Optimizing the Strengthening and Reinforcement of Concrete Beams by the use of CFRP Filament Winding.

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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.
Increases in static, dynamic, impact loading, as well as increased seismic activity, whenever design errors have been made or structures 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 and a numerical finite elements method analysis's has been done bearing in mind the strengthening of scale-reduced beams.
The study of winding parameters to optimize the CFRP reinforcing system has been able when tested in three and four points bending to increase more than the double of the ultimate load of the concrete beam, providing a large deflection as well.
The strengthening process will be described.

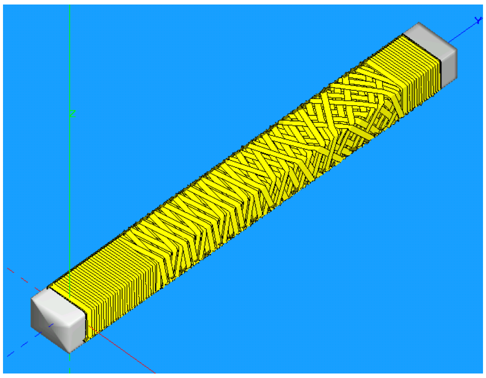
INTRODUCTION

In our days, there are some structures that weren't designed for today's requirements. The increase in static, dynamic and impact loading, at the same time with some seismic activity, not including human error that can appear in project design or even in the construction of the structures, and the prematurely ageing of the structures are some reasons why it is necessary to rehabilitate and strength this concrete structures.
As always, if a problem occurs, men try to solve the problem inventing new solutions. Some new techniques were developed in substitution of the steel plate bonding. The most common techniques are: pre-manufactured FRP composite materials (Pultruded laminate) bonded to the surface to be reinforced by an adhesive or carbon tissues that are impregnated and cured when placed. This strengthening benefits the flexural solicitation and sometimes shear capacity.[1..6]
The filament winding technique for this purpose provides interesting improvements in flexural, compression and shear capacity of concrete beam elements. To make this study of implementing the filament winding technique on strengthening of concrete beams, a research program with scale-reduced beams has been followed.

FILAMENT WINDING

The filament winding technique consists in winding a reinforcing filament (wire, continues fibres,…) around a mandrel that can be removed afterwards or can stay inside the winding (our case of study). The result is a reinforcement with high resistance and low weight shell that can have different solicitations and different characteristics depending on the winding angle. In figure 1, we can see a beam involved in one roving. The winding in that figure has 4 different angles in 5 different places. The possibility of changing in the same beam several angles changes even more the properties of the shell and, consequently, the properties of the beam and the shell together.[7..9]

Figure 1: Winding simulation with different angles



MANUFACTURING THE CONCRETE BEAMS

The beams used are 1 meter long, and have a cross section of 75 x 100 mm^2. The concrete used is C35/45 micro-concrete and internally reinforced as is shown in figure 2. 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 diameter closed stirrups, with 50 mm spacing on the total length of the beam. The external cover provided to the stirrups is 7 mm.

The properties of the steel used for the internal reinforcement are specified in figure 3.

Figure 2: Beams internal reinforcement

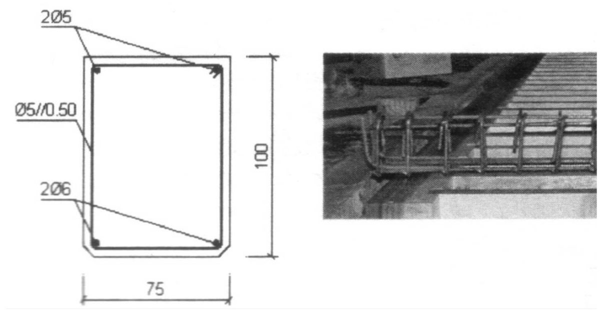
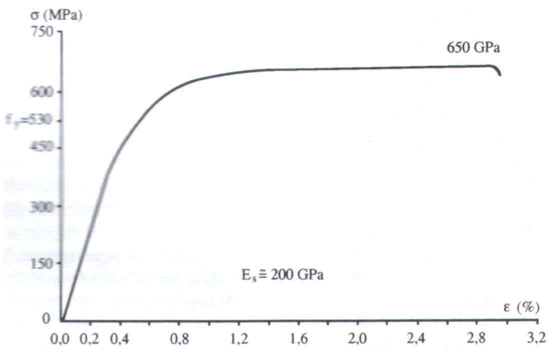


