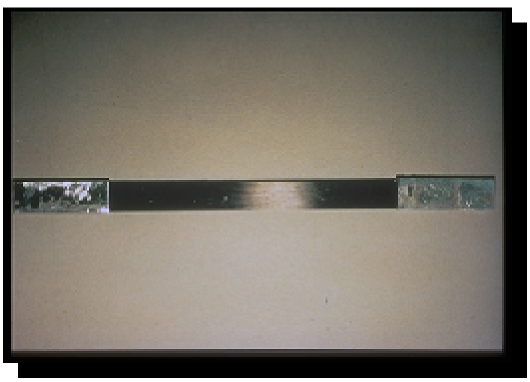

Figure 3a

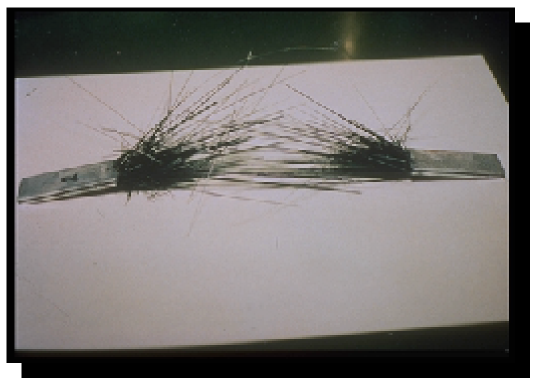

Figure 3b

Mechanical properties of carbon fibres:

Modulus of elasticity	*290-400 Gpa*
Tensile resistance	*2400-5700Mpa*
Ultimate Elongation	*0.3-1.8%*

Their *modulus of elasticity* depends on the carbon fibers type (*Figure 4)* .

So we have,

- *type S* (E > 1.600.000 daN/cm^2)
- *type M* (E > 2.100.000 daN/cm^2)

– *type H* (E > 3.000.000 daN/cm^2)

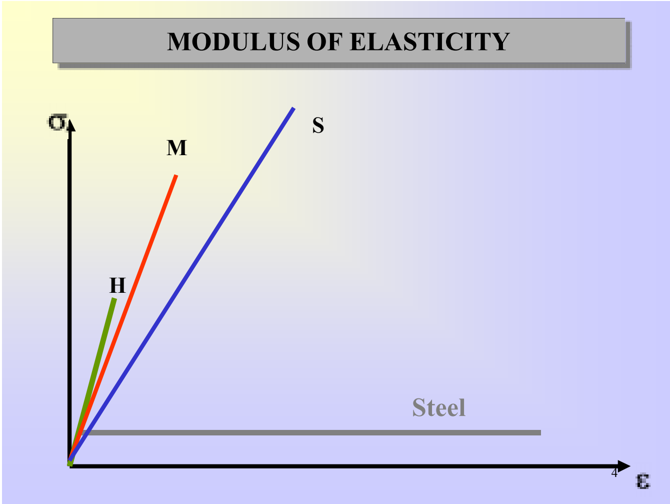

Figure 4

2.Adhesive material (Resine or Matrix Polymer)

Resin/matrix polymer are widely used to produce composite structural elements and it is an insatiate poliester. The matrix polimer with the help of its attribute in shear strength , it must allow the transmission and the distribution of forces and stains in fibres, beside this it protects the fibres from the physi-chemical actions of the outside environment and exercising so a restrictive action necessary to oppose the loss of stability from point loads.

3. Where are carbon fibres used ?

Carbon fibers as mentioned are used for strengthening or reparation of existing structures. Strengthening of existing structures may be necessary for the following reasons:

¬ the constituent materials of the structure are obsolete

¬ the structure is damaged by accidental factors, mentioned here fire, vehicles, corrosion etc.

¬ the increased temporary loads (ex. placing of the heavy devices in industrial units, the increased traffic loads on bridges, etc.)

