Construction and Building Materials 125 (2016) 196–209

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Use of silica fume and recycled steel fibers in self-compacting concrete (SCC)

M. Mastali [a,*], A. Dalvand [b]

[a] ISISE, Minho University, Department of Civil Engineering, Campus de Azurem, Guimaraes 4800-058, Portugal
[b] Department of Engineering, Lorestan University, Khorramabad, Iran

HIGHLIGHTS

- Effects of silica fume and the recycled steel fiber experimentally investigated.
- The hardened properties were characterized by using compressive, tensile, flexural, and impact tests.
- The fresh properties were determined by using the slump flow test and V-funnel test.
- Combined effects of silica fume and the recycled steel fiber improved the mechanical properties and impact resistance.

ARTICLE INFO

Article history:
Received 18 April 2016
Received in revised form 30 June 2016
Accepted 11 August 2016

Keywords:
Silica fume
Recycled steel fiber
Self-compacting concrete
Mechanical properties
Impact resistance

ABSTRACT

This paper aims to investigate the effects of replacing cement with silica fume in the reinforced self-compacting concrete with recycled steel fiber and study its mechanical properties and impact resistance. To characterize mechanical properties and impact resistance, 144 specimens with different fiber volume fractions of 0.25%, 0.5%, and 0.75% were experimentally tested. Mechanical properties of specimens were characterized with regard of compressive, splitting tensile, and flexural strengths. Concerning the obtained large experimental database, an analytical analysis was performed by using regression analysis to investigate the correlate between the impact and mechanical properties of self-compacting concrete reinforced with recycled steel fibers. In addition, the correlation between the mechanical properties of specimens and the content of the replaced cement with silica fume was also examined.

The results revealed that the combined effects of silica fume and recycled steel fiber improved the mechanical properties and impact resistance of specimens. Moreover, linear equations were also developed to correlate mechanical properties and impact resistance of specimens with a high coefficient of determination.

1. Introduction

Over the last three decades, significant studies have been executed to examine the impact of steel fibers as reinforcing matrix on the mechanical properties and impact resistance. The previous findings revealed that steel fibers significantly improves the mechanical properties and impact resistance of the reinforced concrete. In the last decade, with regard of high cost of steel fiber and environmental friendly issues, using recycled steel fibers as reinforcing matrix in cement-based materials attracted the attention of many researchers.

Many researchers examined the fresh state and hardened properties of the reinforced concrete with recycled steel fibers. Recycled steel fibers obtained from different waste sources such as waste tires and waste formworks were used in these studies. To produce recycled steel fibers from waste materials different recycling methods such as conventional pyrolysis and microwave-induced are used [1]. Aghaee et al. studied about the mechanical properties of structural lightweight concrete reinforced with waste steel wires found in the construction sites [2]. Mechanical properties of mixtures were characterized through execution of compressive, tensile, flexural tests. Furthermore, to attain impact resistance of mixtures, specimens were tested under drop weight impact test. Mixtures were reinforced by different recycled steel fiber volume fractions, including 0.25%, 0.50% and 0.75% [2]. The results showed that the maximum compressive strength recorded for the reinforced mixture was associated with the recycled steel fiber volume 0.5%, however, the maximum splitting tensile strength and flexural strength recorded in the reinforced specimens with the recycled

* Corresponding author.
E-mail address: m.mastali@civil.uminho.pt (M. Mastali).

