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BEHAVIOR OF CONCRETE CONFINED BY GLASS AND CARBON FIBERS

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Abstract. *Fiber-reinforced polymer composites are widely applied for strength and ductility enhancement of reinforced concrete members. The improved characteristics of concrete cylinders owing to confinement with different numbers of layers of concrete and glass fiber fabrics were investigated. Among of the objectives of this work was to find out whether and how the relative position of different types of fabrics influences the characteristics of confined concrete. To this end plain concrete cylinders, with dimensions 305 mm height and 152,5 mm diameter that were wrapped with carbon and glass polymer composites have been tested. Both simple jackets, i.e. of only one kind of fibers, and composite jackets, i.e. that consist of more than one fiber types, namely carbon and glass, were tested. For the prediction of the test results models found in the literature have been used which were previously evaluated against available experimental data. The analytical models used were selected among others owing to the accuracy of their predictions compared to experimental results. The behavior of the specimens tested is compared to the predictions of the models selected and the observations are discussed.*

1 INTRODUCTION

Confinement of structural elements with fiber-reinforced polymer composites (FRPs) results in significant improvement of the concrete strength and ductility characteristics. Increase of the compressive strength, the deformation capacity as well as the bond between longitudinal reinforcement bars in anchorage regions are among the beneficial effect accorded to FRP confinement. Ease of application combined to the fact that the stiffness characteristics of the reinforced bearing members are not altered, are important factors for opting for this method among others, e.g. concrete jacketing.

A lot of research has been performed in this area. Experimental work consists in testing mainly concrete cylinders of different dimensions, since they are easy to construct and to test. Furthermore, numerous stress-strain models have been proposed for FRP- and steel-confined concrete since the 1980's. The first stress-strain models for FRP-confined concrete evolved from similar models proposed for steel-confined concrete [1]. Many models are offered in the literature, some assuming a bi-linear curve [2], other a two-segment parabola [3] with a smooth transition, or they are based on an incremental iterative numerical approach [4]. It should be noted that although much progress has been achieved towards understanding of the stress-strain behavior of FRP-confined circular elements, much work still has to be done for the case of rectangular columns [5].

The objective of this work was to investigate the influence on various layers of carbon and glass fiber fabrics on the confined characteristics of concrete. It was also intended to find out whether and to what extent the relative position of glass and carbon fabrics in respect to the concrete surface influences the performance characteristics of plain concrete cylinders [6]. To this end plain concrete cylinders with dimensions 305 mm height and 152,5 mm diameter which were wrapped with one, two and three glass and/or carbon layers, with different layering relative positions, have been tested in axial compression. Specimens with one to three layers uniquely of carbon or glass fabric were also tested for comparison purpose. Previous similar research in this area by Lin and Chen [7] has concluded that the closer the glass fabric to the concrete surface is, the more the compressive concrete strength increases. They attributed this performance to the brittle behavior of the comparatively stiffer carbon fabric, which leads to stress concentration along the concrete cracks.

In what follows, the best models resulting from this investigation are applied to experimental results found in the literature and also to the specimens tested. The test results, as well as the analytical predictions will be briefly presented and discussed.

2 TEST RESULTS

This experimental work, part of which is presented here, was carried out in the Laboratory of Concrete Technology and RC Structures in the University of Thessaly, Greece. Plain concrete cylinders, with height H=305 mm (12 in) and diameter D=152,5 mm (6 in) were reinforced with FRP jackets and subjected to axial compression. The concrete used was ready mixed intended to have 28-day characteristic compressive strength C20/25 (cylinder/cubic strength in MPa). Three plain concrete cylinders were subjected to axial compression in order to define the unreinforced characteristic properties of concrete. Different fiber layouts were tested: “Simple” jackets consisting of only one type of fabric, either carbon or glass, and “composite” jackets, consisting of various layers of carbon and glass fibers, placed in different relative positions with reference to the concrete surface. The cylinder specimens were subjected to axial compression by means of a hydraulic DMG machine. The axial and lateral strains of concrete were measured by means of two DCDTs adapted in a special testing arrangement (Fig. 1c). One DCDT was placed at vertical direction and one at horizontal direction, both at mid-height of the cylinder. The effectiveness of the confinement was evaluated by comparing the enhancement of the compressive strength and the ultimate strains, axial and lateral, of the confined cylinder compared to the respective properties of the unconfined cylinder.

