

Fiber-reinforced concrete with low content of recycled steel fiber: Shear behaviour

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HIGHLIGHTS

- The shear properties of SFRC with fibers recycled from scrap tires were studied.
- Fresh and hardened concrete properties are reported.
- Experimental direct shear tests were carried out on specimens varying the type of fibre reinforcements.
- An analytical analysis was done aims to evaluate the shear stress versus displacement curves.
- The obtained results confirm promising applications of concrete reinforced with RSF.

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ABSTRACT

The sustainability of construction materials is a mandatory issue that started to be strongly felt in view of a global perspective of environmental protection. Wasted materials often may find a new lifecycle if well re-engineered, even in structural applications. In this field short steel fibers obtained from used tyres at the end of their life may find promising applications within a concrete matrix. In the present research the mechanical properties of recycled steel fiber-reinforced concrete in terms of workability, compressive and tensile strength, toughness and shear behaviour are analysed and compared with those of industrial steel fiber-reinforced concrete and ordinary Portland concrete. An experimental campaign is illustrated, and an extensive comparison in terms of shear strength has been studied considering different experimental works available in scientific literature. Moreover, a theoretical analysis aimed at evaluating and comparing the shear modulus of the analysed concrete type was carried out. The results obtained through this study show a satisfactory behaviour of the concrete reinforced with recycled steel fibers compared with industrial new steel fibers reinforced concrete, both in terms of toughness and shear behaviour.

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1. Introduction

Incorrect handling of waste tyres is a crucial issue that annually generates a high environmental global impact. Over the last two decades, an increase of the global waste tyres recovery was observed, encouraged by new technologies that allow retrieving the waste tyres constituent materials (rubber, steel and natural fibers) and reusing them in various fields. In recent years is increasing the interest for these secondary raw materials and their potential applications in the civil engineering field, such as the use of steel fibers obtained by the recycling of wasted tyres as reinforcing fibers for the production of fiber reinforced concrete (FRC). Several experimental works which study the mechanical properties of concrete reinforced with both metal and plastic recycled

short fiber are available in the literature [1–17]. The results obtained in previous research have shown a comparable behaviour between concrete reinforced with industrial and recycled steel fibers in terms of flexural strength and ductility [1,7,18], with an increase of the concrete matrix toughness compared to plain concrete. This is due to the well known bridging effect explicated by the fibers crossing the cracks. The positive effect of the industrial steel fibers in terms of shear behaviour is also widely discussed in several works [18–38] in which an increase of the maximum shear strength and shear deformation were basically detected. This beneficial effect is due to the sliding resistance opposed by the fibers located between the surfaces of shear cracks and depends on several fiber' factors such as their dosage, aspect ratio, distribution within the concrete mix, their orientation along the cracked surface and finally the concrete matrix properties; a similar benefit is expected also when recycled steel fibers are utilized. The available experimental works to study the shear behaviour of

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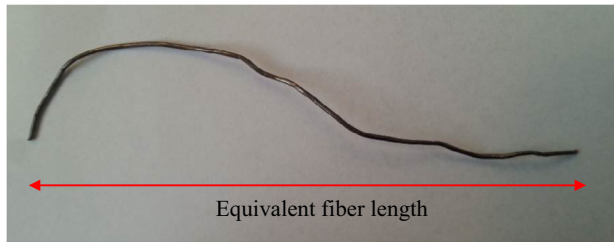


Fig. 1. Recycled steel fiber: Equivalent length.

FRC (Fiber Reinforced Concrete) elements refer to direct shear tests on small FRC specimens or to tests on structural elements (beams). The two approaches are completely different because of the involved shear strength mechanisms change. In fact, the direct shear test is able to furnish the shear strength of the materials, while the test on beams involves other shear strength mechanisms as depth/span ratio of the beam, longitudinal reinforcement ratio, transverse reinforcement ratio, etc. The scope of the authors was specifically the evaluation of the concrete shear strength enhanced by the addition of fibers in order to combine this contribution with the others when passing to the analysis of structural elements. Actually, the results of the direct shear test can be used to predict the shear capacity of FRC beams. According to [38], the results of the direct shear test on FRC specimens can be used to estimate the contribution of the concrete shear capacity in the FRC beams. On the other hand, few information about the shear strength of recycled FRC are to date available in the scientific literature [4], therefore in the authors opinion the more adequate starting point could be the direct shear test in order to use the results obtained for planning an experimental campaign on FRC beam.