¬ the architectural changes made, which have led to structural changes

¬ mistakes made in designing

Carbon fibers are used in RC(reinforced concrete) elements in bending also in pre-stressed RC elemets. In these elements the role of carbon fibers is to increase the bearing capacity as well as against the tensile moment and to the shearing forces.Carbon fibers are also used for strengthening the RC columns. Carbon fiber are also used in elements of wood, steel, in different masonry strengthening, and in many other engineering fields.

4. What problems are solved with carbon fibres?

From the structural standpoint they solve these problems:

¬ Increased load can afford betonarme elements (beam, roof, columns, etc.)

¬ Reduction of deformation

¬ Limiting the size of the cracks

¬ You can not solve problems in printing due to work only in traction fibers

5. The general application technic

Structural strengthening of RC elements is accomplished through the application of one or in other cases of more layers of strips or sheets of fibers, to be attached directly to the structure to be strengthened, in the conditions of a possible maximum discharge of permanent/dead load and in the absence of live loads. If the surface where we must put the carbon fiber is very damaged and disordered then you should first fill the holes with special mortar until we achieve a surface as flat and polished.

Concrete surface must be cleaned with special cleaners. After that, the cleaned surface will be painted with resin until we create a layer 1mm thick. We cut the package of carbon fiber to the desired length then this package is lied on a table and cleaned with a specific solucion. Over the concrete surface we apply a second hand of adhesive until you reach a 1-2mm thickness. Within the required time (avoiding the adhesive to dry) we stick the package of carbon fibres compressing them with a roller, until the adhesive comes out from the both sides of the package.(*Figure 5a;5b*) The excess resin that comes out during the compression on both sides of the carbon fiber package should be cleaned and after this it should be left to rest until the resin is completely dried and hardened. As a final check it's accomplished a prod with an appropriate hammer on the sticked laminates to see that no gaps are created during the attachement and the hardening process. Packages of carbon fibers can be painted or plastered. (*Figure 6*) One of the main important things is to respect all the rules of technical safety at work. So since the worker must work with chemical substances and materials, he must be equipped with groves, goggles, protecting clothing etc. Implementation of carbon fiber attachment must be performed in an element with temprature from +5 to +70 Celcius degrees otherwise, if this limits are overpassed, the attachment process is not allowed. For this reason, that part of the element which will be reinforced, should be heated before and 48 hours after the adhesion process. Surface where adhesion will be accomplished must be completely dry.

Figure 5a and 5b. The adhesion process of carbon fiber strip on the cleaned concrete surface

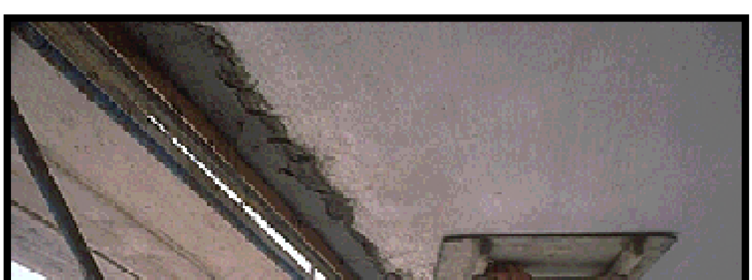

Figure 6. The plastering process of the element reinforced with carbon fibers

6. Textures of carbon fibres

As it is noticed in the first chapter of this article, carbon fibers can be produced also in the form of an unidirectional sheet (*Figure 2)* as a texture, which can work in both directions. Textures are recommended in these cases:

¬ for reinforcement of beams against shear forces

¬ for clothing columns with rectangular and circle section

¬ for reinforcement of elements with non-flat surface

A RC column needs to be reinforced after the building has changed the purpose of use. For this reason the column is clothed with a carbon fiber texture. (*Figure 7a;7b)*

Figure 7a and 7b. The process of ctothing the columns with carbon fiber texture

7. Advantages of the carbon fibres strips and textures use

In comparison with other materials, use of carbon fibers, or the texture carbon fibers have these advantages:

¬ High durabily
¬ a low weight, about 25% of the steel weight
¬ high resistance
¬ easier use and quick to apply
¬ easy to transport
¬ they withstand fatigue excellently
¬ have excellent architectural impact
¬ are resistant to many chemical solutions, like bases ect.
¬ well suited to elements with non-flat(curved) surface
¬ they provide excellent chance to orientate fibers in the right direction, according to the work demands of the material, depending on its strained state.