For the confinement of plain concrete cylinders dry application process was applied. Unidirectional woven fiber fabrics were used, namely carbon SikaWrap-230 C and glass SikaWrap-430G. The direction of the fibers was parallel to the plane of the cylinder diameter. A 2-part epoxy impregnation resin was applied, Sikadur-330. Epoxy components were meticulously weighed to obtain the correct proportions and they were mixed for 4 minutes with a mixing spindle attached to a slow speed electric drill according to manufacturer’s guidelines. A clean container was used each time for mixing. The epoxy was then applied on the cylinder by means of a roller. Consecutively, the fabric was wrapped as tight as possible around the epoxy-covered cylinder and then the fabric was impregnated with epoxy. The overlapping length of each layer amounted to 100 mm. In case more than one layer was applied, the same procedure was followed. If only two layers were applied the second layer was placed at 180-deg. from the first layer. If three layers were applied, the fabrics were placed at angles of 120-deg.

(a) (b) (c)

Figure 1. (a) Roughening of the concrete interface before the application of the FRPs
(b) Epoxy components are weighed to obtain the proportions according to manufacturer
(c) Cylinder specimen inside the testing-rig ready for testing

The properties of the materials used as provided by the manufacturer are:

Carbon fibers: Average weight 230 gr/m^2, fabric design thickness 0,131 mm, nominal tensile strength of fibers f_j=4.300 MPa, tensile modulus of elasticity E_j=234 GPa, ultimate strain at failure $\varepsilon_{j,u}$=1,84% (calculated as the ratio of the tensile strength to the modulus of elasticity).

Glass fibers: Average weight 445 gr/m^2, fabric design thickness 0,172 mm, nominal tensile strength of fibers f_j=2.300 MPa, tensile modulus of elasticity E_j=76 GPa, ultimate strain at failure $\varepsilon_{j,u}$=3,03% (calculated as the ratio of the tensile strength to the modulus of elasticity).

Epoxy resin: Tensile strength equal to 30 MPa, tensile modulus of elasticity E=4,5 GPa, ultimate strain at failure ε=0,9%.

The name of the specimens consists of letters C, G, standing for Carbon and Glass fabric layers, respectively, following the sequence of the layer position, the first letter designating the layer in contact with the concrete surface. The number indicates the specific specimen, since three specimens were tested for each fabric layout. For example, GCC-1 is a cylinder specimen with one glass layer in contact with the concrete and two more carbon layers.

In Figure 1 some phases of the experimental process are shown.

The specimens confined with carbon fabrics failed in general in a much more explosive manner than the specimens reinforced with glass fibers. Some specimens after failure are shown in Figure 2.

Figure 2. Cylinder specimens after failure.

The increased number of layers of fiber fabrics resulted in an improvement of the overall performance in terms of peak compressive stress and respective axial and lateral strain, as was expected. It is interesting to observe, though, that as the number of layers increases the improvement offered by the extra layers diminishes (Figure 3). The most significant enhancement of the concrete characteristics is obtained for the first layer of concrete fabric (specimen C) as compared to the unconfined specimen (UC). The smallest enhancement of the behavior was observed between the specimens with two and three layers.

