FATIGUE BEHAVIOUR OF REINFORCED CONCRET BEAM STRENGTHENED WITH A CFRP REINFORCED SYSTEM

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ABSTRACT

The flexural strengthening and rehabilitation of reinforced concrete elements, with CFRP reinforced system based in unidirectional composites, exhibit superior fatigue performance to that of steel.

Previous research has [1] shown that the dominant factor in the fatigue of FRP-strengthened beams is the fatigue of the steel rebars structure.

For the correct understanding of the fatigue behaviour of CFRP-strengthened beams considering ageing effects, a reduce scale beam experimental testing programme was implemented in the *scope* of a research and development project "POCTI/36059/ECM/2000 – Behaviour and Design of Concrete Structures Strengthened with FRP Considering Ageing Effects", supported by "Fundação para a Ciência e Tecnologia, Portugal".

The CFRP reinforced system (unidirectional composite strips) has been calculated to be able to double the static ultimate load of the reinforced concrete beam. The flexural fatigue behaviour of the beams was analysed, utilising an Instron servo-hydraulic four points bending apparatus testing, and different load parameters.

1. INTRODUCTION

The behaviour of concrete beams under fatigue load is still in the beginning of research [1]. The use of unidirectional CFRP composite reinforcement in those beams changes the behaviour of the beam. Our goal in this work is to make fatigue tests in concrete beams with internal steal rebars, with and without a unidirectional CFRP composite reinforcement system. With these tests we expect to see if the composite reinforcement allows us to improve the mechanical properties of the beam in static and dynamic loads.

2. BEAM CONFIGURATION

The beams to bee tested are made of C40/50 concrete with a reinforced steal structure inside. The steel used is the A500 with $f_{sd} = 435$ MPa.
The beam is 2.5 m long and with a 0.10×0.20 m^2 transversal section.
The beam cross section configuration is shown in Fig. 1.

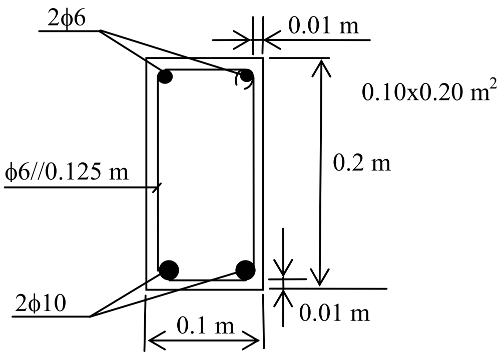

Fig. 1. Beam configuration

The beams were made in a Portuguese specialized company (Maprel) between June and August 2001.

After inspecting the beams, we arrive to the conclusion that the steel rebars structure was not made according to the specification. So, the covering of the surface was not 0.01 m but instead 0.025m. This is important to understand the beam behaviour to damage.

3. REINFORCEMENT SYSTEM (PREPARATION AND APPLICATION)

The reinforcement system is made using a CFRP unidirectional laminate made by pultrusion in our installations [2-4]. The Epoxide/Carbon laminate made is 50 mm width and 1.4 mm thick.

Fig. 2. The reinforcing material

The characteristics of this material are:

- Fibre mass percentage: $m_f = 70\ \%$
- Young modulus: E = 160 GPa
- Tensile strength: $\sigma \geq 2400$ MPa

For assembling the reinforcement with the beam we used the commercial product Epoxy Adhesive Past: **Fermapoxy (Weber & Broutin)**

- Young modulus: E = 5.1 GPa
- Traction tensile strength: $\sigma = 22.4$ MPa
- Shear strength: $\tau = 14$ MPa

For the surface preparation and to improve the adhesion between the beam and the reinforcement we used an Epoxy Resin: **Reapox 520/526 (REA Industries)**

- Young modulus: E = 3.5 GPa
- Traction strength: $\sigma = 80$ MPa

The beam had to be cleaned and prepared for the resin application [5-6]. An abrasive millstone was used to clean the surface. Cleaning the dust was the next step before applying the epoxy resin. After a 24 hours cure, we applied the adhesive past in the beam and in the reinforcement. After the reinforcement application, and a 7 days curing at ambient temperature (more or less 20 ºC) the beam was then ready [7].

Fig. 3. Beam with the reinforcement

4. TESTING EQUIPMENT AND TESTING PROGRAM

For our tests we used a modular structure for multiaxial fatigue tests. This structure is equipped with servo hydraulic Instron actuators with capacities of 100 kN, 250 kN and 500 kN (Fig. 4).

