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Compressive behaviour of concrete columns confined with steel-reinforced grout jackets

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ABSTRACT

This paper investigates the compressive strength of concrete columns confined with a new jacketing system using high strength steel reinforced fabrics embedded in an inorganic matrix (SRG). A comprehensive experimental programme was conducted on 52 cylindrical columns with SRG jackets and 15 control specimens under monotonic uniaxial compression load. The test specimens were designed to investigate the influence of different design parameters including the density of the fabric (1, 1.57, 4.72 cords/cm), number of layers (1, 2), overlap length (24, 36 cm), bonding agent (4 different types of mortar) and the concrete strength (16–30 MPa). The test results highlight the efficiency of the proposed method, where one-layered and two-layered SRG jackets could increase the strength capacity of the unconfined specimens by up to 122% and 193%, respectively.

1. Introduction

Much of the existing building stock in developing countries was designed according to old standards (with little or no seismic provisions) using poor material and construction practices. Moreover, deterioration of structural elements due to ageing and aggressive environmental conditions is another factor that can significantly increase the vulnerability of reinforced concrete (RC) structures. The retrofit of deteriorated or seismically deficient structures provides a feasible and economic approach to improving their load carrying capacity and reducing their vulnerability.

In recent years, the use of composite materials in retrofitting of existing structures has been increased substantially and proved to be efficient in accommodating deterioration of structural elements or damages observed after strong earthquakes [e.g. 1, 2]. Externally Bonded Fibre Reinforced Polymers (EB-FRP) applications have gained ground due to the advantages such as high resistance to corrosion, excellent durability, high strength to weight ratio and adaptability of the technique to different types of structural members. However, there are a few shortcomings related to the high cost, toxicity, poor behaviour at high temperatures and lack of vapour permeability. The replacement of organic to inorganic matrix, cement-based mortars, seems to minimize these drawbacks. Within this context, the first applications developed with carbon sheets combined with inorganic matrix are related to flexural strengthening of beams [3–5]. This was further extended to confinement of concrete columns, where unidirectional carbon sheets with mortar matrix were utilized [6].

In the last decade, several composite systems with inorganic binders have been developed for flexural and shear strengthening and confinement of RC members using different types of fabrics and inorganic matrices. The most popular systems are bidirectional textiles made of continuous carbon fibers embedded in cement-based mortars (Textile-Reinforced Mortar (TRM) systems) [e.g. 7–9], high strength steel and carbon fabrics combined with inorganic geopolymer resins [e.g. 10–12], PBO (poliparafenilen benzobisoxazole) nets embedded in cementitious matrix [e.g. 13, 14] and high strength steel fabrics combined with cementitious grout (SRG) [e.g. 15–25]. In general, the success in these composite systems relies on the bond characteristics between the fabric and the binding material as well as to the penetration and impregnation of the fiber sheets with inorganic binders.

Previous studies on the effect of Steel-Reinforced Grout (SRG) jackets on confined concrete have shown the efficiency of the proposed system in increasing substantially both compressive strength and deformation capacity [17–19]. These experimental studies investigated the effects of density of the fabric (for an uninhibited flow of mortar) and the overlap length on the failure modes. However, further studies are required to obtain a balance between the strength of the fabric (i.e. density) and the properties of the grout, and to investigate the effect of using multiple layers on the compressive strength and deformation capacity of the specimens and the required overlap length.

The main objective of the current study was to investigate the efficiency of SRG jackets when applied on plain concrete cylindrical

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columns using different design parameters. An extensive experimental study was conducted, where 52 columns confined with SRG jackets along with 15 control specimens were tested under monotonic uniaxial compression. The SRG jacketing technique proved to be very efficient in increasing both strength and deformation capacity.

2. Experimental program

2.1. Specimen details - parameters of study

Fifty-two cylindrical columns with a diameter of 150 mm and a height of 300 mm were wrapped with the SRG jacketing system and subjected to monotonically increasing concentric uniaxial compression load up to failure. The test specimens were designed to investigate the influence of the following design parameters: (i) the density of the fabric, (ii) the number of layers, (iii) the overlap length, (iv) the type of the bonding agent and (v) the concrete strength.

The specimens were cast using five concrete batches corresponding to different values of concrete compressive strength ranged between $f_{co}^{/}$ = 16–30 MPa. The lower and upper bound values are representative of the old and typical construction practice in the Mediterranean region and many developing countries, respectively. The variability of $f_{co}^{/}$ has enabled the assessment of the impact of the unconfined concrete strength on the efficiency of the SRG system. The concrete compressive strength for each batch was measured by using three 150 × 300 mm cylindrical specimens (15 control specimens in total). The following average compressive strengths were recorded at the day of the tests: Group A: $f_{co}^{/}$ = 23.4 MPa, Group B: $f_{co}^{/}$ = 16.8 MPa, Group C: $f_{co}^{/}$ = 20.7 MPa, Group D: $f_{co}^{/}$ = 18.3 MPa and Group E: $f_{co}^{/}$ = 30.0 MPa.

The three steel reinforced fabrics, 12X, 3X2, 3X2*, used in the experimental program comprise unidirectional steel cords fixed to a fibreglass micromesh to facilitate installation (see Fig. 1). The 12X wire cord (Fig. 1(a)) is made by twisting two different individual wire diameters together in 12 strands with over twisting of one wire around the bundle. The 3X2 and 3X2* wire cords have identical geometry and structure corresponding to five individual wires twisted together (three straight filaments wrapped by two filaments at a high twist angle, Fig. 1(b), (c)). However, their mechanical properties are different as shown in Table 1. In the same Table, the geometrical and mechanical properties of different types of single cords used in this study are provided. The 12X and 3X2 steel fabrics (used in the specimens of Groups A and B) have a micro-fine brass coating to enhance their corrosion resistance. The 3X2* steel fabric (used in the specimens of Groups C, D, E) has been galvanized and possesses high durability in a chloride, freeze-thaw and high humidity environment.

