Strengthening and Reinforcement of Concrete Beams by the Application of CFRP Using the Filament Winding Method

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ABSTRACT

For the flexural strengthening of reinforced concrete elements, an innovative technique, based in the filament winding method and using carbon fibres and epoxy resin, has been developed in the scope of the research and development activity of INEGI.
An experimental research has been done bearing in mind the strengthening of scale-reduced beams.
The CFRP reinforced system has been able to increase more than the double of the ultimate load of the concrete beam, providing a large deflection as well.

KEYWORDS: **Filament Winding, Rehabilitation, Strengthening, CFRP, Concrete**

1. INTRODUCTION:

Increases in static, dynamic, impact loading, as well as increased seismic activity, whenever design errors have been made or structures are ageing prematurely, are a few of the reasons why it is necessary to make the rehabilitation and strengthening of concrete structures. New techniques are emerging as an alternative to steel plate bonding. One of which involves strengthening existing concrete structures with externally bonded of pre-manufactured FRP composite materials plates, or as unidirectional carbon tissues to be impregnated and cured in-situ, for flexural strengthening and, occasionally, for improvements in shear capacity.
The application of the filament winding technique for this purpose provides an interesting improvement in flexural, compression and shear capacity of concrete beam elements.
To study the application of the winding process for the rehabilitation and strengthening of concrete structures, an experimental research programme has been done bearing in mind the strengthening of scale-reduced beams.

2. FILAMENT WINDING:

The filament winding process consists in a simple operation in which continues reinforcements are wound around a rotational mandrel. The control of the winding angle and the lay up of the fibres are made by the filament winding machine in which the transversal speed of the fibre feeder is synchronized with the rotation movement of the mandrel. The process allows the possibility to obtain components reinforced with high resistance and low weight, taking advantage of the good properties of the fibres soaked in a polymeric matrix. It is possible to make different layers with equal or different angles until obtaining the desirable thickness. The winding angles can vary from a very small, almost 0º to helicoidal winding, almost 90º.

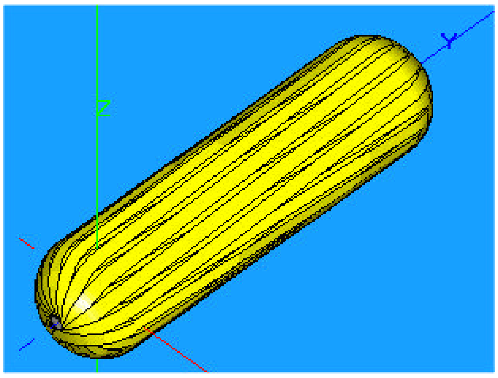

Figure 1. Very small winding

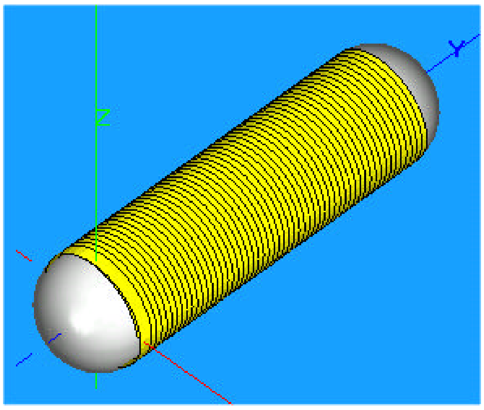

Figure 2. Helicoidal winding

3. MANUFACTURING SCALE-REDUCED CONCRETE BEAMS.

The beam is 1 m long, and has a cross section of 75 x 100 mm^2. It has been made of a C35/45 micro-concrete and reinforced according to figure 3.

The longitudinal reinforcement of the beam is formed by 2 rebars of 6 mm diameter at the bottom and 2 rebars of 5 mm diameter at the top. Transverse reinforcement is formed by 5 mm closed stirrups, with 50 mm spacing on the total length of the beam. The external cover provided to the stirrups is 7 mm.