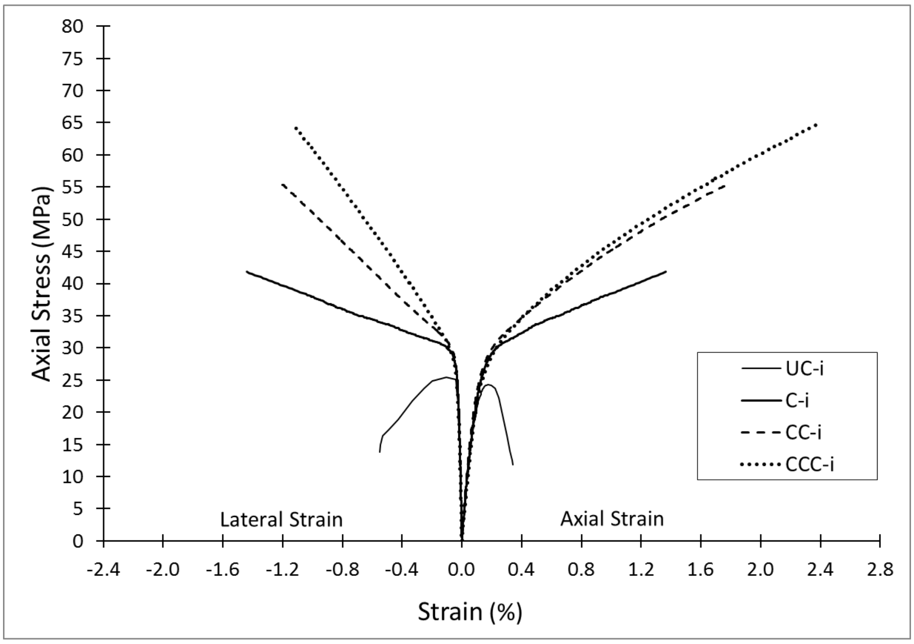

Figure 3. Experimental axial stress-axial strain curves for unconfined cylinders and reinforced with carbon fibers (UC=unconfined, and C, CC and CCC =1, 2 and 3 layers of carbon fabric).

The different placement of carbon and glass layers respective to the concrete surface did not seem to lead to different results in case of two layers of fabrics as depicted in Figure 4. The peaks stresses achieved as well as the respective axial and lateral strains were similar for specimens CG and GC. It is recalled that the first letter in the name of the specimen indicates the layer that is closer to concrete.

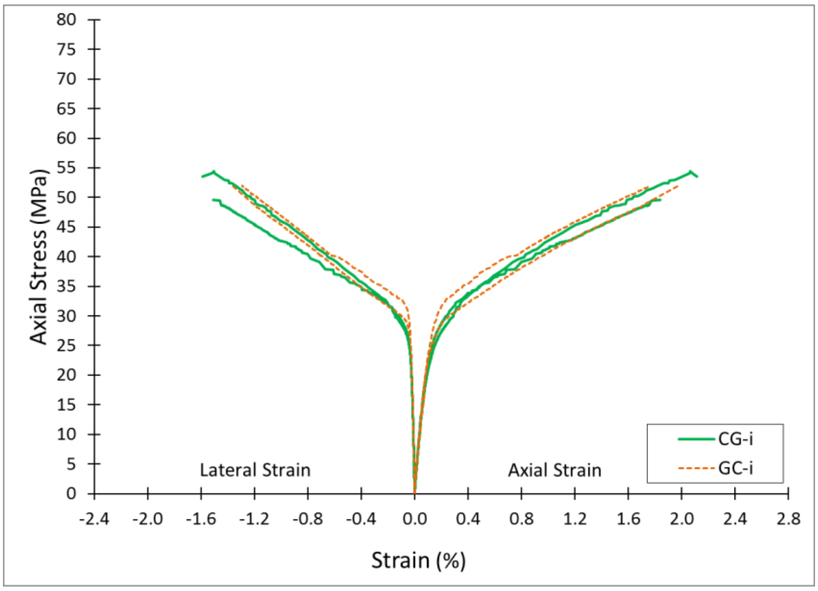

Figure 4. Experimental axial stress-axial strain curves for cylinders with one layer of carbon (C) and one layer of glass (G) fiber fabric, placed in different sequence.