Figure 3: Steel rebar mechanical properties



REABILITATION OF THE BEAMS

For this project we used 2 types of beams, new and rehabilitated. The damage beams as we can see in figure 4 have a large crack on the middle part and a permanent deflection, because they were tested until the maximal load of the beam. The first step on this rehabilitation is removing the deflection that resulted from the plastification of the internal rebars. For this we used a hydraulic press as shown in figure 5. The last step on the rehabilitation is filling the cracks and voids. In figure 6 we see that treatment.

Figure 4: Crack in the beam

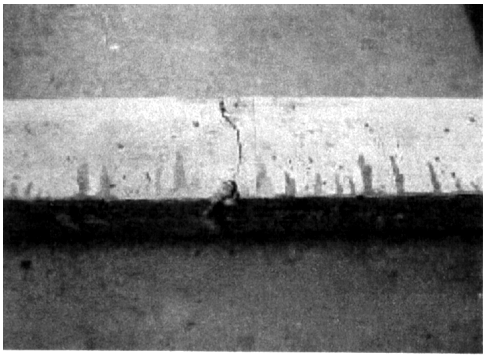


Figure 5: Rehabilitation of the beam

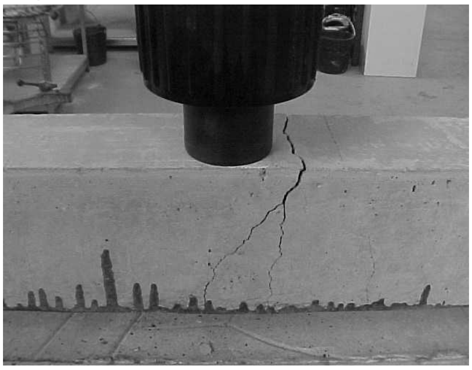


Figure 6: Filling cracks and voids

Figure 7: Surface treatment

SURFACE PREPARATION

The new and rehabilitated beams had to be prepared for filament winding. First the surface defects and the cutting edges were removed with an abrasive millstone. This is very important to prevent damage in the fibres during the winding process. After cleaned with compressed air, an epoxy resin was applied in the beam's surface to improve the adhesion. This resin was left to cure for 24 hours minimum. Figure 7 shows the beam after the resin application.

MATERIALS USED FOR TREATMENT AND WINDING

The materials used are materials available in the Portuguese construction market.
For voids and cracks filling:
Epoxy Adhesive Past: **Fermapoxy (Weber & Broutin)**

Young Modulus:	E = 5.1 GPa
Tensile Strength (traction):	σ = 22.8 Mpa
Adhesion to Concrete:	σ = 3 MPa

For reinforcement:
Epoxy Resin: **Reapox 520/526 (Rebelco)**

Young Modulus (traction):	E = 3.4 GPa

Carbon Fibre: **HTA 5131 1600 TEX F24000 TO (Tenax Fibres)**

Young Modulus:	E = 234 GPa

WINDING STRATEGY

A 6 axes PULTREX 1S-6NC filament winding machine was used. We wind 850 mm of the 1000 mm beam's length, and we used a 64º angle in every beam. The 64º angle is not a study angle, but is the smallest angle possible to make in our machine without fibre sliding and with the dimensions restrains. The fibre tension used was 10 Newton. The only variable used was the number of layers. The next figures show how the winding was made.