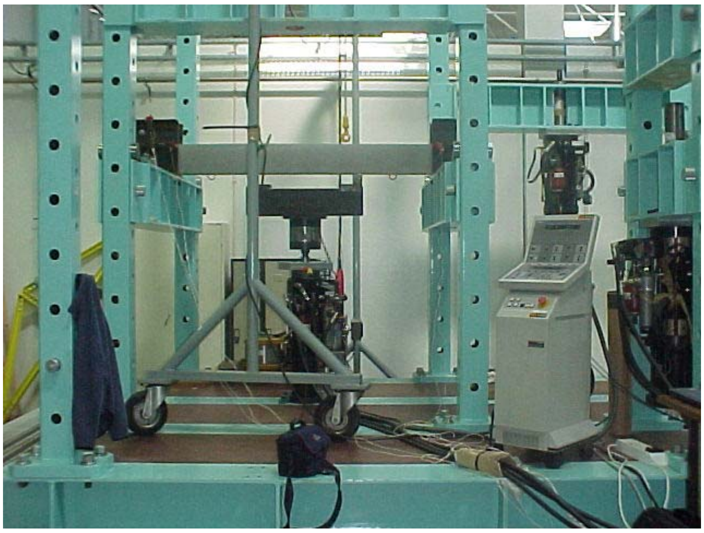

Fig. 4. Test equipment

For this structure we designed an assembly for a four points bending test that permits us testing beams with 2 meters length and with a 12.5 x 25 cm^2 section. The distance between the two load points can be from 50 to 75 cm.

The setup utilised for our testing program is show in Fig. 5.

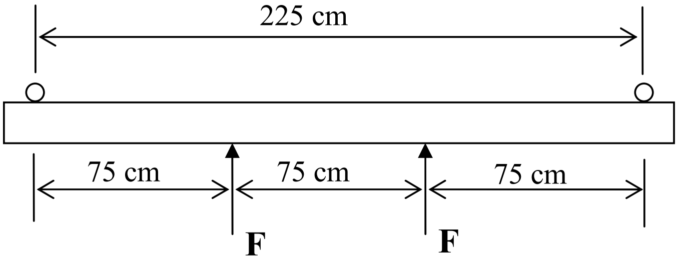

Fig. 5. Test setup

The testing program consisted of two kinds of tests. First, the static tests, needed to characterise the beam and to establish the rupture load value. We tested two beams without the CFRP reinforcement (reference beams) and two with the CFRP reinforcement. Second the dynamic tests. We tested several beams at a frequency of 1 Hz and different dynamic loading cycles, between 20% and 90% of the rupture static load of the reference beam.

5. STATIC TESTS

The static test program began in November 2002 and the tests preformed are shown in Fig. 6. The load scale is the total applied load, sum of the two loads applied to the beam. The resistant bending moment is also calculated and referred in the text.

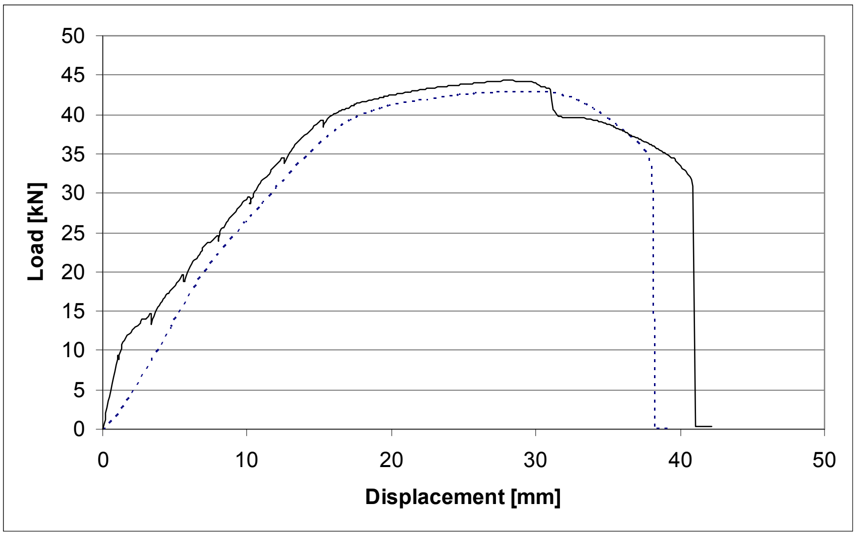

Fig. 6. Reference beams graphic

Here we can see that the maximum load for the reference beams without the CFRP reinforcement (Fig.6), was 43 kN and occured when the displacement was 29.6 mm (average). The correspondent resistant bending moment was 16.09 kNxm. The first beam tested (in the graphic with dots) was used for different tests to check up the set up at several loadings before the beginning of the test. That is why the graphics have some differences in the beginning. It must be said that the start of the second beam (in the graphic with the continuous line) is the correct one, because that difference is due to the initial concrete crack load that occured at 12 kN and in the first beam we can't see this because it occured in previous loadings.

