Experimental Vacuum Process for Retroffiting Concrete Structures

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SUMMARY
Recent investigations - held at the Metropolitan Autonomous University (UAM) Azcapotzalco in Mexico City- dedicated to rehabilitate damaged structures, using external reinforcing systems based on carbon fibers, epoxy resins and a vacuum process have shown very interesting results. In order to increase the adhesion between both phases, this research aims to study the effectiveness of externally bonded fiber fabric for increasing the flexural strength of concrete beams using a vacuum process. The procedure is similar to a vacuum bag process and should help release entrapped air between layers and resin penetration, as well as increasing mechanical interlocking. As a result, flexural strength increased up to 47% on a concrete beam strengthened by hand process, and up to 51 % by a vacuum process. In the case of rigid surfaces, the effect of the process was more notorious. Rigidity was increased up to 48% on a concrete beam strengthened by hand process, and up to 79% by a vacuum process.

Keywords: Vacuum process, Fiber carbon, Retrofitting.

1. INTRODUCTION

Fiber reinforced plastic (FRP) is increasingly used for strengthening or retrofitting reinforced concrete structures. FRP is used as an external tensile reinforcement in the tension face of concrete beams. FRP strengthening is used to increase the flexural and shear capacity of deficient members. Moreover, the selection or the design of a FRP strengthening system is a critical part in this process, considering the various components (fibers, resins and supports) have all different mechanical properties and roles.

Generally fibers used are carbon fibers with epoxy resins. The bonding of external carbon fiber reinforcement to the reinforced concrete members is widely accepted and it is considered to be an effective and convenient method of reinforcement among many methods of strengthening different constructions (Valivonis and Skuturna 2007). Carbon fibers have shown elastic modulus as high as steel with the advantage of having a specific weight 3.5 times lower than steel. Other advantages of these materials in comparison with the traditional strengthen methods are: high resistance to aggressive environment, good formability, easy bonding, and lightweight.

Regarding bond between external reinforcement and concrete, it is influenced by several variables, such as properties of concrete and adhesive and methods of anchoring carbon fibers. Research conducted by authors such as, Kimand Sebastian 2002, Buyukozturk et al. 200, Pimanmas and Pornpongsaroj 2004, shows that depending on the way of fastening external carbon fiber reinforcement and its quantity, would be the behaviour, strength and the failure pattern of the strengthened member changes. The way of anchoring carbon fiber as well as its quantity, largely determines crack formation in strengthened constructions.

Vacuum techniques have become popular in manufacturing composite materials used in structural applications ranging from aircraft and space structures to automotive and marine applications, due to the solid bonds established between fiber and resin (Ragondet 2005). In a vacuum bag process, bagging films are sealed to the edge of the mould with vacuum bag sealant tape to create a closed system (Kang et.al. 2001). The vacuum pump then can be initialized, adjusting the vacuum value by an operator, so that a uniform pressure is applied through all the area, helping the adhesion process.

This kind of process has an interesting effect on the curing process, which is very important to produce composite parts with optimum mechanical properties. Every part, in a composite, is supposed to be produced almost at the same curing conditions to avoid internal stress.

2. EXPERIMENTAL

Concrete beams were reinforced with biaxial fabric carbon fiber and epoxy resin using a vacuum bag process.

2.1 FRP bonding method

In order to apply the FRP to the concrete beam, it is noted that the surface must be cleaned and sand blasted. This action assures a good bond between FRP and the concrete surface. Prior to pasting, all beams are cleaned with steel brushes, removing any possible deformities on them. Descriptions of the material used are shown below.

2.1.1 Concrete

The materials used to make the concrete are: Portland cement Type CPC 30R (according to Norm NMX-C-414), quartz sand and crushed basaltic gravel. Compression strength of concrete is 26.4 MPa. Concrete beams were reinforced with 4 bars of 6 mm (¼") diameter with a nominal yield strength of 600 MPa. Four transverse reinforcement bars of 4 mm diameter are spaced 150 mm from each other. Properties of steel are shown in Table 1.

Table 1. Steel bar´s mechanical properties.

Property	Unit	Value
Yield stress	MPa	611
Maximum stress	MPa	713
Elasticity modulus	GPa	205

2.1.2 Carbon Fiber

The carbon fiber used is a biaxial fabric with an average weight of 119 grams per square meter, and has an average thickness of 0.15 mm. According to the supplier, fibers came from poliacrylic nitrile (PAN) and the properties are reported in Table 2. Picture in Figure 1 shows the carbon fabric used to reinforced concrete beams. The width of the carbon fiber strip was 150 mm. Carbon fiber was glued by using epoxy glue.