Figure 8: Beginning of the winding process

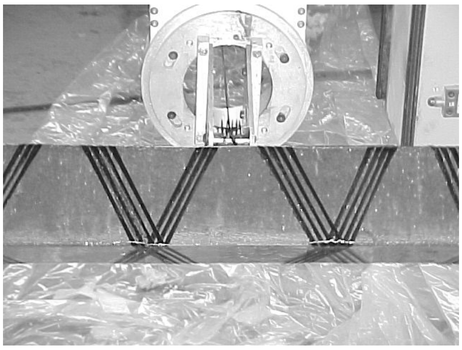
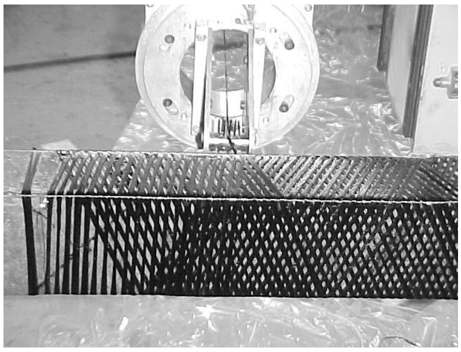


Figure 9: Halfway winding process



TESTING PROGRAM

Five groups of beams were tested in our research. Table 1 shows the order, the beam type, the number of layers, and the type of mechanical test that was made with each beam. Three and four point bending tests were made. The distance between supports in the three point bending test has been 900 mm, being the load applied in the middle (see figure 10). For the four point bending tests the supports were in the same place, but the load was applied with a distance between the two load points of 400 mm (see figure 11). In both cases the test velocity was 5 mm/min in a INSTRON 4208 universal testing machine.

Table 1: Beams groups

Group	Beam type	Nº of layers	Test type
Ref	New	0	3 Point bending
A	New	1.5	3 Point bending
B	Rehabilitated	1	3 Point bending
C	Rehabilitated	2	3 Point bending
D	New	1.5	4 Point bending

The number of layers in filament winding is the number of times that the machine covers the mandrel. The 1.5 in the number of layers is because in one of the layers, the distance between consecutive fibres is 8 mm, instead of the normal 4 mm (the band width). That means, that one layer has half of the fibres that the other layer.

Figure 10: Three point bending test

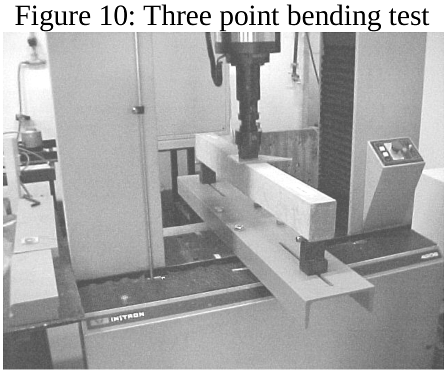
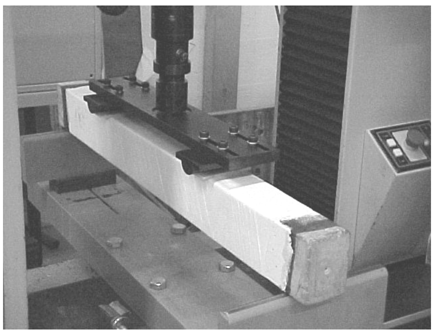


Figure 11: Four point bending test



CALCULATIONS

According to REBAP [10] the maximal load of the reference beam should be 13 kN and 8 mm displacement.

Calculations for the three point bending test in the reinforced beam.

For this calculation, we used Cosmosworks from SolidWorks Corporation [11]. First step was to design the part with all its components. For that, we used SolidWork. The part is shown in figure 12. For the finite element simulation, we introduced the different properties for the different materials. Some properties, we could introduce immediately, but others were more complicated.

