Guidelines for a quality control procedure to ensure sound strengthening and rehabilitation of concrete structures using FRP

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ABSTRACT: In this paper, a discussion will be made regarding the procedures to be followed for the quality control of the strengthening and rehabilitation of concrete structures using carbon fibre/epoxy composites. Bearing in mind the different relevant parameters, which may consider short and long – term behaviour of the application of these materials, the procedure will give information concerning: specifications/quality assurance; quality control of the reinforcement system; quality control of the adhesive; quality control of the surface; monitoring

The work presented follows research work carried out in Portugal, together with collected and treated information from material suppliers.

Résumé: Une discussion concernat le processus surl' assurance de qualité pour le renfort et rehabilitation, avec composites carbon/epoxide, de structures en béton armé sera présentée. En prenant compte des differents parameters relevant, que peuvent considerer le comportement à court et long temps, le processus donnera information sur: specifications, assurance de qualité, control de qualité du renforcement, control de qualité de l'adhésive, control de qualité de la surface et monitoring.

Le travail considére recherché faites en Portugal et information traitée des fournisseurs des matériaux.

KEY WORDS: composites, quality control, concrete structures, mechanical behaviour.
MOTS-CLÉS: composites, control de qualité, structures de béton, comportement mécanique

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1 INTRODUCTION

The strengthening and rehabilitation techniques of concrete structures have been moving, recently, for the use of CFRP – Carbon Fibre Reinforced Plastic (epoxy resin) either as a laminate in a strip shape or as semi-product (prepreg like) to be cured in-situ. In the first case, the strips are bonded to the concrete structure, with or without pre-stress. In the second situation, after the application of a resin rich adherence coating to the concrete, the semi-product will be impregnated with an epoxy resin promoting an exothermic reaction that will end up with the cure of all system.

Today, there are quite a lot of different solutions for the above purpose (wet lay-up systems and systems based on prefabricated elements) correspond to several manufactures and suppliers, based on different configurations, types of fibres, adhesives, etc …, and there is a need for an efficient Quality Assurance and Control to avoid costly surprises and to produce a sound rehabilitation or strengthening of the structure. An interesting approach can be seen in Machida (1997).

2 QUALITY ASSURANCE AND SPECIFICATIONS

It is essential to define clearly what are the requirements for the reinforcement system. Hence, the project of the structure must be available and the actual conditions of the concrete must be evaluated using non-destructive or very little intrusive tests. Particular conditions, such as fire resistance, have to be considered.

As the reinforcement system has a polymeric matrix, there is a need to identify clearly the environmental conditions, particularly temperature and temperature fluctuations, as this may affect the short and, even more, the long-term behaviour of the system. For the same reason, although in a small part, it is necessary to define the type of loads in respect to the possible place where the reinforcement will be applied, as well as their frequency and the likelihood of having vibrations and their possible magnitude. Moreover, the design concepts and safety must be based in the EUROCODE 1 and EUROCODE 2, following the philosophy of limiting states.

In order to have Quality Assurance, it is necessary the integration of procedure to verify the conformity at four levels, Juvandes (1999):

- Certification of reinforcing materials;
- Qualification of suppliers and applicators;
- Control of the application procedure: inspection of local conditions, inspection of surface preparation, inspection of primer and adhesive application, inspection of CFRP composite, inspections of the bonding;
- Inspection in service and maintenance

3 QUALITY CONTROL OF THE APPLICATION PROCEDURE

3.1 *Inspection of local conditions*

Typically, one can do the following:

- ❑ Detection and measurement of the recovering of the internal armatures
- ❑ Esclerometric tests
- ❑ Ultra-sonic tests, by the indirect method to evaluate the depth of the cracks
- ❑ Pull-off tests, to determine the tensile strength of the superficial layer of the concrete

3.2 *Quality control of CFRP system*

Unless the materials are of proven quality and performance the following tests according to standard test methods have to be made:

- ❑ Tensile and bending tests
- ❑ DMTA-Dynamic Mechanical Thermal Analysis to evaluate the influence of temperature in the modulus and to determine Tg
- ❑ Fatigue and creep tests
- ❑ Coefficient of thermal expansion
- ❑ Nominal mass density
- ❑ Fibre content
- ❑ Moiture absorption and chemical stability

Some of the above tests must also be conducted after accelerated ageing.