Figure 1. Picture shows the carbon bi directional fabric appearance.

Table 2.Bi directional carbon fabric (Toray).properties

Specific weight	Tension Strength MPa (kg/cm^2)	Tension elastic modulus GPa (kg/cm^2)	Fracture strain %	Tex grams/1000m
1.78	3,400 (34,670)	220 (2.24x106)	1.5	66

2.1.3 Epoxy resin

Epoxy resin used is a commercial epoxy with low contraction (0.05%), low water absorption (0.06%) and a density of 1.16 g/cm^3. Mechanical properties are reported in Table 3, according to the supplier.

Table 3. Properties of epoxy resin according to the supplier (Poliformas Plasticas).

Properties	Value
Compression resistance	0.90 MPa
Tension resistance	1.01 MPa
Fracture strain	2.00 %
Flexural resistance	0.14 MPa

2.1.4 Vacuum process

This process, developed especially for the FRP process, offers several advantages such as: a guarantee for adhesion between carbon fiber and concrete surface, also a release of trapped air, and it applies a uniform pressure over all the reinforcing area. Pictures in Figure 2 show the main steps of this process, initially, the film cover placing over the beams with the reinforcing FRP, followed by the application of vacuum in order to smear a uniform pressure. The vacuum pressure reached (in Mexico City) was -21 in. Hg(-0.071MPa).

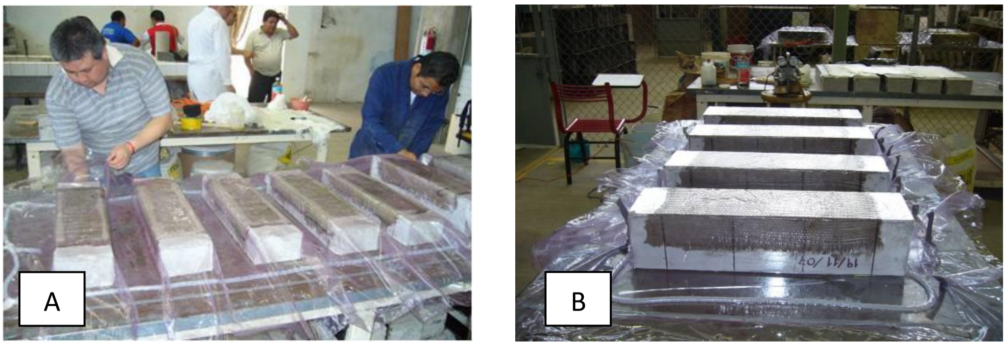

Figure 2. Picture A, shown PVC film placing over the beams with the reinforcing FRP, and Picture B shows vacuum applied.

3. RESULTS

Previous tests show, that it is possible to retrofit a concrete beam, which is tested on bending until fracture. Experimental data shows (Padilla et al. 2010) that reinforcing beams by a vacuum process increased almost twice the value of rigidity when compared to a beam reinforced by hand process. Also, delaminating between FRP and a concrete surface is reduced considerably; furthermore, the cracking beams were reinforced with this process. All of them were reinforced with a "U" carbon fiber layer as it is shown in Fig 3.

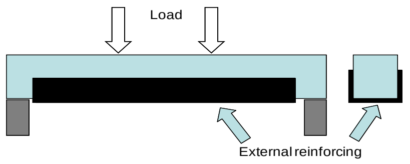

Figure 3. "U" layer of FRP reinforcing.

Beams were tested again through a flexural four points test. Results showed that retrofitting beams reached 84% and 70% of load capacity and rigidity respectively, when compared to the original data. Moreover, this increased on 16% the deflection at mid-span. These data are reported in Table 4 and in Figures 4a to 4c shown the corresponding load vs. mid-span FRP strain curves for both original and retrofit beams.

Table 4. Average mechanical properties of original beams and retrofit beams.

Beam	Maximum Load (Newton)	Mid-span (mm)	Flexural Strength (MPa)	Flexural Modulus (MPa)
Original	94,909	5.42	19	1,126
Retrofit	81,292	6.31	16	788
Variation	-14%	16%	-15%	-30%