Figure 12: Beam design in SolidWorks

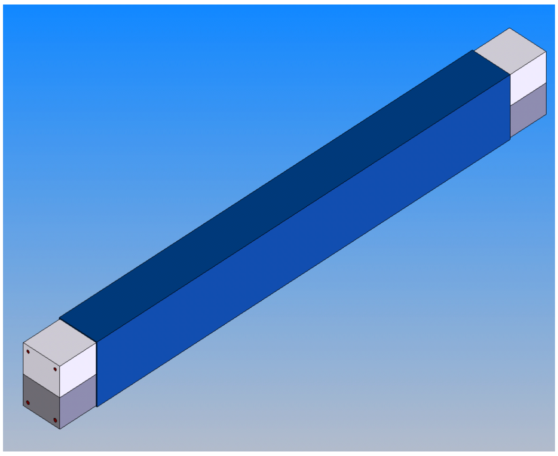
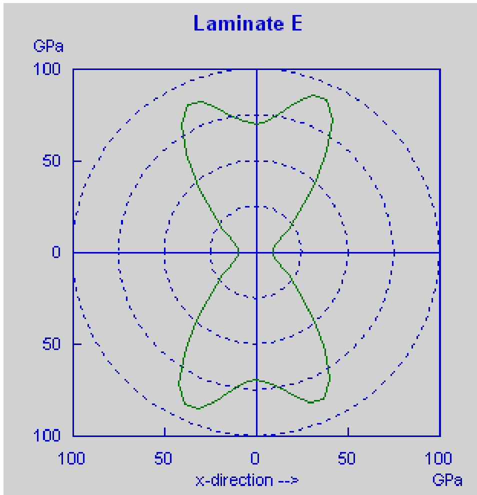


Figure 13: EsaComp simulation



To predict the filament winding properties, we used a simplification. Using EsaComp [12], we predicted the characteristics of a laminated with the following orientations; 64/-64/64/-64. The simulation result can bee seen in figure 13. This simulation is not the ideal for filament winding because we could not simulate the crossing of the fibres, but only different layers together. Introducing the values in Cosmosworks we simulated the deflection using a load of 12 kN. The next figures show us the finite element mesh, the deflection and the nodal stress. For calculations, we divided the beam, simulated in half and used symmetric conditions. Analyzing the results, we can see a 4.3 mm deflection in the middle of the beam. This result is going to be compared with the experimental values. The stress in the steel rebar shows us that there is already some plastification of that material.