In Table1, it can be seen, to illustrate the importance of some parameters, the variation of tensile strength, strain at rupture and tensile modulus as function of ageing conditions for two particular systems of reinforcement, Bravo (1999).

The samples were subjected to 30 cycles of one day in the following conditions: ‘Winter’ 14 h at –5ºC, 10 h at 15ºC‘Summer’ 10h at 20ºC, 14 h at 50ºC.

Table 1 – Mechanical properties as function of ageing conditions for two systems
(A – Replark CF-sheet, Mitsubishi Chemical corporation)
(B – INEGI CFRP-laminate strip 50x1.4)

Sample		Tensile strength (MPa)	Strain at rupture %	Modulus (Gpa)
Non-Aged	A	331	1.1	26.7
	B	1 300	0.8	152
Aged (Winter)	A	334	1.2	24.7
	B	1 310	0.9	151
Aged (Summer)	A	340	1.5	24.6
	B	1 310	0.9	150

3.3 *Primer and adhesive*

The adhesive is a key element in the reinforcing system. Hence the following characteristics have to be known:

- Glass transition temperature
- Shrinkage
- Bond strength
- Shear strength
- Static modulus
- Creep modulus
- Coefficient of thermal expansion

The results of some tests made by Gonçalves(1998) to characterize two adhesives are presented in figure 1 and 2 in order to illustrate typical behaviours.

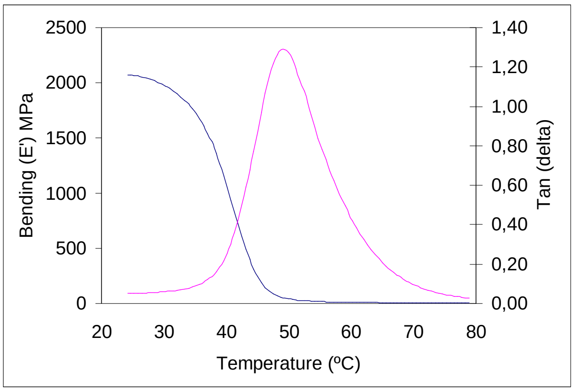

Figure 1. Bending modulus versus temperature for Epotherm like adhesive

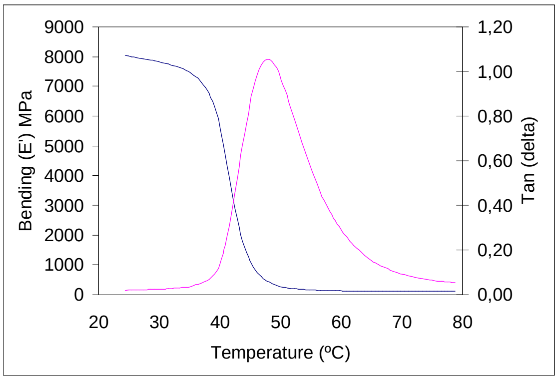

Figure 2. Bending modulus versus temperature for CEMENT like adhesive

For the case of adhesives, the stress/strain curves must be obtained considering equilibrium conditions in respect of temperature and relative humidity, Esteves (1991).

3.4 *Bonding inspection*

The bonding of the composite system to the concrete has to be inspected to detect any problem. The method to be used must be able to detect voids, displacements or delaminations. Hence, thermographic and ultrasound methods, together with ‘tap test type’ method can be used.

The bond performance can be evaluated by means of direct pull-off tensile testing of the CFRP/bonding agent/concrete substrate combination. Test specimens are obtained by taking cores from the applicability test specimen. Tests are performed at 7 days and 14 days under the specified curing conditions.

4 APPLICATION

To guarantee a sound reinforcement, the following procedures may be followed.

4.1 *Surface preparation*

In order to have an adequate bonding, the surface should be roughened and made laitance and contamination free. This must be cleaned by means of blasting (sand, grit, water jet blasting) or grinding. The surface must be dry and free of any oil, grease or foreign matter likely to impair bonding.

4.2 *Anchorages and couplers*

Bearing in mind that the mechanical properties of the reinforcement system may be, significantly, affected by anchorages and couplers. Hence, unless they are placed exactly according to the design specifications, there is a strong possibility of premature failure. They must be corrosion-proofed to avoid reduced durability. A thorough inspection has to be made to these materials, and a specific control technique on the anchoring work must be followed.

4.3 *Application*

The application of the CFRP reinforcement system should be performed by qualified and experienced workers, in accordance with any special specifications given by the manufacturers of adhesives and CFRP reinforcement, provided that they are not at variance with these specifications unless backed up by adequate research data.