Fig. 7. Rupture of a reference beam.

In Fig. 7 we can see the rupture of the second reference beam. The crack happened close to one of the loading points and the rupture occured when the tension steel rebars cracked.

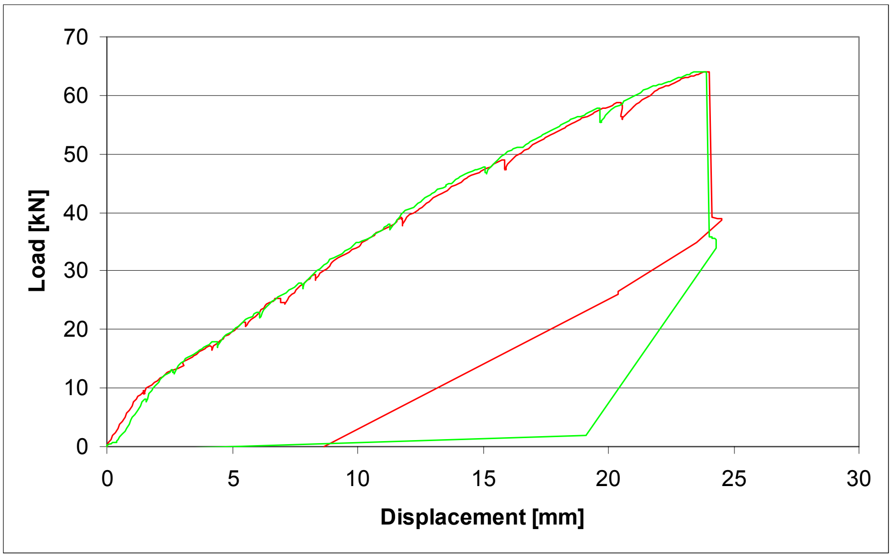

Fig. 8. CFRP Reinforced beams graphics

Analysing the static tests of the CFRP reinforced beams (Fig. 8), the maximum load was 64 kN and the displacement was 24 mm (average). The corresponding resistant bending moment is 24 kNxm. The improvement in load is significant, looking to the graphic we can see that after the initial concrete crack load at 12 kN, the beams developped in an almost elastic curve until rupture. The evolution is normal, but these rupture is not due to the peeling effect or to the rupture of the composite, but due to the shear craking of the concrete in the interface with the steel rebars.

Fig. 9. Rupture of the reinforced beam

The 25 mm covering is too much and is possibly the cause of this kind of rupture. In fig. 10 we can see the failure mode.

6. FATIGUE TESTS

A fatigue research program tests is still in the first steps. In this work, fatigue tests in concrete beams with internal steel reinforced rebars, simple and strengthened with a CFRP Reinforced System, in the tension zone of the beam were made.

A four point bending test is made to a references beams without CFRP reinforcement, with a sinusoidal amplitude load of 30 kN, corresponding to a 20% (8,5 kN) and 90% (38,5 kN) of the static maximal load of the beam.

For the beams with CFRP reinforcement the sinusoidal amplitude load was 32 kN and 38kN corresponding to a 20% (13 kN) and 70% (45 kN) or 20% (13 kN) and 80% (51 kN) of the static maximal load of the beam. All tests were made with a frequency of 1Hz.

Tests results:
Beams without CFRP reinforcement 20% (8,5 kN) and 90% (38,5 kN) – 121 718 cycles (average)
Reinforced beam with CFRP reinforcement 20% (13 kN) and 70% (45 kN) – 648 480 cycles
Reinforced beam with CFRP reinforcement 20% (13 kN) and 80% (51 kN) – 167 056 cycles

Fig. 10. Fatigue rupture of the reinforced beam (20%-70% máx load)

The reinforced beam with CFRP tested with the sinusoidal amplitude load of 38kN corresponding to a 20% (13 kN) and 80% (51 kN) of the static load of the beam, was instrumented with strain gages sensors (Fig. 11), to evaluated the damage evolution of the beam during the test.