The experimental work herein discussed is aimed to study the mechanical properties of concrete reinforced with steel fibers recycled from wasted tyres, in terms of compressive strength, tensile strength, flexural strength, toughness and shear strength. In particular, direct shear test has been carried out on prismatic samples in order to evaluate the shear behaviour of two different SFRC obtained with both recycled (from waste tyres) and industrial

fibers, in terms of shear strength and shear load–displacement curves. Both concrete mixtures have been prepared using a low fibers percentage in volume equal to 0.46%; this was decided in order to maintain a good workability at the fresh state. Moreover, similar tests have been carried out on ordinary plain concrete specimens for comparison purpose.

Finally, an analytical study aimed both to establish whether the analytical formulations available in the scientific literature for industrial steel fibers (ISF) are also applicable for recycled steel fibers (RSF) and to evaluate the cracking and post cracking shear modulus (G_{cr} , G_{pc}) for ISF and RSF was carried out. The results obtained from the performed investigation have shown satisfactory shear behaviour of the recycled steel FRC (RSFRC) in terms of shear capacity and shear displacement and a comparable post cracking behaviour between ISF and RSF specimens.

2. Geometrical characterization of recycled fibers

The high geometrical variability of the recycled steel fibers required a statistical analysis in order to define a mean aspect ratio value. A similar procedure has been previously utilized by the authors in [1,3,5], it may constitute a starting point for assessing a more detailed and general protocol aiming to the geometrical characterization of steel fibers recovered from waste tyres.

Geometrical properties of recycled steel fibers utilized for the experimental campaign herein reported were determined on a sample of 1200 fibers randomly extracted after the shredding process. According to [39], the length of each fiber was recorded as the distance between the outer ends (Fig. 1), obtaining values ranging between 1 mm and 37 mm with a mean values equal to 13.94 mm and a coefficient of variation (C.o.V.) equal to 38%.

The obtained measures were divided in nine different length classes. The length range, including the major number of fiber was 10–15 mm (40.75%), followed by the class 15–20 mm (22.92%) and 5–10 (21.75%) (Fig. 2).

Similarly, the diameter of each fiber was measured by means of a micrometer, averaging two measures taken at the two ends of the fiber itself, in accordance following the indications suggested in [40] for round wire fibers. The fiber diameters varied between

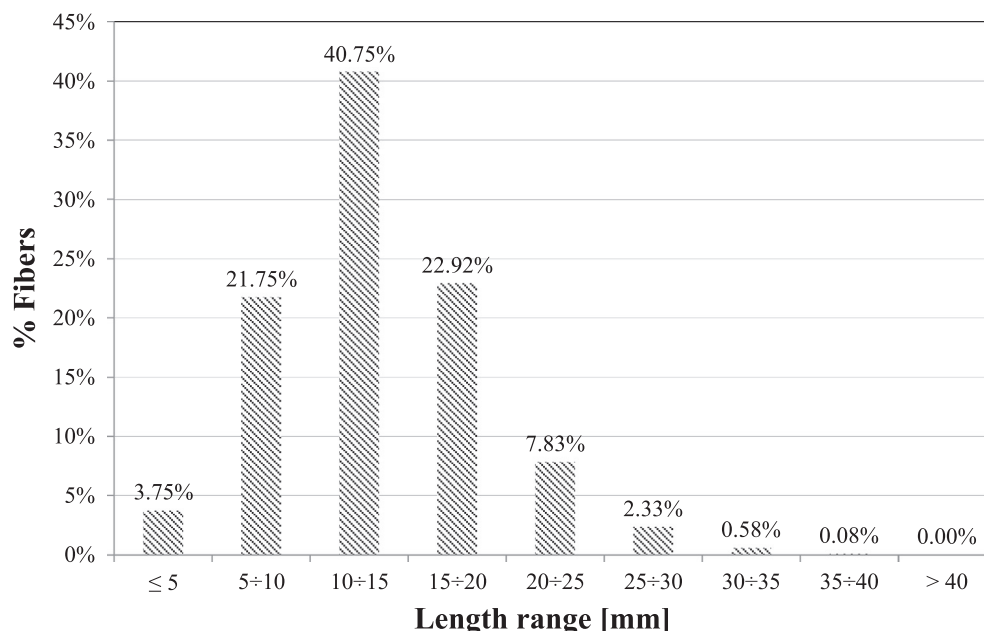


Fig. 2. Relative frequency of the fibers length.

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