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Behavior in compression of concrete cylinders externally wrapped with basalt fibers

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ABSTRACT

This paper gives additional information on the use of new class of composites constituted by Basalt Fiber Reinforced Polymer (BFRP) bonded with epoxy resin to concrete specimens as an alternative confinement material for compressed concrete members with respect to carbon or glass fibers. From the experimental point of view, concrete cylinders are wrapped with continuous fibers, in the form of sheets, applying both full and partial discrete wrapping with BFRP straps, and then tested in compression. For comparison, few other concrete cylinders are wrapped with Carbon Fiber Reinforced Polymer (CFRP) sheets and tested in compression. The number and type of plies (full or partial wrapping), the type of loading (monotonic and cyclic actions) and the type of fiber (basalt and carbon) are the main variables investigated. The experimental results obtained from the compressive tests in terms of both stress–strain curves and failure modes show the possibility of reducing the brittleness of unconfined concrete, resulting significantly increased both the post-peak resistance and the axial strain of confined concrete corresponding to BFRP failure. Form the analytical standpoint, a review of the available models given in the literature is made and verified against the experimental data. Finally, a proposal for analytical expressions aimed at the calculation of the compressive strength and corresponding strain of confined concrete is provided also including the strain at BFRP failure.

1. Introduction

The interest in the use of flexible Fiber Reinforced Polymer (FRP) sheets for the external wrapping of concrete compressed members has been a very popular theme in the last decades. The references available in the scientific literature are numerous; some of them are reported in Refs. [1–37] and cover many issues about the topic. The main interest is the estimation of the effectiveness of such reinforcement in increasing the strength and ductility of compressed members on the basis of the stress–strain experimental relationship of confined concrete columns [1,4,7,9,12,15]. In this regard, it could be worth to mention the work carried out by Wu et al. [15] in which the strength and ductility of confined concrete cylinders is investigated predicting whether they are able to exhibit a strain-hardening or a strain-softening response, depending on FRP confinement efficiency. A boundary value is also given to differentiate between the two types of behavior and methods for predicting the peak and ultimate strength and strain are provided. In the same study, both cylinders fully and partially wrapped are considered.

On the basis of a sufficiently wide database, many authors provided analytical models aimed to describe the response of externally confined specimens [2,5,8,10,16,17,20,21,27,28] and developed comparative studies of models on confinement of concrete cylinders reinforced with composite fibers [6]. Among the theoretical studies, design-oriented and analysis-oriented stress–strain models can be considered, such as the ones developed by Lam and Teng [8] and Teng et al. [16,21]. Particularly, in Ref. [8] a design-oriented stress–strain model is formulated including the actual hoop strain in FRP jackets at rupture, the sufficiency of FRP confinement for a significant strength enhancement and the effect of jacket stiffness on the ultimate axial strain. Such model was successively refined by Teng et al. [21]. In Ref. [16] an analysis-oriented stress–strain model is developed for FRP confined concrete in which the response of the concrete core and the FRP jacket as well as their interaction are taken into account also given a widely applicable equation for the lateral strain.

In the technical literature, also the influence of the column parameters has been investigated [3,11,29–31,34] with special insights on the effect of corner radius on stress–strain behavior of FRP confined prisms [29–31].

Furthermore, even if one of the most widespread application of FRP reinforcement is as confining material for concrete in the

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retrofit of existing columns with low unconfined compressive strength, few authors also considered the case oh high strength concrete in their experimental and theoretical studies [8,15,22,26,47].

Most of the abovementioned works are mainly concerned on carbon, glass and aramidic fibers; only few studies deal with specimens confined with basal fibers [24,25,35–37].

All authors cited above highlight that several advantages are observed by using FRP wraps compared to the most common other techniques based on the use of steel reinforcements, such as high mechanical properties of the material (tensile strength and elasticity modulus) compared with its lightness, insensitivity to corrosion, easiness of applying the reinforcement, etc.

As already observed for concrete members confined with steel transverse reinforcement, also in members reinforced with FRP there is a greater increase in strength [3,5,26,29,31] in the case of members with circular transverse cross-section with respect to those having a square or rectangular cross-section, the latter even showing, in some cases, no increase in strength due to the presence of FRP.

Focusing the attention on the effects of FRP on compressed members, the most important aspects taken into account in the majority of researches are the following: – type of FRP material (i.e. kind of fiber and polymer used as matrix) and architecture of the fabric (i.e. unidirectional or bi-directional wraps); – shape of the transverse cross-section of the members; – dimensions and shape of specimens; – strength of concrete; – types and percentages of pre-existing steel reinforcements, if any; – mode of loading (monotonic or cyclic); – investigation of hybrid schemes.

