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Flexural strengthening of low-grade reinforced concrete beams with compatible composite material: Steel Reinforced Grout (SRG)

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HIGHLIGHTS

- Part of the existing housing stock erected with concrete of very bad quality, necessity of repair.
- Steel Reinforced Grout (SRG) as externally bonded strengthening solution in flexure for low-grade RC beams.
- Despite SRG premature debonding specimens have enhanced their flexural capacity and ductility.
- Premature debonding of SRG is counteracted with anchors applied at the ends of beams.
- Two systems have been tested: anchors steel plates and SRG U-Shaped anchors, the latter has proven to be effective.

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ABSTRACT

A substantial fraction of the existing housing stock is built with low-quality reinforced concrete that shows poor mechanical properties. Those concretes, labelled low-grade concretes, present certain drawbacks when common strengthening techniques are used for their rehabilitation. Over recent decades, a number of investigations have added to our knowledge of strengthening materials in the form of inorganic-based composites. Amongst those materials, Steel Reinforced Grout (SRG) presents optimum characteristics for flexural strengthening in situations where the use of other retrofitting techniques is not recommendable.

Previous applications of SRG include the reinforcement of constructive components that include masonry walls, arches, and even slabs, in positions where the adherence of externally bonded organic composites such as FRP can present difficulties. The adherence of organic binders is not appropriate for low-performance concrete substrates and can cause FRP laminate debonding and the detachment of the concrete substrate.

The central theme of this study is the strengthening of low-performance RC beams with SRG to resist flexural forces. This innovative material forms a cement-based matrix, rather than an organic binder, which is a partial solution for the above-mentioned lack of full compatibility between ancient concrete and externally bonded strengthening solutions. In addition, SRG presents additional advantages such as: fire resistance, durability, and some reversibility. Tests are performed on eighteen reinforced concrete (RC) beams (17 MPa): two reference specimens and sixteen specimens to study particular aspects of the SRG strengthening solution: the strengthening ratio and the performance of two anchorage systems. The results achieved in this research work lead us to conclude that SRG is an effective solution for the retrofitting of low-grade reinforced concrete to increase its load-flexural and deformation capacity.

1. Introduction

The financial crisis of 2008 seriously affected the construction sector in Spain, a macro-economic sector the contribution of which to the national Gross Domestic Product (GDP) has since halved: 10.1% in 2009, 5.2% in 2017 [1]. With the aim of invigorating construction sector activity, new business niches were sought and other existing ones promoted, among which Rehabilitation. This subsector is gaining ground in Spain, although it is still far from the European average. In parallel, the slow, yet inexorable ageing of Spanish housing stock calls for interventions to strengthen RC

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structures previously constructed from low-grade concrete. The combination of these two factors is driving the research of innovative and economical solutions.

This need for rehabilitation is more evident in structures and buildings erected in the earliest decades of the past century, when RC became a relevant (and rapidly an essential) construction material. A considerable number of structures, some of them with historical value, were built, even though working knowledge of RC was still at an early stage of development and durability issues were not addressed in building codes. Low-grade concrete structures built at that time could never have met the specifications of modern building standards, in terms of both mechanical characteristics and durability requirements.

The efforts of several research groups have centred on innovative, effective, and low-cost solutions. The introduction of Fibre Reinforced Polymers (FRP) for reinforced retrofitting of RC structures began mid-way through the 1990s. Since that time, FRP has become a popular material within a sector often reluctant to adopt new techniques or materials. The well-known advantages of FRP composites over traditional strengthening techniques have been reported in several studies: easy application, corrosion proof, insignificant specific weight, high-tensile strength, and flexibility. Carbon fibre fabrics are the most frequently used solution, among which FRP core, even though several materials are used for this purpose, including steel wire (Steel Reinforced Polymer, SRP) [2–5].

Despite its advantages, FRP external retrofitting has yet to become a widely used system, as many designers still prefer conventional techniques. Epoxy resins, the material that is used as the composite matrix, present incompatibility problems with some substrates, which result in weaker strengthening, due to premature debonding. They behave poorly at temperatures above the glass transition phase, which is not very high in some materials. Another important drawback is the high economic cost of epoxy resins in comparison with conventional techniques where steel and concrete are the main materials. Finally, the use of FRPs is banned in the case of heritage interventions, because the application of these techniques has irreversible effects.