3 EVALUATION OF STRESS-STRAIN MODELS FOR FRP-CONFINED CONCRETE

3.1 General

The existing models used to calculate the stress-strain characteristics of FRP-confined concrete are based on empirical assumptions, and may be classified into two broad categories: (1) design-oriented models and (2) analysis oriented models. The former treat the FRP-confined concrete as a single composite material and consist of closed forms directly derived from test results, are simpler and therefore more convenient for design; the latter consider the FRP jacket and the concrete core separately and take into account radial displacement compatibility and equilibrium conditions [8]. The analytical-oriented models are considered to be in general more versatile and accurate, and they are capable of predicting the whole stress-strain curve of the FRP-confined concrete. In the work the results of which are presented here [9], four design-oriented models [5], [10]. [11], [12] and one analysis-oriented model [4] have been evaluated with three test databases from the literature [2], [7], [8].

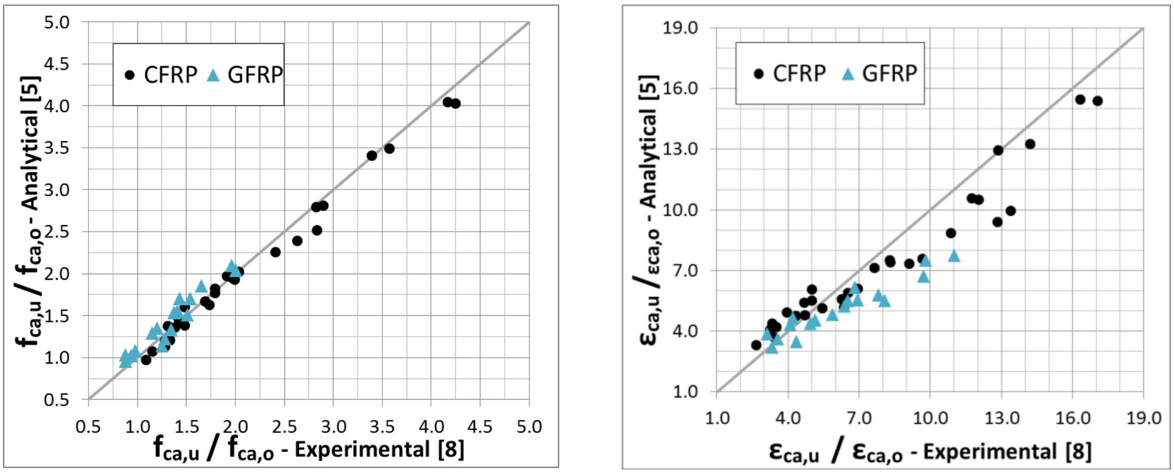

Figure 5. Confinement efficiency of Carbon (CFRP) and Glass (GFRP) fiber reinforced cylinders according to the model of Wei and Wu [5] for the test data of Jiang and Teng [8].

3.2 Predictions of test database from the literature

The prediction of the confined compressive concrete strength was good in general, while the predictions of the axial strain at peak were not equally good for all the models examined.

The best among the models examined was the one of Wei and Wu [5]. In Figure 5 the results of the application of this model on the experimental data of Jiang and Teng [8] are shown, both for peak stresses $f_{ca,u}$

and for axial strains at failure, $\varepsilon_{ca,u}$. The analytical and experimental peak stresses and strains of the confined concrete are expressed as a ratio of the respective values of the unconfined concrete, $f_{ca,o}$ and $\varepsilon_{ca,o}$.

3.3 Predictions of confined characteristics of the specimens tested

The prediction of the Wei and Wu [5] model of the peak compressive stresses for the specimens tested was also good as shown in Figure 6. The composite specimens with fabric layers both of carbon and glass are symbolized as (C+G)FRP.

