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Steel fibers from waste tires as reinforcement in concrete: A mechanical characterization

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HIGHLIGHTS

- ▶ We studied mechanical properties of SFRC with fibers recycled from scrap tires.
- ▶ Fresh and hardened concrete properties are reported.
- ▶ Flexural tests on notched specimens were carried out according to UNI 11039.
- ▶ Flexural tests on square slabs were carried out according to EFNARC specification.
- ▶ The obtained results confirm promising applications of concrete reinforced with RSF.

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ABSTRACT

The environmental damage caused by improper management of waste tires increased over the past years creating a relevant problem to be solved. In the field of civil engineering results possible to re-utilize the steel fiber and the rubber of the waste tires. In particular the concrete obtained by adding recycled steel fibers shows a good mechanical improvement of the brittle matrix, as a consequence it appears to be a promising candidate for both structural and non-structural applications. In the present experimental work, as a continuation of the research already performed in this field by the authors, the post-cracking performances of RFRC (Recycled Fiber Reinforced Concrete) were evaluated by means tests on flexural elements and slabs. The effectiveness of the recycled fibers was evaluated in comparison with the experimental data obtained for specimens realized with IFRC (Industrial Fiber Reinforced Concrete). All fresh and hardened proprieties of concrete mixes were experimentally estimated. The post-cracking behavior of the RSFRC, obtained by flexural tests, was comparable with that of ISFRC. RSFRC specimens showed good energy absorption and good residual strength after cracking.

However, technological issues related to fibers production and concrete mixes preparation, must be still investigated and a wider research is still required to validate the interesting founds.

1. Introduction

In the last years the indiscriminate disposal of large amounts of Waste Tires (WT) into landfills has caused serious environmental damages in many European States, because of their well known not biodegradable feature. On the other hand, according to [1], since July 2006 the disposal of whole or shredded tires into landfill became illegal. As a consequence almost all the European Governments transposed this directive into national laws and codes, promoting the development of sustainable options for the disposal, recovery, and reuse of tires. In this regard, Italy has been very careful and farsighted: the recent 2008/98/Ce European Directive expands in Europe the "end of waste" concept, already introduced by the Italian legislature [2]. In particular the possibility to market rubber granules and dusts as well as steel fiber without being subject to the stringent requirements of waste legislation, deriving from Codes provisions, could greatly facilitate the diffusion and use of materials obtained by the treatment of waste tires.

The main markets for recycling WT currently are energy recovery (as kiln fuel in the cement industry) and raw materials recovery. Mechanical and chemical processes, such as tire shredding, pyrolysis and cryogenic reduction are used by the tire recycling industry.

Recently, in the context of a growing interest towards innovative materials recycling and sustainable buildings, some studies proposed the use of granulated rubber and steel fibers, recovered from waste tires, in concrete [3–11]. In particular the concrete obtained by adding recycled steel fibers showed a good improvement of the brittle matrix, especially in terms of toughness and

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post-cracking behavior, as widely already experienced for ISFRC (Industrial Steel Fibers Reinforced Concrete). In fact it is well known that the dispersion of steel fibers in concrete allows a noticeable improvement of the concrete mechanical properties, mostly in terms of dynamic and fatigue resistance, shear and post-cracking strength [12–16].

The post cracking strength is mainly due to the capability of fibers in controlling the cracks growth and the cracks opening, depending primarily on fibers properties, bond between fibers and concrete and on fibers distribution. A successfully application of added steel fibers concerns the concrete slabs, where traditional layers of a steel wires mesh can be substituted by fibers, guaranteeing a similar or even improved structural response, with a reduction of costs and time of execution [17–21]. The RSFs (Recycled Steel Fibers) appears to be a promising candidate for realizing concrete slabs, road barriers and precast elements, usually produced with traditional technologies. Referring to concrete pavement, where generally steel mesh reinforcement are utilized, a partial substitution by recycled steel fibers could be considered on the basis of the promising results already obtained using industrial steel fibers, [22].

As a result, economic advantages, non-minor physical–mechanical properties and a contribution to the well known pollution problem related to waste tires can be obtained.

On the basis of the results reported in the available literature and also of the previous studies performed by the aforementioned authors, an experimental investigation devoted to the analysis of mechanical properties of RSFRC (Recycled Steel Fibers Reinforced Concrete) is presented in this paper. Workability, compressive and flexural tests were executed for different mix-design, varying the volume ratio of steel fibers added in the concrete. Thereafter, the improving in post-cracking behavior of the specimen, due to the crack-arrestor action of the fibers, was evaluated in four-points flexural tests carried out according to [23]. Finally, flexural tests on slabs, according to EFNARC guideline [24], were executed to analyze the post-cracking performance of bidimensional concrete elements, widely used in practical applications. To evaluate the effectiveness of the RSFRC, all tests were conducted also on plain and industrial steel fibers reinforced concrete. The comparison between the experimental data furnishes a reasonable estimation of the mechanical performance of the analyzed material.