Figure 14: Finite elements Mesh

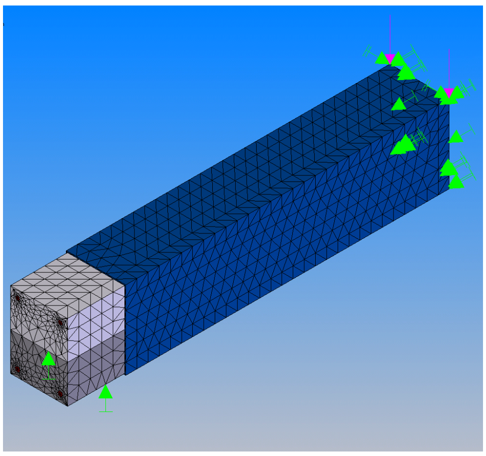


Figure 15: Stress in the beam

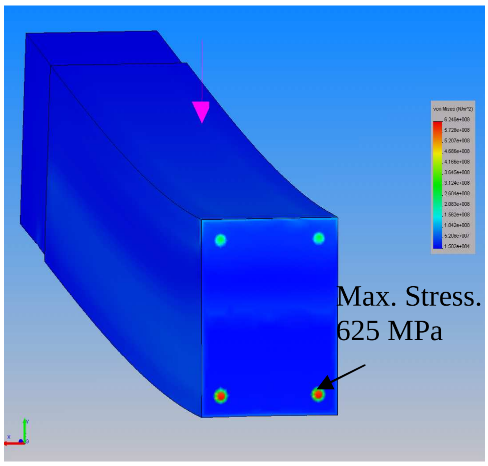
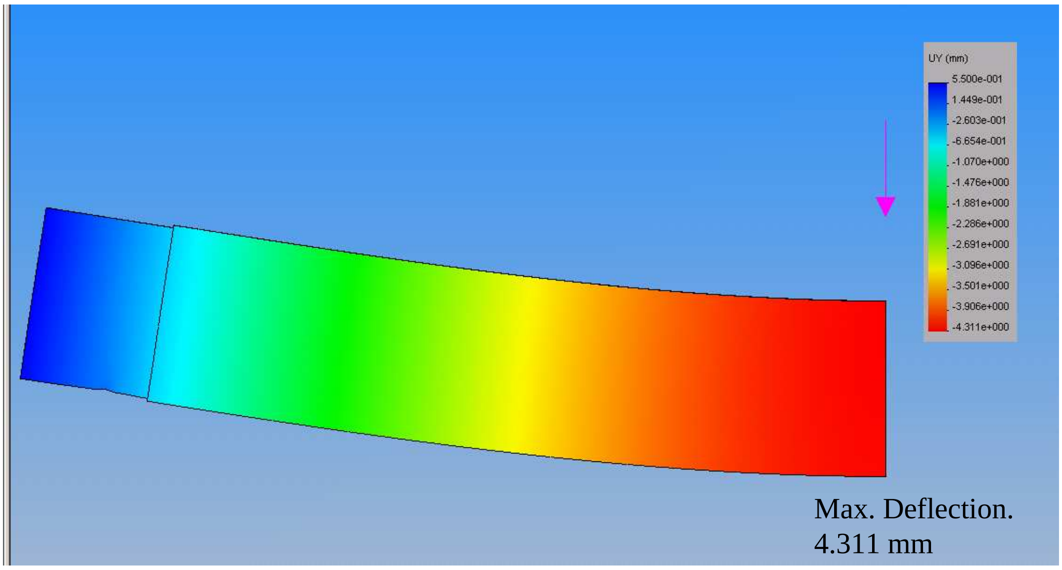


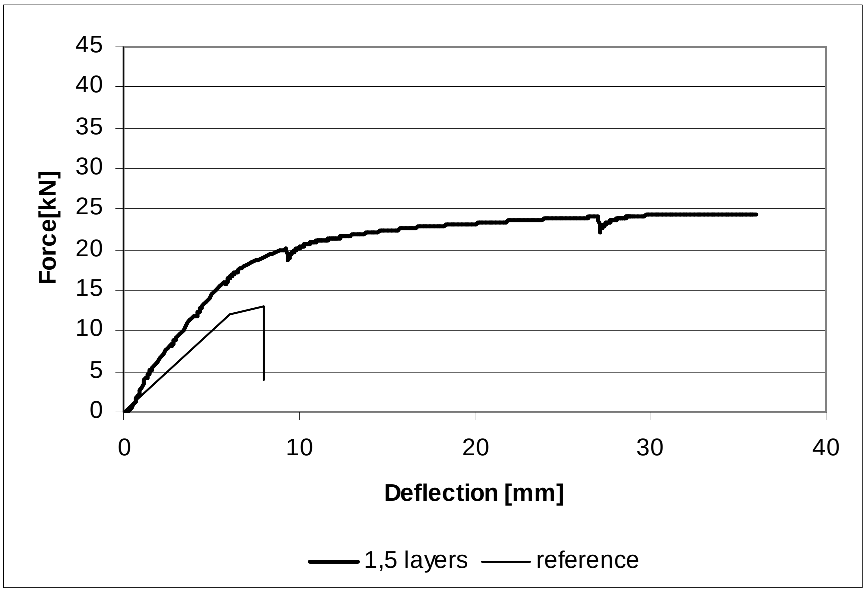
Figure 16: Deflection of the beam



EXPERIMENTAL RESULTS

The results of our experimental beams were very interesting. In figure 17 we can see the reference beam and the 1.5 layer reinforced beam. In the calculations above we expected a 4.311 mm deflection for 12 kN load. Looking for the results obtained from the testing machine, we have the load 12.08531 kN with a 4.222 mm deflection. This is a very good result, because is less than 3% of error.

Figure 17: Three point bending for groups A and REF



For the rehabilitated beams, it was impossible to make a simulation. The concrete and the steel have already damage, which makes this simulation impossible. In figure 18 we can see the beams that have been reinforced.

