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Shear retrofitting of reinforced concrete beams with steel fiber reinforced concrete

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HIGHLIGHTS

- RC beams strengthened and repaired with SFRC jacketing were tested under shear.
- Fibers help preventing debonding of the jacketing.
- Shear strength of RC beams with stirrups can be improved with SFRC jacketing.
- Damaged RC beams repaired with SFRC jacketing recover/increase initial shear strength.

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ABSTRACT

With the objective of evaluating the performance of steel fiber reinforced concrete (SFRC) as a retrofitting material for reinforced concrete beams the experimental study of reinforced concrete beams repaired and strengthened with a SFRC jacketing and tested under shear is presented in this paper.

The reinforced concrete beams were designed with high amount of longitudinal steel and minimum transverse reinforcement so that they present shear failure. Some of the beams were strengthened with very fluid high strength SFRC jacketing and some of them were first tested under shear to produce some damage and then they were repaired with the same technique. Plain concrete and SFRC with two different fiber dosages, 30 kg/m^3 and 60 kg/m^3, were used for the reinforcement.

The experimental program showed the possibility of performing the retrofitting at work place. The repaired beams showed excellent strength and deformation capacity restitution. The strengthened beams exhibited increase of load bearing capacity. The addition of fibers to the concrete played an important role in the prevention of the jacketing debonding from the beams.

1. Introduction

Concrete is the most used constructive material all over the world [1]. Compared with other constructive materials it has the less cost/strength ratio [2]. Reinforced concrete (RC) structures often require repairing and/or strengthening, due to a change of use, design with old normative, change of design philosophy as the case of capacity design of reinforced concrete, aging or deterioration of materials produced by environment factors, construction mistakes or material damage due to extreme loads [3]. The reduction of governmental funds for new constructions has also led to the new tendency of increasing service life of existent structures [4].

There are many different techniques to repair or strength reinforced concrete structures like steel plates, polymers or concrete. Some retrofitting methods like addition of steel or reinforced concrete present corrosion problems or failure of the retrofitting system [5]. Generally, the most important problem is adherence and durability of the retrofitting layer.

The reinforced concrete structures retrofitting technique using fiber reinforced concrete (FRC) avoids some of the problems that other systems present like the brittle failure of the interface retrofitting layer/concrete. Compared with fiber reinforced polymers, fiber reinforced cement composites present higher resistance against high temperature and ultraviolet radiation, more long term durability and fundamentally more compatibility with the substrate [6]. Moreover, the use of fibers in the retrofitting concrete layer helps controlling shrinkage cracking.

FRC is a material composed of a concrete matrix with addition of fibers that improve its behavior. Many different types of fibers can be used like steel, glass, organic polymers [7] or vegetable fibers [8]. While glass and organic polymer fibers present brittle failure under tension loads without previous plastic strain or

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yielding [7], steel fibers generally can deform plastically. The most important geometric fibers characteristics are their aspect ratio (length/diameter) that define the slenderness and the shape of the fibers axis that can be straight or including some type of anchorage, smooth or wavy, etc. Sometimes a combination of different types of fibers is also used. Short fibers are responsible of bridging thin cracks (0.2–0.3 mm), improving durability, while ductility development requires greater deformations and wider cracks that are sewn by the longer fibers [9].

The main effect of fibers is controlling cracking processes. This effect leads to important increases of material toughness as well as additional benefits related to strength mainly under tension loads. FRC presents more distributed cracking pattern, evidencing thinner cracks. As a result, the durability of the retrofitting layers is increased preventing the entrance of aggressive agents that favor the layers debonding. All these improvements are connected to the load transfer process from the matrix to the fibers. The main mechanism contributing to this process is fibers pull out that is strongly dependent on fibers shape. FRC is normally designed in a way that the fibers are pulled out before breaking [10].

Although any concrete can be reinforced with fibers the tendency nowadays is the use of fibers to improve ductility of high or ultrahigh strength concrete. In this way a material with the required strength and ductility to be used in reduced thicknesses is obtained. The use of self compacting concrete has also became popular since it requires less hand work and it has more dense internal structure, better strength and less permeability. This concrete is easy to be poured in small thicknesses and this property makes it suitable for retrofitting works.

All these properties make FRC an attractive material for retrofitting concrete structures. The effectiveness of the FRC retrofitting is strongly influenced by the adherence between fibers and concrete matrix and between matrix and the concrete substrate [6]. It has been proved both in experimental tests and field experience that the incorporation of fibers helps controlling cracking and delaying debonding initiation and its propagation [11].