Numerical Example

In a reinforced concrete beam which works in flexing there are known: The active shear force V_{Ed} = 12000 daN; the dimensions of the rectangular cross section are b=30 cm(width) and h=50 cm(height); the concrete class C25/30; the design value of concrete compressive strength f_{cd} = 166.6 daN/cm^2 ; the axial tensile strength characteristic of concrete f_{ctd} =12 daN/cm^2; the steel class S-500, the design yield strength value of reinforcement f_{yd} = 4350 daN/cm^2; the design value of modulus of elasticity of carbon fiber E_f = 2100000 daN/cm^2; the cross sectional area of reinforcement A_s = 4.62 cm^2; there are placed ties for the shear reinforcement, with a diameter 8 mm every 10 cm.
It's needed to be calculated the required surface of carbon fibers, necessary for strengthening of the element, if the active shear force due to external loads is doubled. The cross sectional area of reinforcement at the compressed zone is considerd A'_s=0.

First we have to calculate the value of $V_{Erd,c}$,the design shear force which is suported by the element without reinforcement.

$$V_{Rd,c} = [C_{Rd,c} \cdot k(100\rho_1 f_{ck})^{1/3} + k_1 \cdot \sigma_{cp}] \cdot b_w \cdot d \quad (1)$$

where,

f_{ck} - is the comressive cylindrical characteristic strength of concrete in Mpa, f_{ck} = 25 Mpa

$C_{Rd,c} = 0.18/\gamma_c = 0.18/1.5 = 0.12$

d - effective depth of cross-section, d = 46.5 cm = 465 mm

b_w - width of the cross-section, b_w = 30 cm = 300 mm

$$k = 1 + \sqrt{\frac{200}{d}} \le 2, \text{ (where d is substituted in mm)}$$

$$k = 1 + \sqrt{\frac{200}{465}} = 1.655 < 2$$

$\rho_1 = A_{s1}/b_w d = 4.62/(30*46.5) = 0.00331$

A_{s1} - the cross sectional area of the longitudinal reinforcement of beam, A_{s1} = 4.62 cm^2

σ_{cp} - compressive stress in concretefrom axial load or prestressing,

$\sigma_{cp} = N_{Ed}/A_c$

N_{Ed} – the axial force compressive or tensile caused by the external loads or caused by prestressing, $N_{Ed} = 0$, pra edhe $\sigma_{cp} = 0$
$k_1 = 0.15$

Based on the formula (1) :

$$\mathbf{V_{Rd,c}=[0.12*1.655*(100*0.00331*25)^{1/3}+0.15*0]*300*465=56000N=5600\ daN}$$

As the shear force V_{Ed} = 12000 daN > $V_{Rd,c}$ = 5600 daN, we necessarily need to reinforce the element.

Then we can calculate the design value of the shear force applied in the element considering also the respective reinforcement.

$$V_{Rd,s} = A_{sw} * z * f_{ywd} * \cot\theta / s \quad (2)$$

where,

A_{sw} - the cross sectional area of the reinforcement, $A_{sw} = 2*0.5 = 1\ cm^2$
s - spacing of stirrups, s = 10 cm
*z = 0.9d = 0.9*46.5 = 41.85 cm*
f_{ywd} – the design yield strength of stirrups toward shear forces, $f_{ywd} = 0.8 f_{yd} = 0.8*4350 = 3480\ daN/cm^2$
Is recomanded that $1 \le \cot\theta \le 2.5$, so we accept $\cot\theta = 1$

Based on the formula (2) : $\mathbf{V_{Rd,s} = 1*41.85*3480*1/10 = 14563\ daN}$

The last control is related to the not overcoming the maximum of the projection shear force that the section can afford, without destroying the pressed area. This force is noted as $V_{Rd,max}$ and is calculated with the above formula:

$$V_{Rd,max} = \alpha_{cw}* b_w* z* v_1* f_{cd} / (\cot\theta + \tan\theta) \quad (3)$$