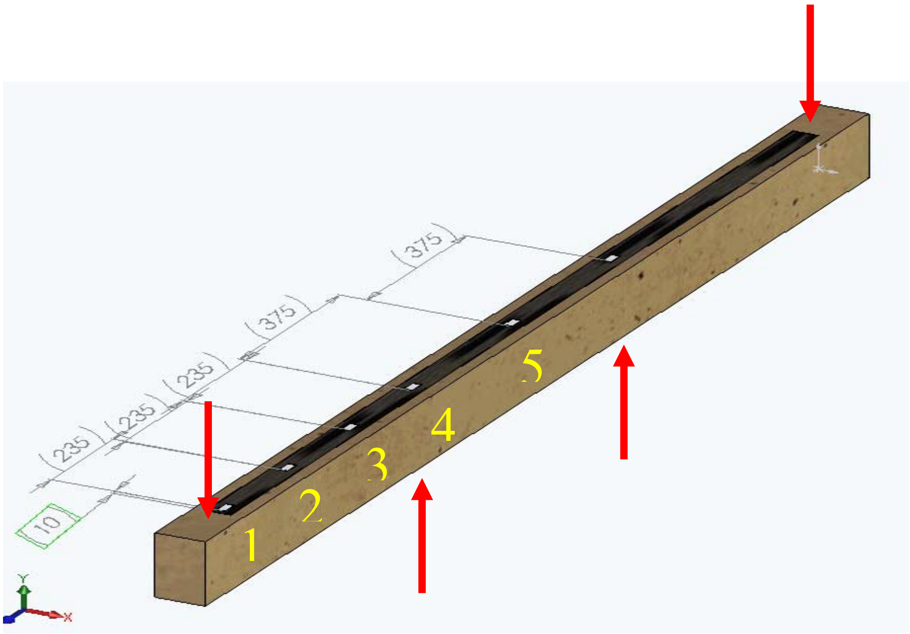

Fig. 11. Strain gages sensors placed on the surface of the CFRP laminate

In Fig. 12 to 13 we present the graphics of the strain values readings from de strain gages sensors. In Fig. 14 it is possible evaluate the loss of stiffness of the beam during the test observing the change of the displacement at the middle of the beam.

