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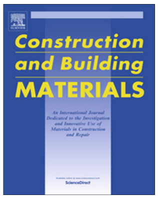

Development of self-consolidating rubberized concrete incorporating silica fume

Basem H. AbdelAleem, Assem A.A. Hassan *

Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador A1B 3X5, Canada

HIGHLIGHTS

- SLFSCRC mixtures with different CR and binder content were investigated.
- Increasing CR content negatively affected the mechanical properties of mixtures.
- Performance of SLF compared to other SCMs was investigated.
- Adding MK and SFs to SLFSCRC mixtures improved mechanical properties of mixtures.
- Mixtures with maximized percentage of CR and SFs further enhanced the STS and FS.

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ABSTRACT

This investigation was carried out to evaluate the effect of using silica fume on the development and optimization of self-consolidating rubberized concrete (SCRC). In particular, the investigation aimed to optimize successful silica fume self-consolidating rubberized concrete (SLFSCRC) mixtures with maximized percentage of crumb rubber (CR) (as a partial replacement of fine aggregate) and minimized strength reduction. The study also compared the behaviour of silica fume (SLF) with other supplementary cementitious materials (SCMs) in optimized SCRC mixtures. The results indicated that the use of SLF helped to develop SCRC mixtures with improved strength and acceptable fresh properties with up to 25% CR. Using SLF or metakaolin (MK) in SCRC exhibited superior behaviour among other SCMs in terms of strength. However, using SLF in SCRC showed better mixture flowability and less dosage of high range of water reducer admixture compared to using MK in SCRC. It was also noticed that adding steel fibres (SFs) to SLFSCRC mixtures greatly enhanced the mechanical properties, especially the splitting tensile strength and flexural strength. The results also showed that since there is no challenge to achieving acceptable self-compactibility (especially passing ability) in vibrated rubberized concrete, it was possible to develop silica fume vibrated rubberized concrete (SLFVRC) with higher percentages of CR and SFs and with further improved flexural and tensile strengths.

1. Introduction

Large amounts of solid waste materials have been generated due to global industrialization and technological innovation. About 1.5 billion tires are discarded every year as a result of ineffective methods of disposing of waste tires, which has polluted the environment. Many studies have investigated reusing waste tire rubber as a partial replacement of aggregate in concrete. The rubber material itself has high durability and elasticity, which can compensate for concrete's low elasticity and capacity to absorb energy [1]. Topcu and Avcular [2] reported that adding rubber to concrete improved its impact resistance and enhanced its elastic behaviour. Adding rubber also improves the fracture properties of concrete [3,4]. Khaloo et al. [5] studied the effect of replacing aggregate by crumb rubber (CR) and rubber chips on the toughness of concrete. They found that the addition of up to 25% rubber as a partial replacement of aggregate enhanced the toughness of concrete.

Using rubber, in general, has a negative effect on the fresh properties of self-consolidating concrete (SCC) mixtures. Previous researchers reported that the low density of CR encourages CR particles to float towards the concrete's surface, thus increasing the risk of segregation [6,7]. The addition of rubber also has a significant effect on the mechanical properties of concrete. Many studies reported that compressive strength, splitting tensile strength

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* Corresponding author.

E-mail addresses: b.abdelaleem@mun.ca (B.H. AbdelAleem), ahassan@mun.ca (A.A.A. Hassan).