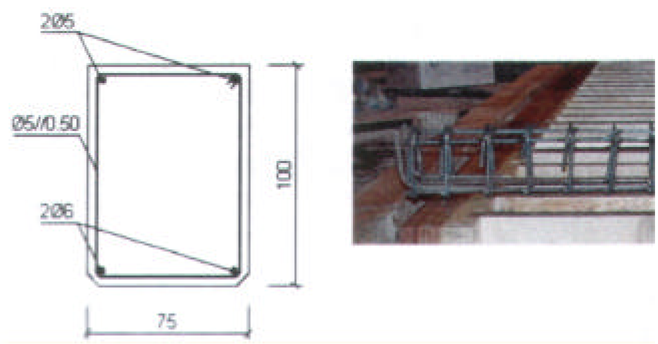

Figure 3. Beams reinforcement

The properties of the steel adopted for the beam reinforcement are specified in figure nº 4.

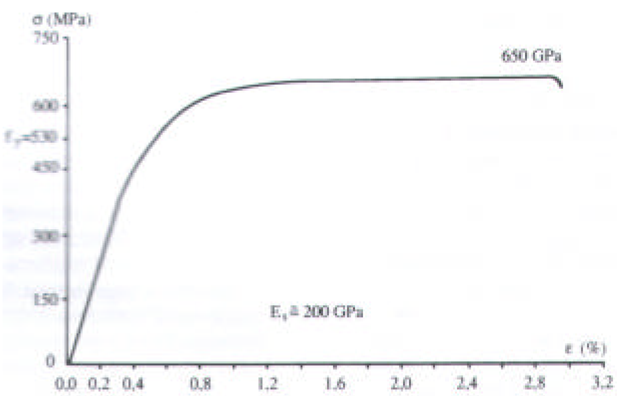

Figure 4. Steel rebar mechanical properties

The average compressive strength of the concrete is 53 MPa, evaluated on 150 mm cubes, aged 28 days.

4. TESTING DEVICE.

Three point bending tests were made with a beam span of 900 mm (see figure 5). The vertical speed of the actuator was 5 mm per minute.

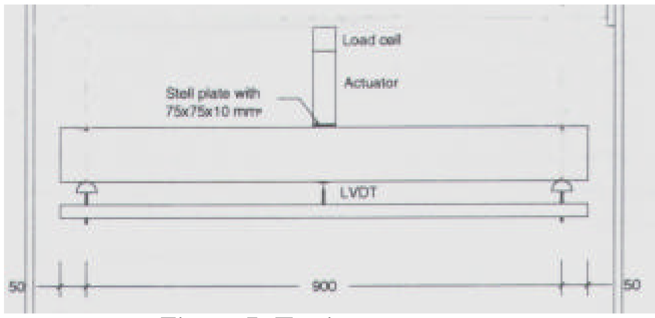

Figure 5. Testing parameters

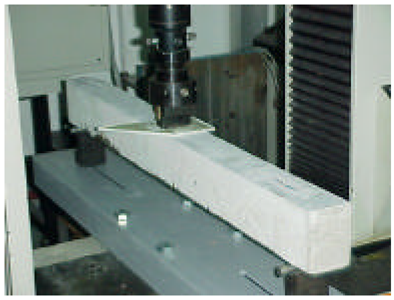

Figure 6. Testing reference beam

5. TESTING PROGRAMME

There were three different series of beams tested.

- Reference beams (not reinforced)
- Reinforced beams (using filament winding)
- Reinforced damage beams (reference beams rehabilitated and reinforced after damaged)

6. REINFORCEMENT SYSTEM

The materials used for the rehabilitation, and the reinforcement of the beams are commercial materials available in the market and described below.