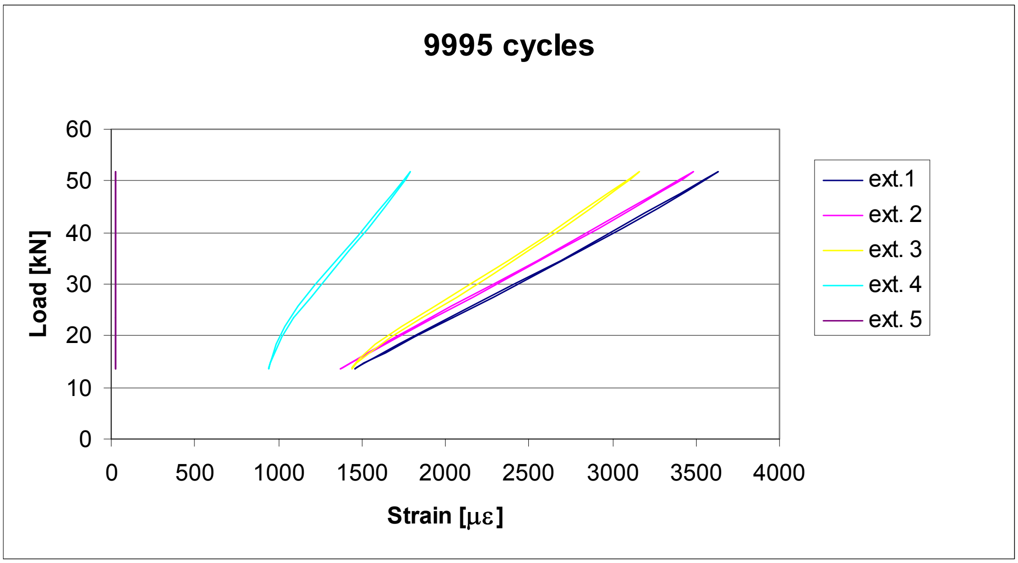

Fig. 12. Strain values during the 9995 load cycle for strain gage 1 to 5

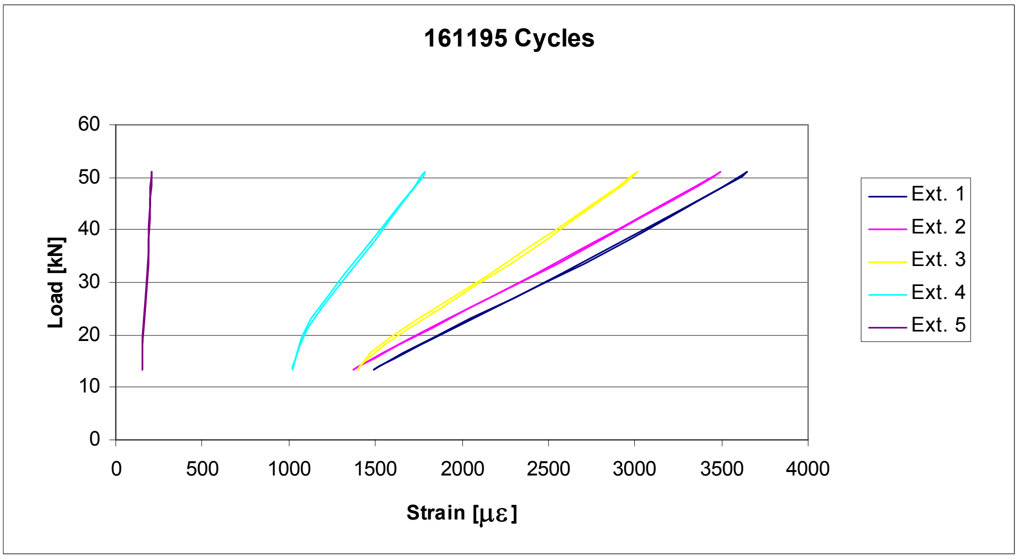

Fig. 13. Strain values during the 161195 load cycle for strain gage 1 to 5

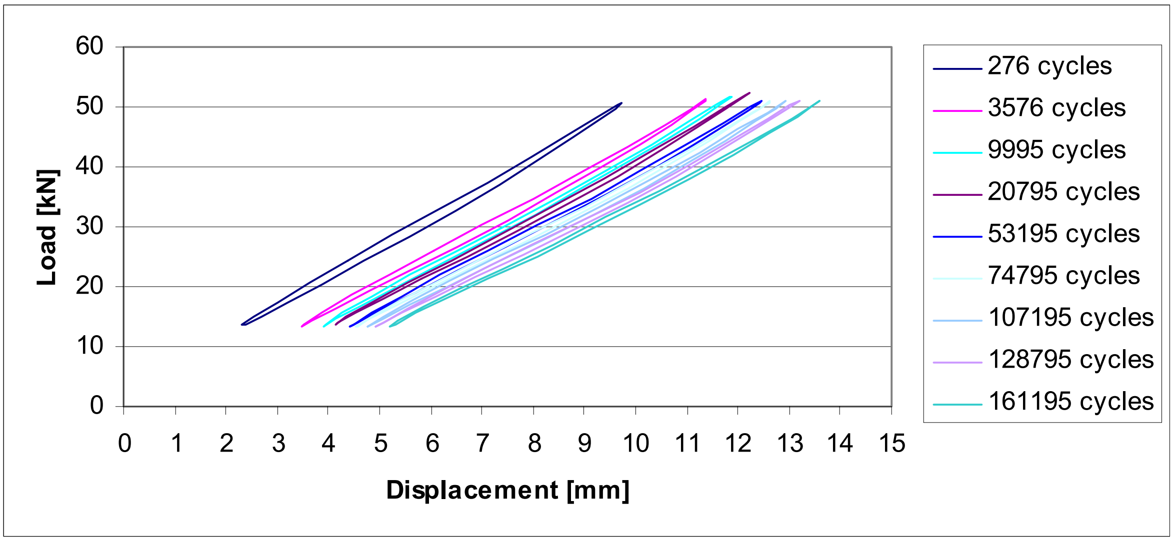

Fig. 14. Loss of stiffness (change of the displacement at the middle of the beam)

7. CONCLUSIONS

From the static and fatigues tests carried out, it can be seen, that the behaviour of the reinforced concrete beams strengthened with a CFRP Reinforced System, are very interesting.

The utilisation of a sinusoidal load with a maximal load of 70% of maximal static load of the beam, corresponding to a 1,42 security coefficient, gives a $6x10^5$ life cycles, and is very promising for the fatigue behaviour of the beam.

It is necessary to advertise that the 1Hz testing frequency, was higher than the usually loading frequency of concrete structures. So with security we expect a real number of life cycles grater than $1x10^6$ for the same load conditions at lower application frequencies.

Further tests to understand the fatigue behaviour of carbon fibre reinforced beams are been made.

ACNOWLEDGEMENTS

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