2. Repairing/strengthening of reinforced concrete structures with fiber reinforced cement matrix. Brief review

Much research has been done to assess effectiveness of FRC retrofitting technique during the last years. This section presents a brief review of research done related to the use of fiber reinforced composites with cement like matrix for repairing or strengthening purposes. The research done concerning retrofitting with this type of materials has two main motivations. By one side, it is aimed at solving durability or aging problems or prolonging service life of the structure and by the other side, it is aimed at solving strength or structural problems.

The use of fiber reinforced both for the strengthening and repairing of different types concrete and reinforced concrete elements like beams, columns, panels, joints, slabs and pavements has been extensively investigated during the last years. Different types of cement based materials for the matrix like normal strength, high strength concrete or self consolidating concrete, were used and compared. Moreover different types, sizes and shapes of fibers were used.

Independently of the motivation and materials used, improvement of the mechanical behavior of the retrofitted element or structure and cracking process was usually investigated.

The use of slurry infiltrated mat concrete (SIMCOM) for repair and rehabilitation of reinforced concrete beams and columns was studied by Naaman et al. [12]. They concluded that SIMCOM can successfully interact with reinforced concrete elements substantially increasing flexural strength and energy absorption capacity.

The flexure behavior of beams repaired in the bottom concrete cover with self compacting concrete and self compacting FRC was experimentally studied by Mesbah et al. [13]. The beams repaired with FRC presented thinner cracks. The use of self compacting concrete has shown to be a good option to facilitate the pouring. The behavior of the repaired beams seemed to be not influenced by the placing and the length of the repaired zone.

A system for the stiffening of frame structures with precast engineering cement composites (ECC) plates was proposed by Li et al. [14]. They studied the performance of the system numerically. The plates contributed to energy dissipation of the structure through the early cracking of ECC. Although the ECC has strength not very different from the FRC or mortar used, structural strength and structural ductility was all much higher when ECC was used, especially when ECC composition (fiber, matrix and interface) was adequately tailored taking into account the influence of material micromechanics on composite macromechanics and structural behavior. The use of this material in a bridge deck patch repair was presented later [15]. A very high performance fiber-reinforced concrete composite combining macro and microfibers of steel was developed and applied to repair a parking garage by Banthia and Bindiganavile [16].

A repair method consisting of the replacement of damaged materials in aged structures due to the lack of maintenance was proposed by Kim et al. [17]. They used ductile fiber reinforced cementitious composite (DFRCC) as repair material for over reinforced concrete beams under flexure. Neither the strength nor the deformation capacity were significantly changed with this type of repair and the importance of the interface between the old and the new material and the debonding prevention were showed.

The use of ultra-high strength steel fiber-reinforced concrete (UFC) jacketing for the strengthening of internal nodes of reinforced concrete frames was proposed by Wang and Lee [18]. They showed that the use of UFC leaded to an increase of ductility and the formation of plastic hinges in the beams.

A new material called ultra-high performance cement-based fiber composite (CARDIFRC) was presented by Farhat et al. [19]. It is an ultra high performance composite reinforced with 8% in volume of short fibers. They used this material for the reinforcement of under reinforced concrete beams under flexure and over reinforced concrete beams under shear. The reinforcement consisted of thin plates made of CARDIFRC that were glued with epoxy cement to previously damaged beams. In all strengthening setups the strength of the beams was increased with the reinforcement.

Experimental results of two actual scale bridge piles repaired with high performance fiber reinforced concrete (HPFRC) were presented by Massicotte and Boucher-Proulx [20]. The concrete cover of one of the piles was removed and replaced by HPFRC. The piles were tested under quasistatic cyclic load. The strengthened pile presented greater load bearing capacity, increasing with load cycles, and also greater ductility.

An ultra high performance fiber reinforced concrete (UHPFRC) was used by Brühwiler and Denarié [21] to restore reinforced concrete structures that have suffered environment attacks and surface mechanical actions. Taking advantage of the low permeability, high mechanical strength combined with the self compacting property, they proposed the use of thin layers of this material that can be combined with steel bars or in precast elements. They showed some applications already done in bridge decks, highways protection barriers, bridge piles and industrial floors.

Marini et al. [22] numerically studied the behavior of a FRC diaphragm as vertical load transferring element to perimeter structure. They concluded that the use of FRC would allow the use of lower thicknesses than in the case of reinforced concrete and that the thickness could be reduced if the fiber content was increased.