2. Opening considerations

The mechanical characterization of RSFRC has been carried out on the basis of the results obtained in previous studies [3] in order to further validate the experimental founds and get a deeper insight into the mechanical performance of the RSFRC in the post cracking stage. In addition the potential use of RSF in concrete slabs is investigated, aiming to evaluate if the addition of fibers could greatly contribute to overcome or, at least, reduce the problems related to the use of conventional steel mesh in consideration of the promising results already available when ISF are used in substitution of the traditional reinforcement. The mixes preparation is a crucial aspect, due to the tendency of the recycled steel fibers to bundle within the fresh concrete more than industrial fibers. In fact, recycled steel fibers are generally recovered by a shredding process of tires, followed by an electromagnetic procedure aiming to separate steel from rubber; the fibers obtained are characterized by an irregular shape and a variable length besides a residual magnetization. These aspects significantly affect the maximum amount of fibers being added to the concrete mix as well as the quality of fibers dispersion in concrete. Based on the already performed investigation, when a traditional concrete mixer (made by revolving drum) was employed the highest amount of fibers that could be effectively added to the mix was 0.26% by volume of concrete. On the other hand the use of a planetary mixer resulted particularly advantageous to improve the homogeneous distribution of fibers within the concrete. In fact an increased fibers percentage was allowed in the concrete mix (0.46% by volume of concrete), that significantly improved the mechanical properties of the matrix, guarantying at the same time a good concrete workability. Up to 0.46% of recycled steel fibers were used also in the investigation reported in this paper; results have been compared with those of concrete mixes obtained with a similar percentage of industrial steel fibers and with results referred to the plain concrete. The concrete workability, compressive and flexural strength were evaluated and discussed also in comparison to the already mentioned available results.

The RSF, obtained by the process before mentioned, have different lengths and diameters. To better understand the properties and the effectiveness of the used fibers, a geometrical characterization was done in [3] on a sample of 1400 recycled steel fibers. A further geometrical characterization will be reported here on recycled steel fibers, supplied by a different industry even utilizing the same shredding process, in order to better appreciate the reliability of results obtained also in relation to the expected variability of fibers properties.

3. Geometrical characterization of recycled fibers

Geometrical properties of recycled steel fibers have been determined on a sample of 2000 fibers, extracted randomly after the shredding process.

The diameter of each fiber was recorded by a micrometer and determined averaging three measures, namely at the two extremities of the fiber and at the mid length. The fibers diameters varied between 0.10 mm and 2.00 mm, while the average value is 0.24 mm. In addition, in order to give details on the geometrical properties of the utilized recycled fiber, eight diameter ranges were defined and the number of fiber included in each range was counted; this allowed plotting the percentage of the fiber in each class, Fig. 1. The range that included the largest number of diameter values was 0.15–0.2 mm (32.75%) followed by the class 0.30–0.35 mm and 0.20–0.25 mm, which presented respectively 27.0% and 24.6%.

Similary, the length of the reinforcement, referred to the distance between the outer ends of the fibers (Fig. 2), [25], was recorded for each specimen; the minimum and the maximum value was 3 mm and 170 mm respectively while the average was 31.4 mm. In this case the recorded measures were divided in fifteen classes, Fig. 3. The range including the major number of fiber

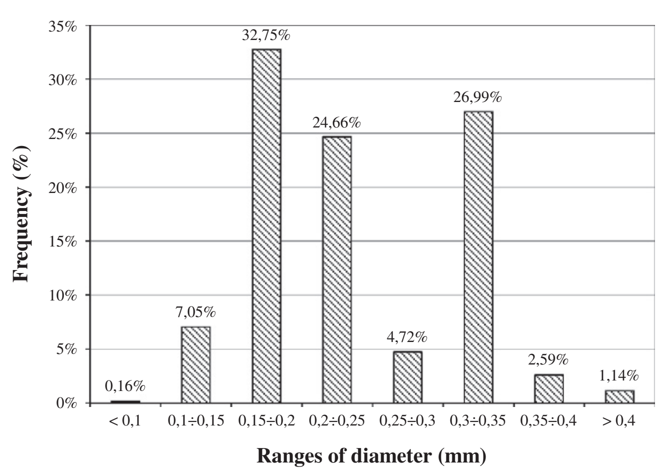

Fig. 1. Relative frequency of the diameter of the fibers.