The most common types of fibers utilised are carbon, aramid and glass [24,25,34]. More recently, basalt fibers have also been utilised. Basalt fibers are obtained by melting basaltic rock and subsequently spinning the molten product. In particular, the current production technology for continuous basalt fibers is very similar to that used for E-glass manufacturing. The main difference is that E-glass is made from a complex batch of materials, whereas basalt filament is made from melting basalt rock with no other additives and, as a consequence, with an advantage in terms of cost. Thanks to the simplicity of the manufacturing process, lower energy is needed [35].

They offer further advantages if compared with other fibers with high strength and high modulus such as: – lower environmental cost (in the ratio 9:1 compared to carbon fiber); – very high temperature resistance [36] and chemical stability [37] compared with carbon or glass fibers; – reduced thermal and electrical conductivity compared with those of conventional metallic materials.

In the present paper, an experimental investigation is presented dealing with the compressive behavior of concrete cylinders externally wrapped with continuos basalt fibers in the form of a sheet, applying both full and partial discrete wrapping with BFRP straps, under monotonic and cyclic actions. The experimental results are also compared with those obtained by the authors on few other concrete cylinders wrapped with Carbon Fiber Reinforced Polymer (CFRP) sheets and tested in compression.

2. Experimental research

The present work concerns an experimental investigation aimed at assessing the effectiveness of basalt fiber wraps externally applied to cylindrical compressed concrete specimens to increase the strength and ductility of the material. Some of the specimens are wrapped with one or three layers of basalt fibers arranged in full or discrete wrapping along the specimen depth. Similarly, some other specimens, for comparison, are wrapped with one or three sheets of carbon fibers, realizing a full wrapping. As a matter of fact, in the existing technical literature, other authors conducted researches on the efficiency of discrete and continuous confinement systems mainly concerning CFRP wrapping [38]. The experimental results carried out by Barros and Ferreira [38] showed that, as compared to the full-wrapping confinement arrangement, partial confinement arrangements were not as effective in terms of load carrying capacity, but provided a significant increase of the load carrying capacity, assured a high level of deformability at the specimen failure, were easier and faster to apply, and consumed less CFRP and epoxy adhesive materials.

2.1. Materials and specimens

The concrete used for the manufacturing of the samples is a ready mix whose average compressive strength equal to 43.75 MPa has been evaluated by standard compressive tests at 28 days' curing.

It can be worth to note that most studies in the literature typically refer to the use of FRP confinement for improving the performance of existing structural members with low concrete strength and the experimental campaigns are mainly conducted on specimens with average compressive strength lower than 20 MPa. However, according to some authors (among others Refs. [8,15,22,26,47]) it can be useful to evaluate the strengthening effectiveness also for the case of higher strength concrete both in terms of strength and ductility improvement and with reference to the increase of the material brittleness with the concrete compressive resistance, which could influence the number of layers to be used for the wrapping. Moreover, most studies in the literature mainly deal with carbon, glass and aramidic fibers, while only few studies concern BFRP wrapping. For instance, among the latter, in [47] concrete cylinders with unconfined strength equal to 12.3 MPa and 49.2 MPa, to be wrapped with basalt windings, are tested. Therefore, also in the present paper, a concrete with quite high unconfined strength has been considered allowing the widening of the available experimental results on the topic.

The basalt fibers used are in the form of continuous bidirectional sheets of fabric as shown in Fig. 1. The bidirectional fabric is a balanced twill weave one, having areal weight 300 g/m^2. An

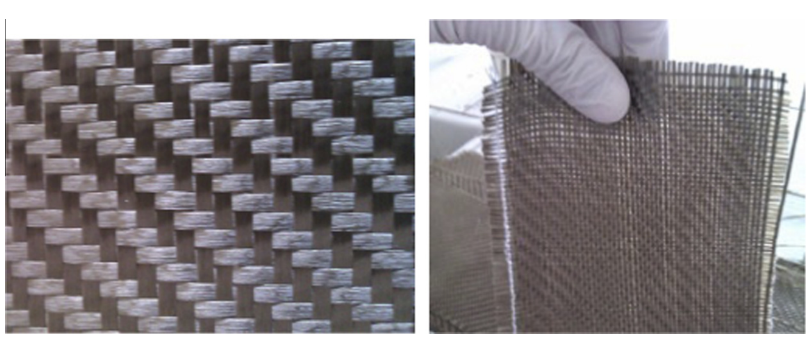

Fig. 1. Bidirectional balanced twill basalt fabric.