In case when: $\sigma_{cp} = 0$, the recomanded value for $\alpha_{cw} = 1$

Then: $v_1 = 0.6$, for $f_{ck} \le 25\ MPa$

We have accepted: $\cot\theta = \tan\theta = 1$

Based on the formula (3) $\mathbf{V_{Rd,max} = 1*30*41.85*0.6*166.6/(1+1) = 62745\ daN}$

The active shear force :

$$V_{Ed} = 12000\ daN < V_{Rd,s} = 14563\ daN$$
$$V_{Ed} = 12000\ daN < V_{Rd,max} = 62745\ daN$$

So we can safely say that the element is insured against the shear forces.

We may assume that the active shear force value duplicates, so we have a $V_{Ed} = 24000\ daN$.

Carbon fibers should afford a shear force equal to :

$$V_{Ed} - V_{Rd,s} = 24000 – 14653 = 9347\ daN$$

Suposse that, we have chosen a reinforcening with strips of carbon fibers, as shown in *Figure 5 and 6.*

$t_f = 1.2\ mm = 0.12\ cm$
$b_f = 2\ cm$

$s_f = 15\ cm$
$\rho_f = (2t_f/b_w)(b_f/s_f) = (2*0.12/30)*(2/15) = 0.00107$

The projection shear force that carbon fibers can handdle V_{fd}, is calculated :

$$V_{fd} = (0.9*0.8*0.006*2100000*0.00107*30*46.5*(1+0))*1)/1.2 = 11283\ daN$$
$$V_{fd} = 11283\ daN > V_{Ed} - V_{Rd,s} = 9347\ daN$$

Definitely the element is insured against the shear forces action.

CONCLUSION

Through out this study article we have tried to give general information for Composite Carbon Fiber materials, their properties and characteristics, their wide use importance for reinforcening concrete structures ,which need to be strengthen, their advantages and a simple way how to applicate this strengthening method.
In the end of this short paper we have explained a numerical example to design and calculate the required amount of carbon fibers to strengthen a reinforced concrete beam in flexing.

REFERENCES

[1] Eurocode 2
[2] Eurocode 8
[3] A. Cirillo – Il cemento armato, Napoli 2009
[4] AICAP – Guida all'uso dell'EUROCODICE 2, Roma 2006
[5] Niko Pojani – Inxhinieria Sizmike, Tirane 2003
[6] A. Biondi – Cemento armato, Catania 2005
[7] A. Biondi – Strutture in c.a, dalle tensioni ammissibili agli eurocodici, passando per gli stati limite, Catania 2004
[8] Caterina Rubino, Davide Pini & Paolo Iannelli – Rinforzi di strutture in cemento armato
[9] F. Biasioli, P.G. Debernardi, P. Marro – Eurocodice 2, esempi di calcolo, Torino 1999
[10] E.C. Bentz, "Sectional analysis of reinforced concrete members", PhD thesis, Department of Civil Engineering, University of Toronto, 2000.
[11] Delitalia G.F – Calcolo delle sezioni in cemento armato
[12] Triantafillou T.C – Guidelines for the dimensioning of reinforced concrete elements strengthened with CFRP (Carbon Fibre Reinforced Polymers), Department of Civil Engineering, University of Patras, Patras 26500, Greece1998
[13] Caterina Rubino,Davide Pini, Paolo Iannelli – Rinforzo di strutture in cemento armato con il software FRP travi & pilastri, Luglio2005
[14] Anders Carolin,- "Carbon Fibre Reinforced Polymers for Strengthening of Structural Elements", Doctoral Thesis, Department of Civil and Mining Engineering, Division of Structural Engineering, Luleå University of Technology, 2003
[15] Carbon Fibre Composite Reinforcement,A Safety Belt for Structures and New Possibility to Light Constructions, An Article Published in Teollisuus Nyt 3/2006 .