For voids and cracks filling:
Epoxy Adhesive Past: **Fermapoxy (Weber & Broutin)**

For reinforcement:
Epoxy Resin: **Reapox 520/526 (Rebelco)**
Carbon Fibre: **HTA 5131 1600TEX F24000 TO (Tenax Fibres)** (E=234GPa)

7. APLICATION APPROACH

7.1. New beams

Surface defects and beam cutting edges were removed mechanically using an abrasive millstone. Beams were cleaned with the use of pressurised air. For a better adhesion of the reinforced system, it has been applied an epoxy resin to the surface, and left to cure for 24 hours before the application of the carbon winding strengthening.
The surface preparation is required for a good bond between the beam and the reinforcement.

Figure 7. Surface epoxy resin application

7.2. Damaged beams

Tested beams, used for the reference tests are recuperated to be reinforced and later on studied.
The existing deflection of the beams consequence of the damage and the plastic deformation of the traction rebars are removed applying a bending load using an hydraulic device. The concrete cracks and voids are filled with an epoxy adhesive past. The next procedures are the same as for the new beams (see 7.1.).

Figure 8. Cracks and voids in the damage beam

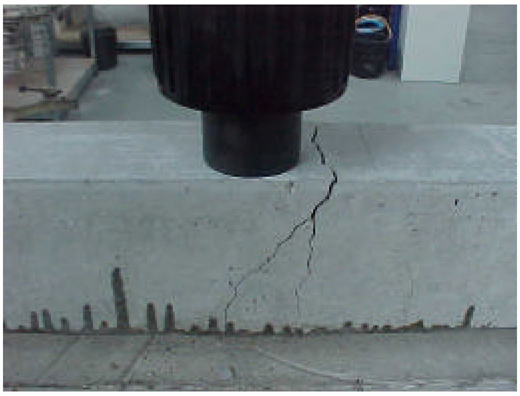

Figure 9. Removing existing deflection

Figure 9. Filling cracks and voids

7.3. Description of the winding process

A six axes winding machine was used for the winding of the beams. The reinforcement made has an overall length of 850mm. A 64º angle and a 10 Newton tension on the fibres was used for this application. The number 64 isn't an experimental value, but is the result of the program possibilities for the length imposed. It has been difficult to make an angle smaller than 60º, because of fibre sliding in the beam.

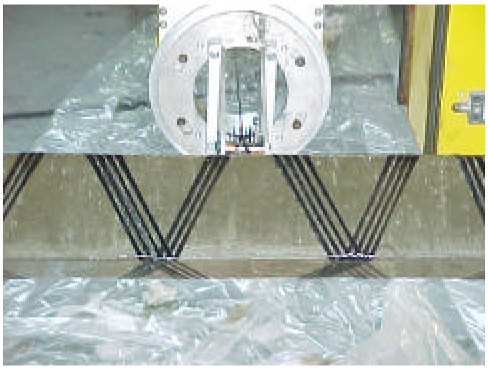

Figure 10. Winding of first layer

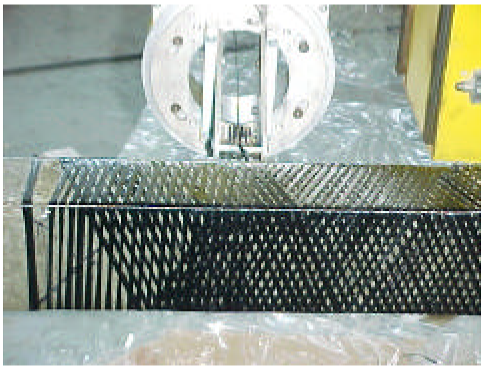

Figure 11. Winding

There were three groups of reinforced beams using this system. The first group was intact and reinforced with two layers. The other two were damage and reinforced one with a layer and the other with two.

Figure 12. Complete wound beam

8. TEST RESULTS AND DISCUSSION

8.1. New beams

The results for the reference beams were as expected by calculation applying the Eurocode, 13 kN force and 8 mm deflection are measured (see figure 13).