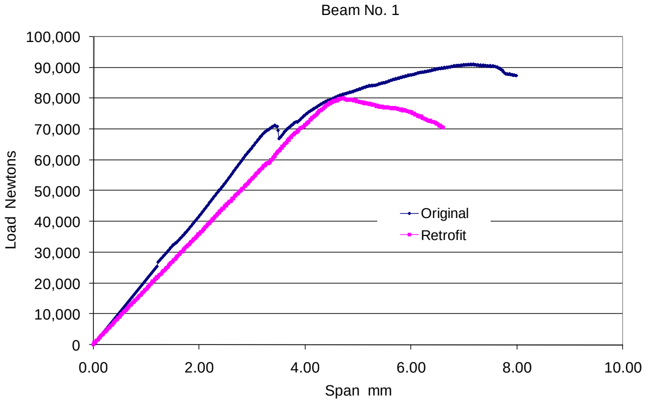

Figure 4a. Curves load versus span of the original and retrofit beams corresponding to beam No.1

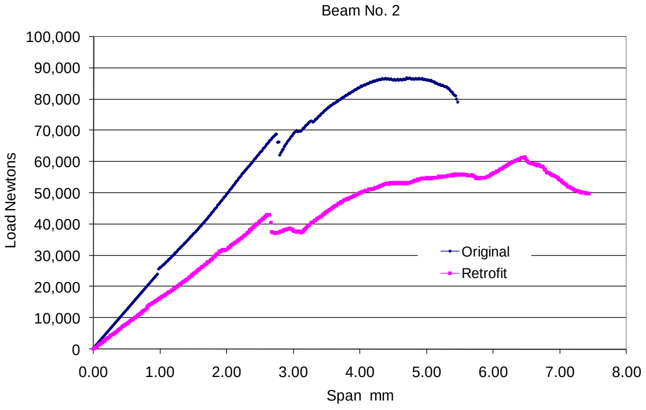

Figure 4b. Curves load versus span of the original and retrofit beams corresponding to beam No.2

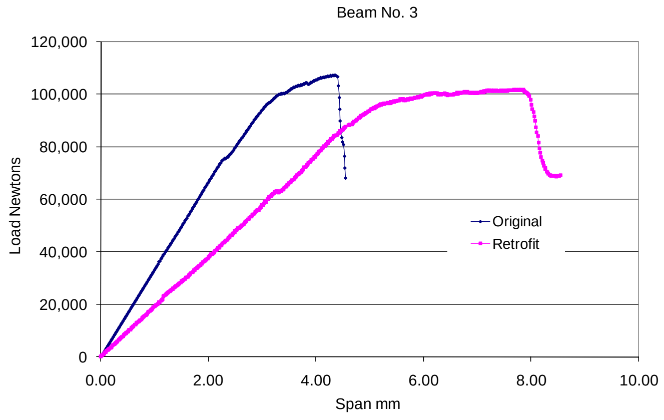

Figure 4c. Curves load versus span of the original and retrofit beams, corresponding to beams No3.

3.1 Load and deformation record

In order to evaluate the effect of reinforcing FRP on preloaded concrete structures, concrete beams were subject to a flexural test. The maximum load was around 50% of the maximum load capacity. Then the beams were reinforced with a RFP layer and tested again. Deformation and load were registered along the test.

In this stage, beams were reinforced with a layer of FRP based on epoxy and carbon fiber and in this case the beams were reinforced only to flexion as it is shown in Fig. 5.

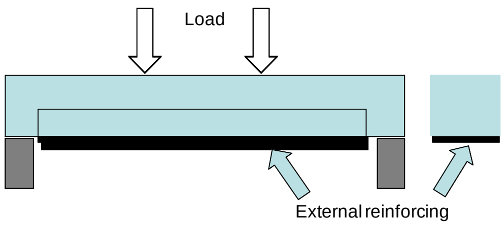

Figure 5. Reinforced concrete beam with a carbon layer.

As we mentioned, in order to evaluate the effect of the FRP on the flexural properties of the beam, a set of witness concrete beams were tested. Figure 6 shows the representative load-deflection curve obtained from tests.

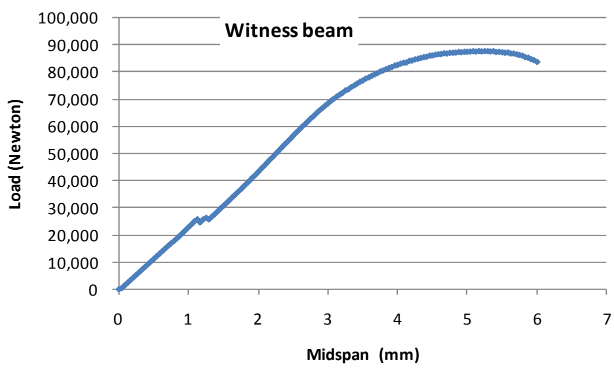

Figure 6. Average load deflection curve of witness beam until fracture.