The spacing between successive cords, which defines the density of the steel fabric, is one of the key design parameters of the SRG jacketing technique as has been highlighted by Thermou et al. [16–20]. While the spacing should be wide enough as to provide uninhibited flow of the cementitious grout through the steel fabric, it should be designed to develop adequate bond between the fabric and the matrix. In this study, three different densities 1, 1.57 and 4.72 cords/cm are examined as shown in Fig. 1(d)–(f). The equivalent thickness per unit width for a single layer of steel fabric, t_s, was calculated to be 0.062, 0.084 and 0.254 mm for the 1, 1.57 and 4.72 cords/cm, respectively. The axial stiffness of the steel fabric, K_f (= $t_s \cdot E_f$), which also appears in Table 1, is directly related to the density of the fabric (the numbers in Table 1 should be doubled for the two-layered jackets).

In general, the overlap length should be sufficient to avoid a premature debonding failure mode. Previous experimental studies [18,19] indicated that the overlap length of 36 cm usually provides adequate anchorage for the single layered SRG jacketed cylindrical specimens to allow the tensile fracture of the fabric. To investigate this further, in the current study two different overlap lengths of 24 and 36 cm were used for the specimens with two- and the one-layered jackets, respectively.

Four different types of mortars were selected to provide different mechanical properties as presented in Table 2. The objective was to assess on one hand the impact of the mortar flexural strength on the compressive strength of SRG confined concrete and on the other hand the role of the adhesive bond strength on the composite behaviour of the SRG system. For the specimens of Groups A and B, a commercial fiber reinforced cementitious grout with pozzolanic additives, classified as M1 and two custom-made inorganic mortars M2 and M3 were used. M2 comprises of NC182 cement enriched with nanoparticles N20 (nanosilica, surface area: BET m2/g 200 ± 25), whereas M3 uses NC182 cement with propylene fibers and additional anticorrosive. In Groups C, D and E, a commercial geo-mortar M4 is used which has a crystalline reaction geobinder base with very low petrochemical polymer content and free from organic fibers. The adhesive bond of the mortars M2 and M3 was measured according to standard BS EN 12636:1999 [26].

The test specimens were given the notation Gi#L_N, where G stands for the group of the specimens (A, B, C, D, E in Table 3), i (=1 to 10) corresponds to the type of the SRG jacketing system, L indicates the number of fabric layers (1 and 2) and N refers to the specimen number for each subgroup of the identical specimens. The type of the SRG jacketing system is related to the type of fabric (12X, 3X2 and 3X2*), the density of the fabric (1, 1.57 and 4.72 cords/cm), the overlap length (24 cm and 36 cm) and the type of inorganic matrix (M1, M2, M3, M4) as defined in Table 3. For example, A2#1_1 specimen belongs to the Group A and refers to the first specimen of the subgroup constructed with the one layer Type 2 SRG jacket which is made by using mortar M1, 3X2 steel reinforced fabric of 1 cord/cm density and overlap length

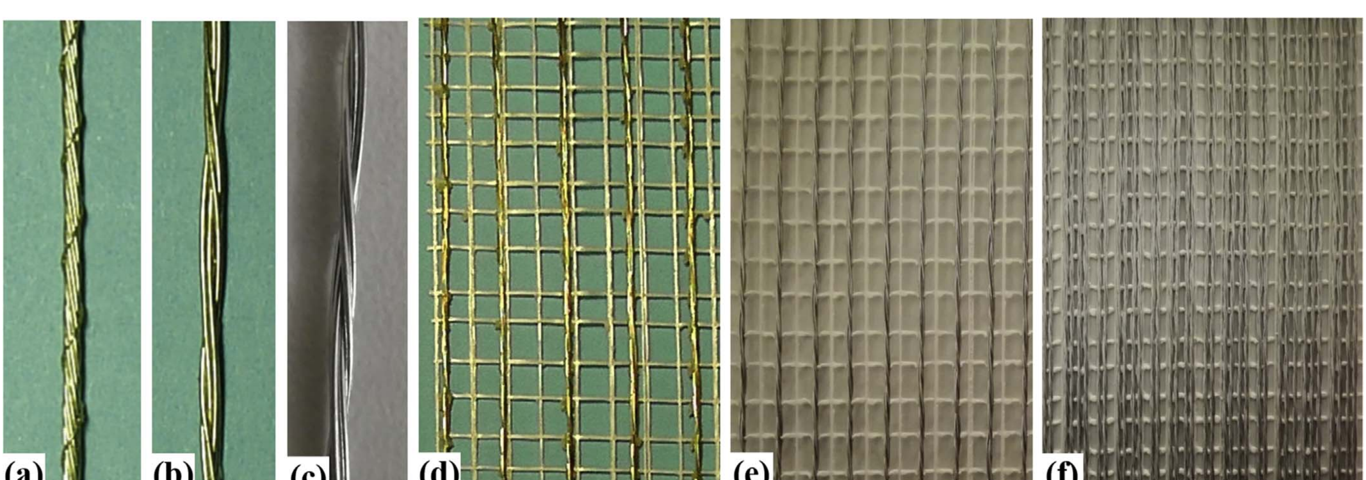

Fig. 1. High strength steel cord types (a) 12X; (b) 3X2; (c) 3X2*; The density of the fabrics used (d) 1.0 cord/cm; (e) 1.57 cords/cm; (f) 4.72 cords/cm.