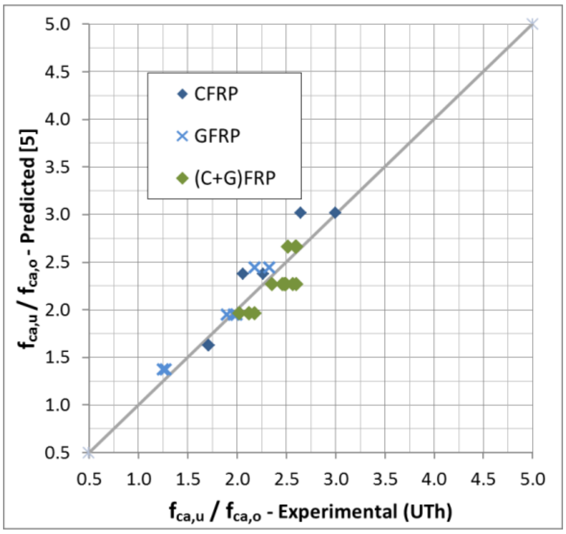

Figure 6. Confinement efficiency of specimens tested in Univ. of Thessaly as predicted by Wei and Wu [5].

The analytical model of Teng et al [4] predicts well both the axial stress-axial strain and the axial stress-lateral strain curves of the specimens tested. In Figure 7 the experimental curves of two specimens with three layers of carbon fabric are compared to the respective calculated curves.

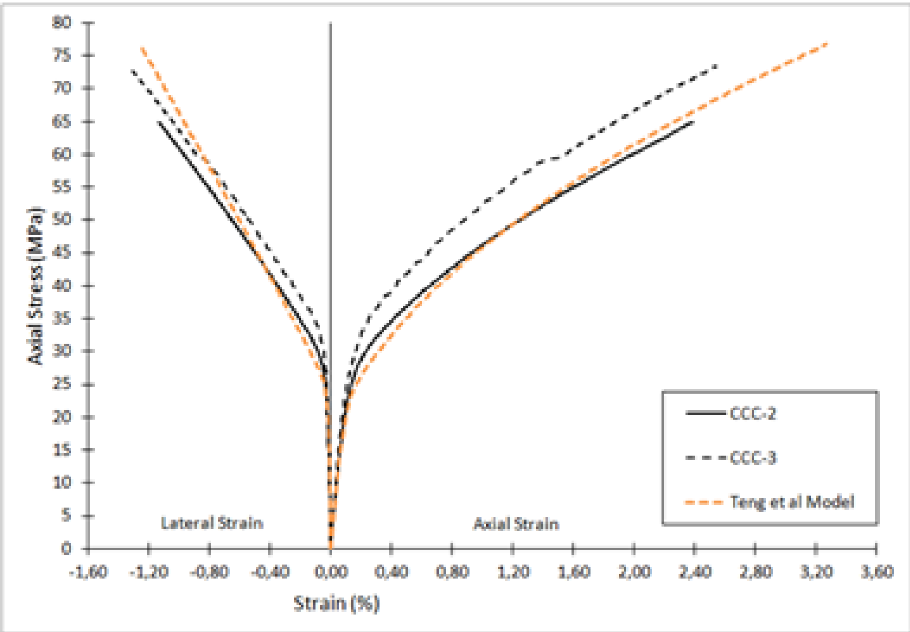

Figure 7. Experimental vs. predicted stress-strain curves [4] for specimens with three layers of carbon fabric.

4 CONCLUSIONS

The position of different types of fiber fabrics does not seem to influence the confined characteristics of concrete for two layers of fabric. The model of Wei and Wu [5] was the best among the models considered to estimate the behavior of confined concrete. The axial stress-strain curve may reliably be estimated by the analytical model of Teng et al [4]. It is noted that the estimation of strains of the confined concrete at the ultimate axial stress was not reliable according to the models examined, contrary to the predictions for strength.

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