Figure 18: Three point bending for groups REF, B and C

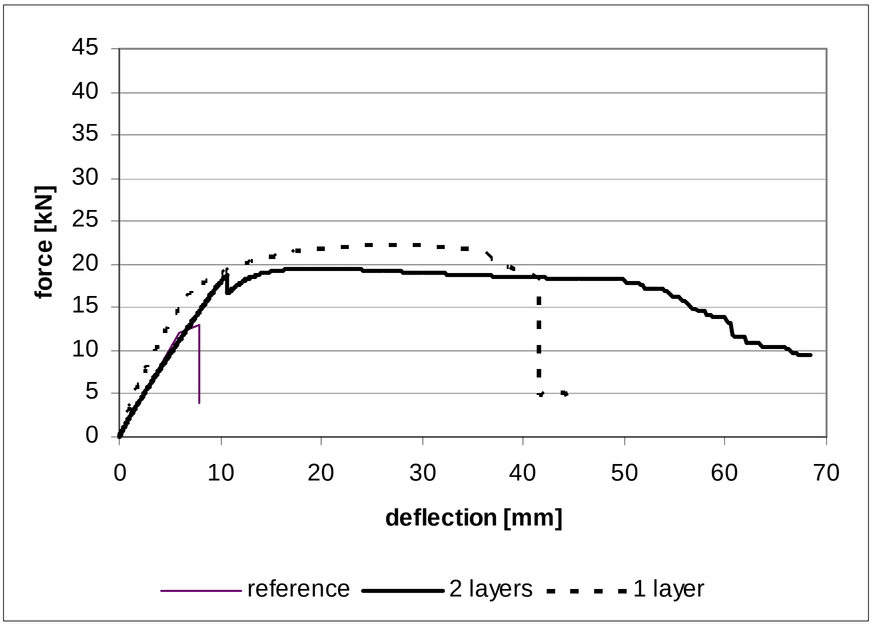


Figure 19: Four point bending for group D

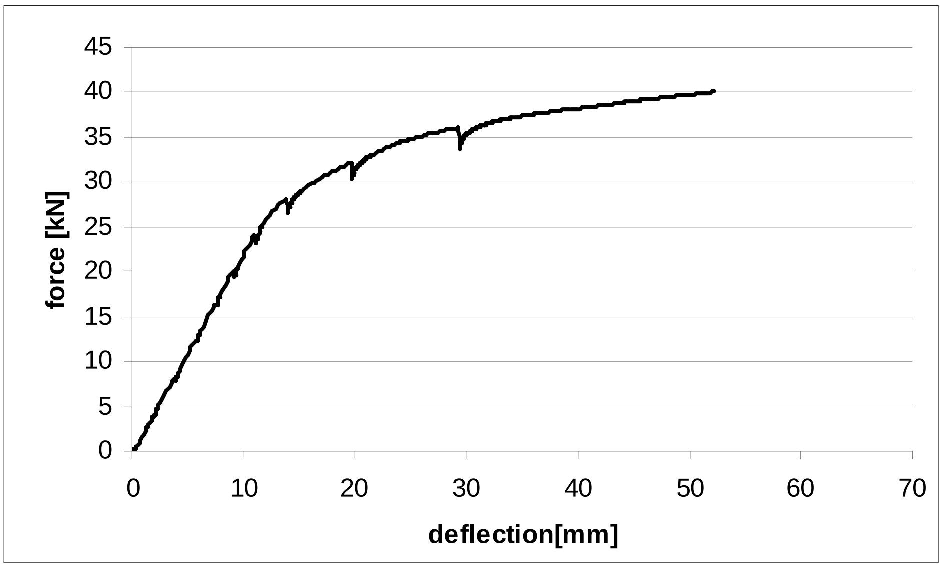


Table 2: Beams results

Group	Beam type	Nº layers	Test type	M. Load [kN]	Def. [mm]	Bk L. [kN]	Def. [mm]
Ref	New	0	3 Point	13	8	13	8
A	New	1.5	3 Point	24	34	24	36
B	Rehabilitated	1	3 Point	22	28	20 #	37 #
C	Rehabilitated	2	3 Point	29	18	18 #	52 #
D*	New	1.5	4 Point	43	52	-	-