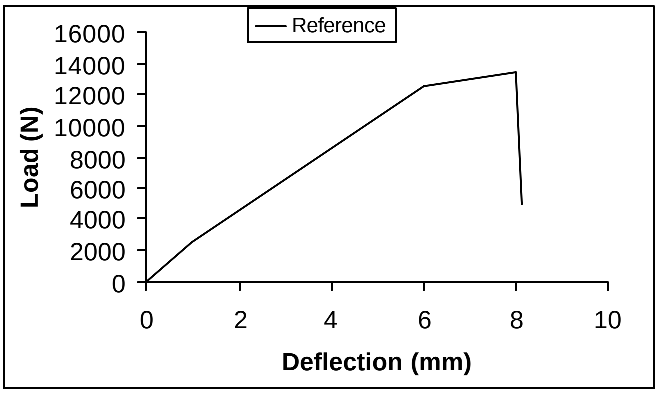

Figure 13. Reference beam load-deflection curve.

The intact beams were reinforced with two layers, to evaluate the difference in the results.
Analysing the figure 14 it is possible to see the difference between the non reinforced and the reinforced beams. The reinforced was almost capable of absorbing the double of the load (23.9 kN), and when the test was stopped it had more than three times the deflection of the non reinforced beam (28 mm).

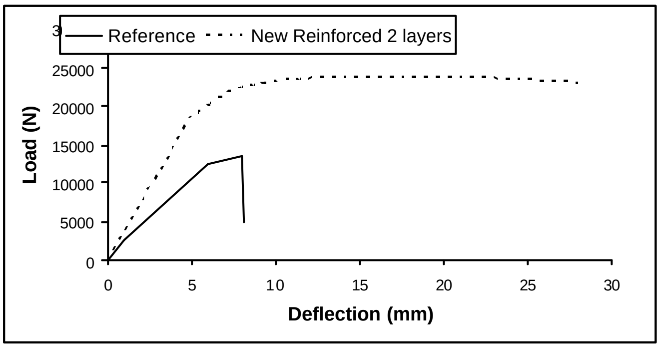

Figure 14. Reference beam / Reinforced Intact beams.

The values above gave us the reference in load and in deflection for the damage and reinforced beams.
The first group of beams was wound with two layers, so there can be a good comparison with the reinforced new beam.

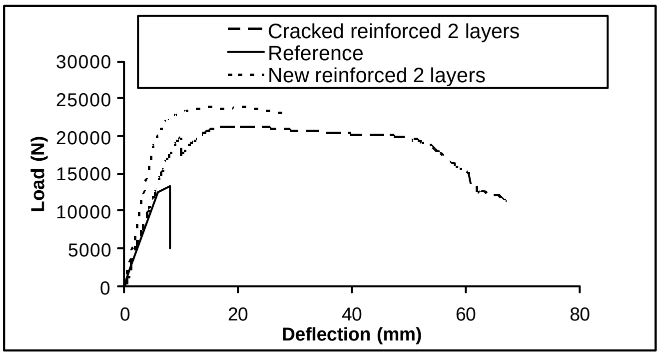

Figure 15. Two layers damage beam.

The two layers reinforcement worked perfectly. Damage beams could be repaired almost achieving the characteristics of a new beam. These tests lasted until rupture, and with these results we can say that the damage concrete beam after reinforced with filament winding has very good results, 19.5 kN load and 50 mm deflection (after 50 mm, fibres started to crack).

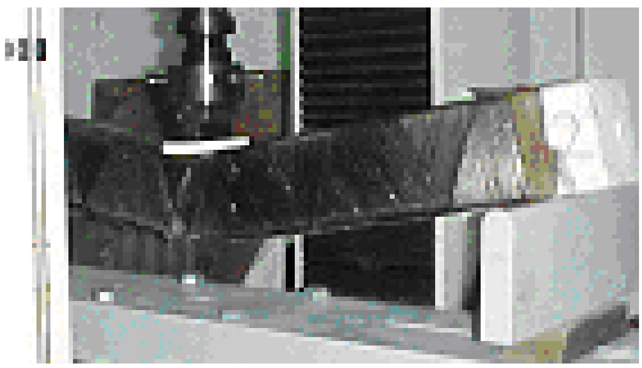

Figure 16. Deflection of the two layers reinforced Beam.