http://dx.doi.org/10.1016/j.conbuildmat.2016.08.046
0950-0618/

steel fiber volume 0.75% [2]. Khaloo et al. investigated the use of polymer fibers recycled from waste car timing belts in reinforcing high performance concrete [3]. Fresh-state of mixtures were assessed by slump flow diameter. In addition, the mechanical properties of the reinforced specimens also were determined through measuring compressive and flexural tests [3]. Different fiber lengths (20 mm and 40 mm) and different volume fractions (0.2%, 0.5%, 1%, and 1.5%) were used to reinforce the mixtures [3]. In their study, it was found that increasing fiber length from 20 to 40 mm leads to achieving a higher efficiency in the flexural strength of the fiber reinforced concrete (3–64% for fiber length 20 mm and 25–125% for fiber length 40 mm) [3]. Khaloo et al. worked on the mechanical properties and rheology of the self-compacting concrete reinforced with steel fibers [4]. Four different steel volume fractions of 0.5%, 1%, 1.5%, and 2% were used in the mixtures. Slump flow diameter, T500, T_V, and L-box tests were carried out to evaluate the rheology of those mixtures. Compressive, splitting tensile, and flexural tests were also performed to estimate the mechanical properties of mixtures at 7, 28, and 91 days [4]. Concerning the results, it was revealed that adding steel fibers reduces the workability of the SCC. More, specifically adding fiber at a volume fraction of more than 2% intensify this reduction [4]. Adding steel fiber also reduced the compressive strength of the material, while splitting tensile strength and flexural strength were improved. Moreover, flexural toughness of the SCC beams increased as the content of steel fibers increased [4]. Nili et al. investigated the combined effects of silica fume and steel fibers on the impact resistance and the mechanical properties of concrete [5]. Hooked steel fibers of 60 mm and the aspect ratio of 80, with three different volume fractions 0%, 0.5%, and 1% were used as reinforcing matrix. Cement was replaced with 8% weight silica fume. The experimental results showed that steel fibers improve the strength performance of concrete, particularly the splitting tensile and the flexural strengths. Furthermore, significant improvement was also observed in the impact resistance of the reinforced specimens, compared to the reference specimen. The results demonstrated that using the steel fiber in the mixtures containing silica fume significantly increase the ductility and impact resistance of the resulting concrete [5]. Dalvand et al. studied the effects of replacing cement with silica fume on the impact resistance and mechanical properties of conventional concrete [6]. Cement was replaced with 7% and 14% weight silica fume. It was observed that increasing the content of silica fume improved both mechanical properties and impact resistance of conventional concrete. Hence, the maximum improvement in the mechanical properties and impact resistance of specimens were recorded for the 14%-cement mixture replaced with silica fume [6].

With respect to the previous studies, adding the silica fume to the fiber reinforced concrete (FRC) with particular shapes, lengths, and diameters of steel fibers improves the impact resistance and the mechanical properties. To the authors' best knowledge there is no study reporting the effects of replacing silica fume on the reinforced self-compacting concrete mixtures with recycled steel fibers presenting different characteristics such as different diameters, lengths, and shapes. In this regard, this study was established to investigate the effects of replacing cement with silica fume on the impact resistance and the mechanical properties behavior of the reinforced self-compacting concrete mixtures with recycled steel fibers.

Different contents of silica fume (7% and 14%) used instead of cement in the mix compositions. Moreover, the mixtures were reinforced by three different levels of fiber volume fractions, including 0.25%, 0.5%, and 0.75%. The effects of replacing cement with silica fume on the rheology were investigated through the use of slump flow test (diameter and time) and V-funnel test. The mechanical properties of mixtures were characterized using compressive, splitting tensile, and flexural tests. Experimental investigations on the hardened properties of mixtures were performed for with 144 specimens divided into four groups, including 36 cubic specimens for compressive tests, 36 cylinders for splitting tensile tests, 36 prismatic beams for flexural tests, and 36 disk specimens for impact resistance tests. Considering the gathered relatively large experimental database, regression analysis was used to analysis the experimental data and some equations were linearly developed to investigate the correlation between the impact and mechanical properties of self-compacting concrete reinforced with recycled steel fibers. In addition, some equations were also presented to indicate the effects of silica fume contents on the impact resistance and the mechanical properties of mixtures.

2. Experimental study

2.1. Materials and concrete mixture design

Concrete mixtures consisted of Portland cement (type II based on ASTM C150 recommendations [7]), silica fume, fine and coarse aggregates, water, and superplasticizer (SP). Cement was replaced with silica fume of 7% and 14% weight. The chemical compositions and physical properties of a used silica fume and cement are listed in Table 1. The coarse and fine aggregates were obtained from the crushed limestone with a specific gravity of 2.63 g/cm^3 and a maximum size of 10 mm. In addition, the fine aggregate provided from

Table 1
Chemical composition and physical properties of cement and silica fume.

Chemical composition	Cement	Silica fume
SiO_2 (%)	21.10	85–95
Al_2O_3 (%)	4.37	0.5–1.7
Fe_2O_3 (%)	3.88	0.4–2.0
MgO (%)	1.56	0.1–0.9
K_2O (%)	0.52	0.15–1.02
Na_2O (%)	0.39	0.15–0.20
CaO (%)	63.33	–
C_3S (%)	51.00	–
C_2S (%)	22.70	–
C_3A (%)	5.10	–
C_4AF (%)	11.90	–
Physical properties		
Specific gravity (g/cm^3)	3.11	2.21
Specific surface (cm^2/g)	3000	14,000

Fig. 1. Used recycled steel fiber.