* Beam didn't went till rupture
# Breaking Load at 10% of Maximal Load

Looking only for the three point bending tests, we can see that the reinforced beams are almost able to support twice the load of the reference beam. In addition to that, a four times more deflection makes this process a very interesting one. The deflection decreases with the increase of the number of layers in the maximum load deflection point. However the deflection when rupture occurs increases with the number of layers. Another interesting aspect is that the new beams have a violent rupture, very different from the rehabilitated. In those beams the load decreases gradually and slowly. We measure the breaking load when it decreases 10% from the maximum. Rehabilitating a beam is a very good solution, because we can almost obtain the same characteristics as in a new and reinforced one. In figure 20 and 21 we can see the test and the rupture of the reinforcement.

Figure 20: Bending of one of the C beams

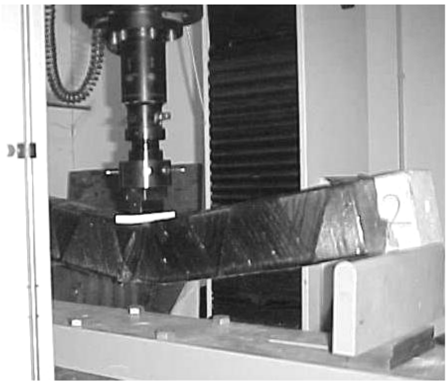
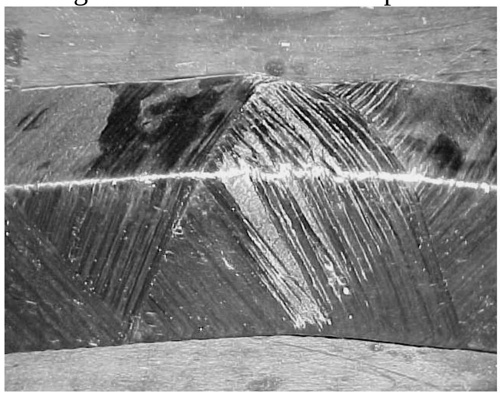
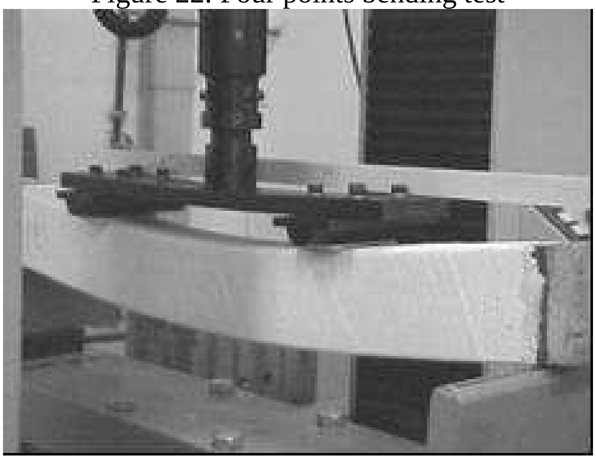


Figure 21: Reinforcement rupture



In the four point bending tests we have found some setup problems, and it was impossible to make the test until the rupture of the beam, as the supports moved away from the initial position. For that reasons we had to change the testing machine setup. We hope to solve the problems as quickly as possible, so that we can test again this solution. Figure 22 shows the setup test for the four point bending test.

Figure 22: Four points bending test



CONCLUSIONS

The reinforcement or/and rehabilitation of concrete beams using the filament winding technology with CFRP, is a good alternative to the conventional ways. It gives the possibility of almost doubling the load. The difference between the new beams and the rehabilitated ones is very low. The weight increment is of 0.8 kg. Hence, a cracked beam can be almost as trustee as a new one. The most difficult part in all this process is winding the beam. Only beams that allow access from all sides can be reinforced using this technique. For that matter a new concept of filament winding machine design must be implemented to solve this problem. A prototype is already in the study fase.
In future work, reinforcement of pillars is going to be implemented in our study.

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