As shown, the first flexural crack appears at a load of 26,000 N and there is a second crack that appears at 28,000 N. These cracks are still into the elastic zone. Using data from load mid-span curves it is possible to calculate the ultimate flexural capacity and the initial flexural modulus. The average flexural capacity for this set of beam was around 11.69 MPa and elastic modulus was 884.6 MPa.

Based on this information, the second set of beams without external reinforcing were loaded until 46,000 N, in order to assure there were at least one or two cracks. Figure 7, shows a typical curve of the beams, in which we can observed two cracks, the first one at load of 25,000 N and the second one at load of 35,000 N. The test was stopped at a load of 46,000 N. The calculated elastic modulus average was 822 MPa, which is similar to those determined for the witness beam (884MPa).

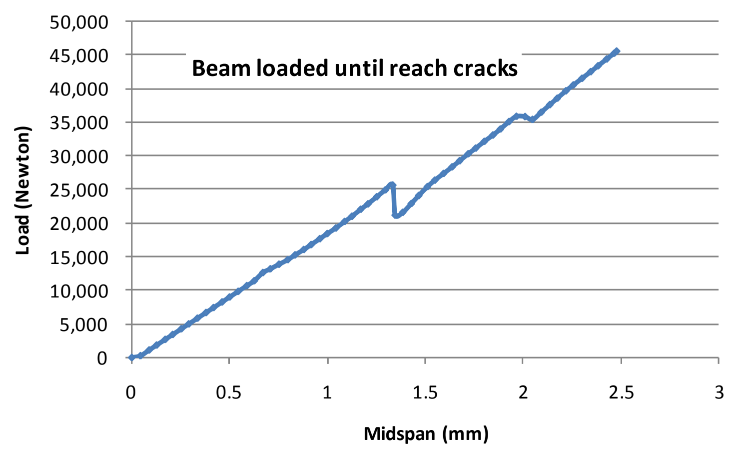

Figure 7. Typical load mid span curve of beam concrete.

Also in these set of beams, the tension on the steel bars was recorded through strain gages. From average data, curve tensile strength deformation is drawing, as it shows Figure 8. The curve shows that the bar is under a maximum tensile stress of 180 MPa which is only 27% of the yield stress value (661 MPa).

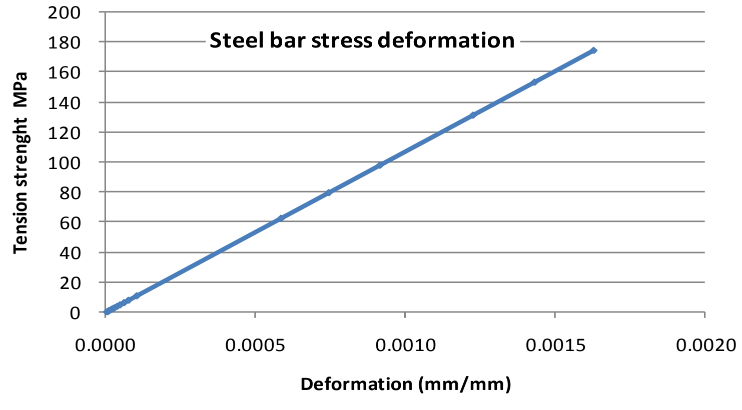

Figure 8. Curve tensile strength versus deformation of steel bar.

These beams were reinforced with an external FRP based on carbon fiber and epoxy resin. After, beams were tested again until reaching failure.

One would expect, as it is reported in many laboratory experiments held in the tension zone of the reinforced concrete beam, that external reinforcement carbon fiber increases the strength at bending, reduces deflections as well as cracks' width. In this case, the average flexural capacity was increased from 11.69 to 13.4 MPa with the external fiber carbon reinforcing. This change represents an increase of 14%.

Regarding deflection, the original average of deflection went from 5.2 mm to 4.3 mm when the beams were reinforced. Figure 9 shows the typical curve of external reinforced beams. By other hand, average flexural modulus was around 806 MPa, which is little lower than the original average modulus (822 MPa). This reduction is really small and close to 2%. Considering dispersion values of beam tests, we can suppose that external reinforced beams maintain this property.