Care must be taken to avoid excessive bending or impact during placement of CFRP, as well as excessive temperatures, chemicals, welding sparks and over-tightening.

During application, the working area must be clean and having the adequate ambient conditions to promote cure of the polymeric systems. If necessary, an external source of heat must be used to get complete cure.

4.4 *Handling and storage*

Bending beyond the limits, shocks, dragging during transport; temperature, humidity, dampness or direct sunlight during storage; welding sparks and chemicals may affect the reinforcing system prior to start the work. Hence, CFRP must be handled and stored carefully to prevent any damage caused by the referred factors.

Anchorages and couplers and any material used for this purpose must be carefully stored to have them clean and undamaged.

5 MONITORING

Composite materials are particularly prone to become smart materials and to make smart structures. The laminate is made in such way that gives the possibility to incorporate fibre optical sensors and to perform remote monitoring. The application of this technique has been described by Frazão (2000) and is illustrated in figure 3 and 4.

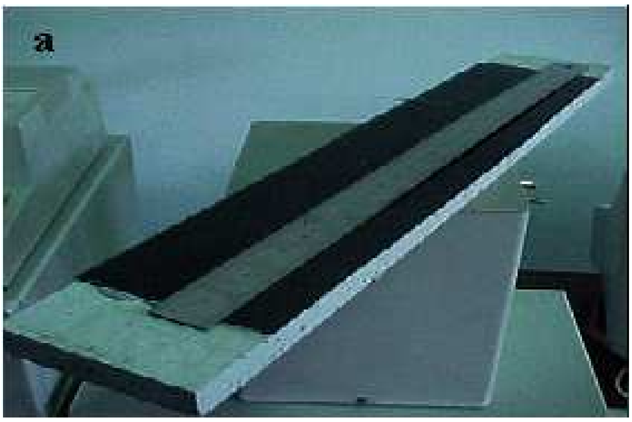

Figure 3. CFRP reinforced concrete plate containing FBG (Fiber Bragg Gratings) sensors.

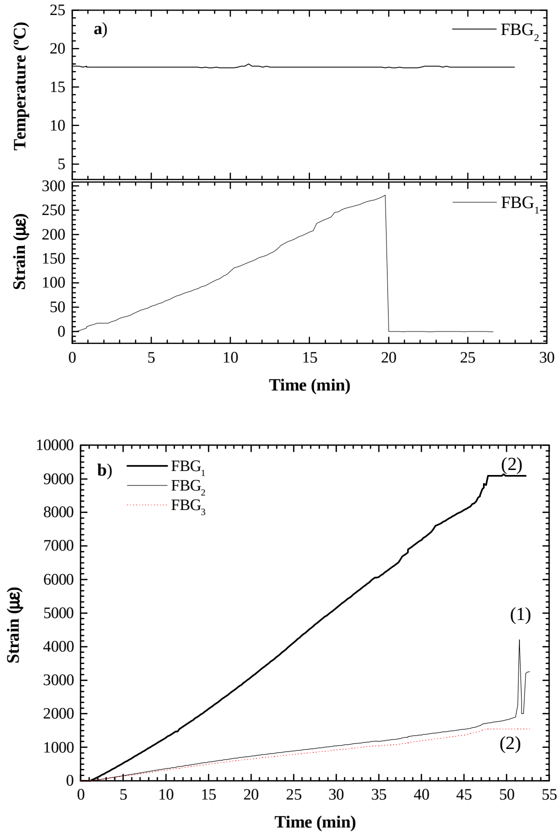

Figure 4. Test results of the strain and temperature evolution of the a) non-reinforced concrete plate and b) reinforced concrete plate containing 3 FBG sensors, Frazão (2000)

Traditionaly the monitoring of the CFRP reinforcement system can be made by the utilisation of electrical stain gauges illustrated in figure 5.

Figure 5. Monitoring of the CFRP reinforcement system applied on “Nossa senhora da Guia Bridge”, Ponte de Lima, Portugal.

6 CONCLUSIONS

A sound strengthening and rehabilitation of concrete structures can be obtained providing that an adequate design methodology is followed, good surface preparation is done, application conditions are correctly executed and a quality control methodology is applied to avoid catastrophic surprises.

A smart monitoring system can be used, in order to have a close eye to the evolution of the reinforcing system.

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