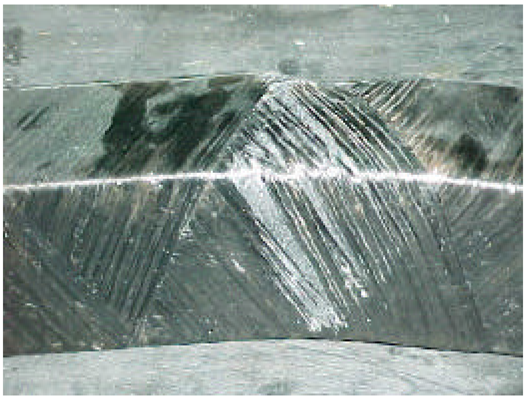

Figure 17. Rupture of the fibres after the tests.

Figures 16 and 17 show the deflection and the final condition of the winding after cracking. Due to matrix cracking, some filaments cracked and others were separated from each other.

A last group of beams was tested only with one layer of filament winding. These tests could give an idea how the layers influence the final force and the deflection of the beams.

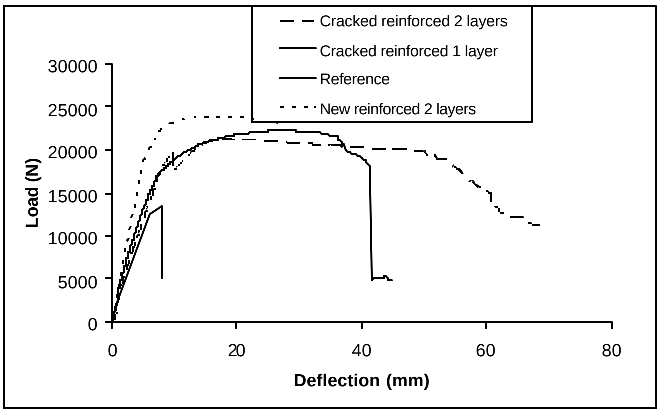

Figure 18. One layer beam damaged.

The one layer beams could reach a load peak (22.3kN) a little higher than the two layers beam, but the deflection (35mm) was 30 % less than in the two layers beam.

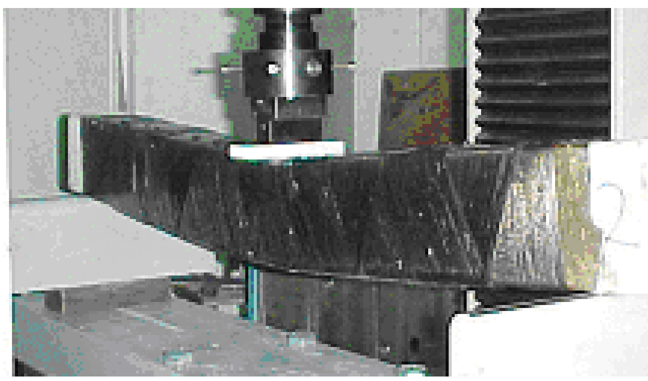

Figure 19. One layer beam deflection.

Figure 20 Rupture of the fibres

The rupture of the fibres is more "violent" in a one layers reinforced beam than in the other.
The Table bellow summarizes the results.

Beams	Load (kN)	Deflection (mm)
Reference	13	8
2 layers new	23.9	28 *
2 layers cracked	19.5	50
1 layer cracked	22.5	35

Table 1. Results table summarizing.

* The beam wasn't tested till crack

9. CONCLUSIONS

An innovative technique, based in the filament winding method and using carbon fibres and epoxy resin as matrix, was tested for the flexural strengthening, rehabilitation and reinforcement of concrete elements. This technique has excellent results on bending deflection behaviour and has good perspectives for the rehabilitation and reinforcement of very damage structures.
The application on site of this technique presently has some difficulties. A prototype of a filament winding machine for these propose is on study.

8. REFERENCES

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