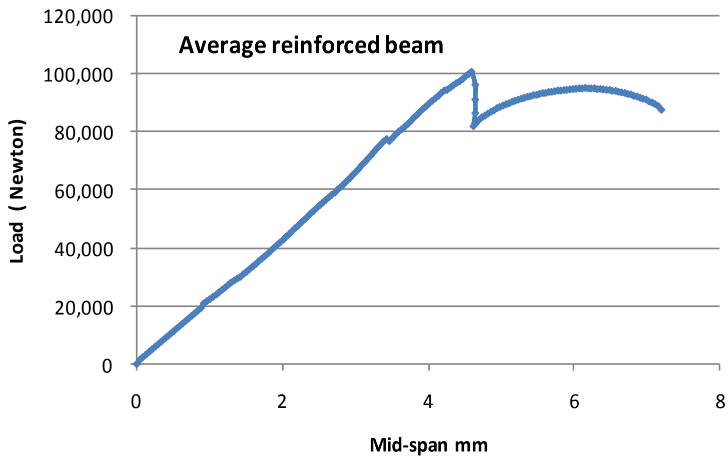

Figure 9. Typical load mid span curve of external reinforced beams

When we compare load deflection curves of witness and external reinforced beams, we can see there is not any difference in the elastic zone and there is an increase of the load capacity in the external reinforced beam and also and small increase on deflection (see Figure 10). However, there is another difference in the load behaviour: the first flexural cracks in the original beam (witness) appear at around 25,000N (see Figure 7), but in the reinforced beams, the first cracks appear with a load close to 80,000N (see Figure 9). This could mean than external reinforcement not necessarily increases rigidity and only has an effect on load capacity, deformation, and in control cracks.

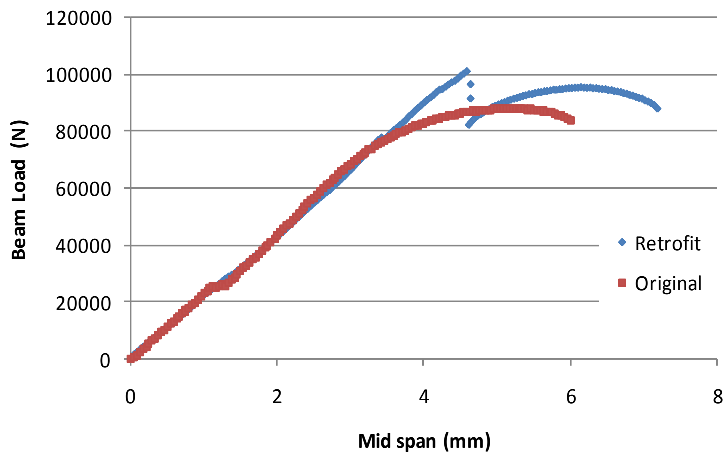

Figure 10. Load deflections curves of witness and external reinforcing beams

3.2 Reinforcement behaviour

According to the average data, when a reinforced concrete beam reaches failure, a FRP carbon fiber system reaches a maximum deformation of 0.4%, which represents maximum load strength close to 195MPa, and each steel bar reaches a maximum stress of 578MPa, which corresponds to a deformation of 0.28%. This is shown in Figure 11, where a notorious elastic modulus difference between FRP external reinforcing and internal steel bar is shown (close to four times).

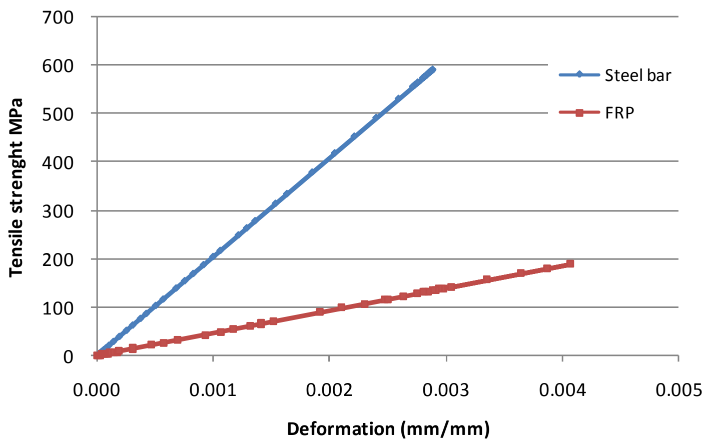

Figure 11. Tensile strength deformation curves for the steel bar and the external.

4. CONCLUSIONS

As reported results show, external reinforcing FRP has an important effect to control the concrete structural damage on concrete structures. Moreover, the mechanical behaviour of retrofit beams by external reinforcing FRP is better than the witness beams. In this way, load capacity of retrofit beams is 10% higher than that present in witness beams.

A vacuum process could be an excellent procedure for strengthening and retrofitting concrete structures, due to the fact that it guarantees the adhesion between glass fiber and a concrete surface. The process releases entrapped air and increases the adhesion area between both surfaces. This process also is independent of hand labour, which could also be an advantage. Particularly, it helps obtaining repetitive products with the same quality. On the other hand, the cost is very small, because the process employs such cheap materials as PVC film or double faced tape, which can be reused.

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