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Design-oriented models for concrete columns confined by steel-reinforced grout jackets

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HIGHLIGHTS

- The axial stress–strain response of SRG confined concrete columns is investigated.
- An experimental database of 80 SRG confined concrete columns is developed.
- Brittle, semi-ductile & ductile response is observed based on confinement stiffness.
- Existing code-based models cannot accurately predict the SRG confined behaviour.
- Efficient models are proposed for SRG confined concrete using confinement stiffness.

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ABSTRACT

This paper investigates the axial stress–strain response of concrete confined with Steel-Reinforced Grout (SRG) jackets comprising of Ultra High Tensile Strength Steel (UHTSS) textiles embedded in an inorganic binder. Brittle, semi-ductile and ductile stress–strain response curves are identified according to the level of confinement stiffness provided by the SRG jackets. A comprehensive experimental database of 80 SRG-confined columns is developed and used to assess the influence of key design parameters. The results are then used to propose new design-oriented models to predict the strength and ultimate strain of SRG confined concrete columns by taking into account the confinement stiffness of the jackets.

1. Introduction

The use of externally-bonded composite reinforcement impregnated by resin is an efficient retrofit solution for accommodating deficiencies of existing reinforced concrete (RC) structures due to substandard detailing (e.g. sparse stirrup spacing, short lap splices) and ageing of the construction materials (e.g. steel corrosion). Fiber-Reinforced Polymer (FRP) jacketing is one of the most popular and widely used systems mainly due to the advantages such as not changing the geometry of retrofitted members, high-strength-to-weight ratio, corrosion resistance and relatively fast and easy application (e.g. [1–12]). However, the use of organic binders has some disadvantages such as high cost, toxicity, poor behaviour at high temperatures (low fire resistance), lack of vapour permeability and inapplicability on wet substrate or at low temperatures. The substitution of the organic binders with inorganic ones seems to minimize most of these drawbacks.

The first experimental studies demonstrated the effectiveness of carbon fiber sheets embedded in mortar matrix for the flexural strengthening of beams and confinement of concrete cylinders [13–16]. This led to a new generation of mortar-based composite systems, Fiber-Reinforced Cementitious Mortar (FRCM), where bidirectional textiles made of continuous composite fibers (i.e. carbon, glass, basalt, poliparafenilen benzobisoxazole (PBO)) are combined with mortars (e.g. [17–21]). Most of these composite systems have been used for confinement, flexural and shear strengthening of RC members.

In general, the success of a composite system relies on the bond developed between the composite fabric and the mortar. Therefore, the continuous fiber sheets used in FRP systems have been

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replaced by textiles which comprise bidirectional fabric meshes made of continuous woven or unwoven fiber rovings. The width of the rovings and their clear spacing define the density of the textile, which in turn controls the mechanical characteristics of the textile [17]. The degree of penetration of the mortar through the gaps between fiber rovings determines the quality of the interlock mechanism developed between the mortar and fabric [22–25].

Previous research studies towards the development of innovative and cost-effective retrofit solutions have led to the Steel-Reinforced Grout (SRG) system, where Ultra High Tensile Strength Steel (UHTSS) textiles are combined with inorganic binders for retrofitting of RC structures. The steel-reinforced fabrics comprise high strength unidirectional steel cords made by twisting filaments having a micro-fine brass or galvanized coating. The density of the steel fabric is defined by the distance between the cords. In a pilot study, Thermou and Pantazopoulou [22] investigated experimentally the confinement effectiveness of the SRG jackets applied to pre-damaged cantilever specimens with old type detailing. More recent studies highlighted the efficiency of the SRG jacketing in increasing both the compressive strength and the deformation capacity of confined concrete specimens [24,26]. While the above studies demonstrated the efficiency of the SRG system for strengthening of RC columns, there is still no comprehensive research on the mechanical characteristics of steel cords and mortar mixes suitable for externally bonded reinforcement systems and the key parameters that affect their performance. Moreover, reliable and practical confinement models should be developed to predict the performance of SRG jacketed concrete specimens before this new system can be widely used in common practise.

In this paper the results of all available tests on SRG jacketed cylindrical concrete columns subjected to uniaxial compression are collected to create a comprehensive database. The adequacy of the existing FRP and FRCM confinement models is assessed by using the experimental database and it is shown that they cannot accurately predict the response of SRG confined concrete. The data is then used to develop a new design-oriented confinement model to predict the confined strength and ultimate strain of SRG-confined concrete. This is achieved by identifying the key design parameters and their impact on the axial stress-strain behaviour of SRG jacketed concrete specimens.