In relation to the above-mentioned structures, the use of FRP in those buildings erected with low-grade concrete (f_{cm} < 17 MPa) is not recommendable for the following reasons: (i) the considerable deformation capacity of those components may be incompatible with the stiffness of FRP materials, especially when carbon fabrics are used; (ii) the poor quality of the low-grade concrete may cause the concrete cover to peel off even before any shear failure of the organic binder, and this failure mode may be catastrophic, damaging the beam beyond repair; and, (iii) FRP is incapable of uniform stress distribution. In the case of flexural strengthening, the formation of cracks causes stress concentration points, increasing the likelihood of premature debonding of the strengthening composite, if critical values are reached in the interfacial bond. Moreover, organic binders show weaker adherence when exposed to moist and chemical environments.

The proposed solution to these drawbacks is to replace the organic matrix with an inorganic cement-based matrix [6]. The fluidity of organic resins is far greater than the fluidity of mortars, so the impregnation between the fabrics and the inorganic matrix might be insufficient to achieve a monolithic composite behaviour. However, fibres in the form of textiles will improve interaction between the matrix and the reinforcing core and will ensure good impregnation. The name given to this composite material is Textile Reinforced Mortar (TRM).

Initially, the commercial use of TRM and its study have, almost exclusively, been centred on the structural strengthening of masonry components such as stone walls [7–10] and arches [11–13]. Over the past few years, the material has been used in RC components and there are several European research institutes and groups that are currently investigating possible uses, ranging from rehabilitation (as externally bonded strengthening system) [14–18] to the production of precast components [19,20].

Among all the materials that could be used as the composite core, interest has centred on steel wire. This material is assembled into a fabric by means of cords made of twisted wires. The steel-wire based composite, due to its nature, is usually referred to as Steel Reinforced Grout (SRG).

Few studies have demonstrated the efficiency of SRG for improving masonry [21–26] and reinforced concrete structures [27–31] and further research is still needed. In this paper, the results of a thorough research program focusing on SRG will be presented. The composition of SRG will first of all be characterized and then the mechanical behaviour of the composite will be studied; subsequently, its effectiveness will be analysed, following its application to 18 low-grade concrete scaled beams.

2. Steel Reinforced Grout (SRG)

SRG consists of steel wires, previously twisted into cords, that are woven into a fabric. The cords are held together in a latticework structure that resembles a net, usually in the form of regular polyester textile sheeting. As the cords are responsible for absorbing the tensile forces, they must be in alignment with those forces. Usually, SRG fabrics are formed by unidirectional cords, a useful arrangement for several applications, among which the strengthening of RC beams to withstand flexural forces. The nature of these steel-cord textile sheets means that this reinforcement can be easily handled without damage, which facilitates its installation [32].

The quantity of steel wires and their geometrical arrangement in the form of a textile (*i.e.* the gaps running along each direction between each cord) can be customized in such a way as to alter the mechanical characteristics of the textile and any mortar penetration through the mesh (cell) openings. SRG internal reinforcement is also dependent on the transfer of stresses from the matrix through the wires, a stress transfer process that single wires will facilitate, due to their low interfacial shear strength, on account of their smoothness [33]. The shear strength of several wires twisted together to form a cord will therefore overcome that problem. The cord shown in Fig. 1 consists of two wires twisted together with three wires.

The same manufacturing technique is used for the vulcanized metallic reinforcements of automobile tyres [33]. These types of steel reinforcement are usually stranded wires that are manufactured by drawing the metal through a hole in a die or draw plate. The effects of this metal working process are significant. Small diameter cold-drawn austenitic stainless-steel wires have the highest tensile strengths, even reaching 3760 MPa [34]. However, some drawbacks such as increased brittleness should also be mentioned.

The matrix must protect the steel cords against corrosion; for this reason, corrosion inhibitors may be combined with the inorganic mortar. Another alternative is to protect the steel wires with metallic coatings, e.g. bronze and even stainless steel can be used as the steel protector.

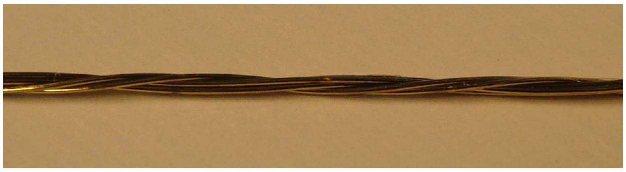

Fig. 1. Steel cord manufactured with five wires.