2. SRG jacketing method

Steel-Reinforced Grout jackets comprise Ultra High Tensile Strength Steel (UHTSS) fabrics combined with a mortar that serves as the connecting matrix. As shown in Fig. 1, the steel-reinforced fabrics are made of unidirectional steel cords (wires) fixed to a fibreglass micromesh to facilitate installation. The types of cords generally used are 12× (made by twisting 12 strands with over twisting of one wire around the bundle), 3×2 and $3 \times 2^*$ (made by wrapping three straight filaments by two filaments at a high twist angle) (see Fig. 1). Table 1 provides details regarding the geometrical and mechanical properties of the single cords as provided by the manufacturers. The 12× and 3×2 individual wires have a micro-fine brass coating to enhance their corrosion resistance. The $3 \times 2^*$ individual wires are galvanized, and therefore, have higher durability in a chloride, freeze-thaw and high humidity environment. The densities of the fabrics (i.e. cords per cm) examined in the previous studies by Thermou et al. [23] and Thermou and Hajirasouliha [26] were 1, 2, 9.06 cords/cm for the 12 × and 3×2 fabrics and 1.57 and 4.72 cords/cm for the $3 \times 2^*$ fabric (see Fig. 1).

The first step of the SRG application procedure involves the preparation of the substrate and the fabric. Unconfined cylindrical specimens should be cleaned and saturated with water before putting the first layer of the cementitious grout (usually with around 3 mm thickness). The fabrics are then cut into the desired lengths accounting for the number of layers and the overlap length. The fabrics with the density higher than 1 cord/cm are usually pre-bent to facilitate the wrapping process (Fig. 2a and b). The cementitious grout can be applied manually with the help of a trowel directly onto the lateral surface of the specimens (Fig. 2c). The steel fabric is placed immediately after the application of the cementitious grout (Fig. 2d and e). The grout is then squeezed out between the steel cords by applying pressure manually (Fig. 2f). After having placed one or two layers of fabric, the remaining length is lapped over the lateral surface. A final layer of the cementitious grout is then applied to the exposed surface (Fig. 2 g). In the experimental tests conducted by Thermou et al. [23], the thickness of the grout layer including the steel reinforced fabric was 7 and 10 mm for one- and two-layered jackets, respectively, allowing the steel fabric to be fully embedded in the cementitious matrix.

It should be mentioned that, based on the Thermou et al. [23] and Thermou and Hajirasouliha [26] observations, using the 4.72 cords/cm fabric can impose some difficulties in the penetration of mortar through the small gaps, while in case of the 9.06 cords/cm fabric it is practically impossible. Additionally, handling of a dense fabric, even if it is pre-bent, can be very difficult due its high axial stiffness.

3. Experimental database

In this study, a comprehensive experimental database was compiled by gathering all the available tests on SRG jacketed cylindrical columns subjected to uniaxial compression [23,26]. The database consists of 80 SRG-confined cylinders 150 × 300 mm. In general, the key design parameters in the experimental tests were the type and the density of the fabric, the number of layers, the overlap length, the mechanical characteristics of the inorganic matrix and the unconfined concrete strength.

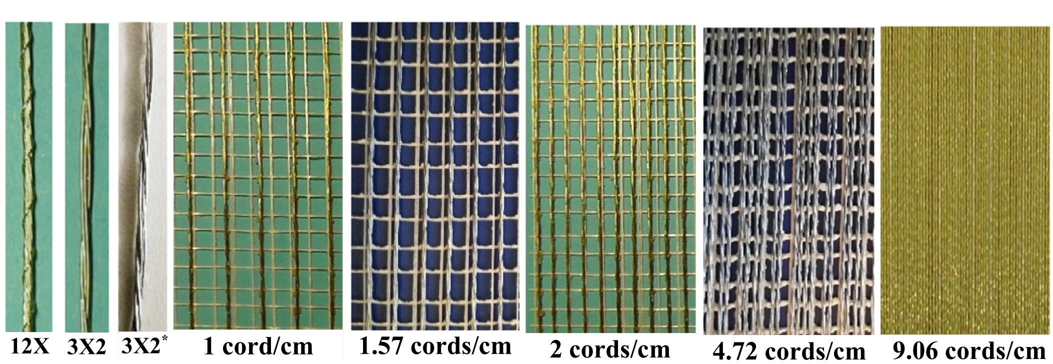

Fig. 1. High strength steel cord types 12×, 3×2, $3 \times 2^*$ and Ultra High Tensile Strength Steel (UHTSS) textiles of 1, 1.57, 2, 4.72, 9.06 cords/cm density.