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(STS), and flexural strength (FS) decreased as CR content increased. To alleviate the reduction in the mechanical properties resulting from using CR, supplementary cementing materials (SCMs) have been used. Silica fume (SLF) is considered one of the most effective SCMs to improve the mechanical properties (especially compressive strength) of mixtures due to its high pozzolanic reactivity [8,9]. Adding SLF also appeared to improve the impact resistance of concrete and increase the adhesion between aggregate and cement paste in concrete mixtures [10,11]. Sohrabi and Karbalaie [12] conducted an experimental study on rubberized concrete and reported that SLF fills the nanometric voids in cement mortar, producing a denser structure and, in turn, increasing the compressive strength. Güneyisi et al. [13] observed that using SLF in rubberized vibrated concrete appeared to increase its modulus of elasticity, but this increase was less than that observed in compressive strength. Metakaolin (MK) is also considered one of the most SCMs that enhances the viscosity of SCC, which in turn improves the aggregates' suspension in the mixture and reduces the risk of segregation [14,15]. MK also proved to increase the mechanical properties of SCRC. For example, Ismail and Hassan [16] observed that using 20% MK in SCRC mixtures improved the compressive strength, STS, FS, and modulus of elasticity by an average of 49.2%, 17%, 14.6%, and 24.9% when the CR increased from 20% to 40%.

Using fibres, especially steel fibres (SFs), proved to alleviate the reduction in mechanical properties such as STS and FS that resulted from adding CR [17,18]. The inclusion of SFs also showed enhanced ductility, crack resistance, impact resistance, toughness, and energy absorption [19,20]. As a result, the addition of SFs in SCRC may alleviate the reduction in STS and FS resulting from using CR and allows to maximize the percentage of CR in the mixtures. On the other hand, there is a challenge in optimizing the fresh properties of SCRC with SFs. Adding SFs to SCRC mixtures further reduces the flowability and passing ability [19,21–23]. However, despite the challenge of optimizing the fresh properties, developing SCRC with maximized percentage of CR and SFs is essential as it can further increase ductility and enhance mechanical properties (especially STS and FS).

Because of the limited number of studies that optimize SCRC mixtures with SLF, the main objective of this study was to develop SLFSCRC mixtures with maximized percentage of CR and minimized reduction in strength and stability. The study also included the development of silica fume vibrated rubberized concrete (SLFVRC) for comparison. The experimental test parameters included concrete type (SCC and VRC) percentage of CR (0%–40%), binder content (500 kg/m^3, 550 kg/m^3, and 600 kg/m^3), SFs volume fraction, and type of SCMs (SLF, MK, fly ash (FA), and slag (SG)). The fresh properties tests included slump flow, J-ring, L-box, V-funnel, air content, and sieve segregation tests, while the hardened properties tests included compressive strength, STS, and FS.

2. Research significance

Developing SCRC mixtures with high percentages of CR has the promising potential of increasing the ductility, energy absorption, and impact resistance of concrete. Moreover, using high percentages of CR reduces the self-weight of mixtures and promotes the development of eco-friendly and sustainable concrete. However, increasing the percentage of CR in SCRC reduces the strength and stability of mixtures, which challenges the development of such mixtures. By reviewing previous studies, it was found that there are a few studies that have investigated the effect of using SLF on the behaviour of VRC, but there is no available data regarding optimizing the fresh and mechanical properties of SCRC by using SLF. This study investigates the effectiveness of SLF in developing SCRC with maximum percentage of CR and minimized reduction of strength and stability. This research offers a significant contribution to the development of SLFSCRC with great potential for structural applications.

3. Experimental program

3.1. Materials

General use Portland cement [24], MK (ASTM C618 Class N), FA (ASTM C618 Type F) [25], SG (ASTM C989 Type I), and SLF were used to produce the developed mixtures. Natural crushed stone with a maximum size of 10 mm and natural sand were used for the coarse and fine aggregates, respectively. Each aggregate type had a specific gravity of 2.6 and absorption of 1%. The CR used in this investigation had a maximum size of 4.75 mm, specific gravity of 0.95, and negligible water absorption. The aggregate gradations of the 10-mm crushed stones, natural sand, and CR are presented in Fig. 1. Hooked-ends steel fibre with 35 mm length, aspect ratio of 65, and tensile strength of 1150 MPa was used. The fibre was chosen based on the types commercially available on the world market. A polycarboxylate-based high range water reducer admixture (HRWRA) similar to [26] with specific gravity, volatile weight, and pH of 1.2, 62%, and 9.5, respectively, was used to achieve the required slump flow of mixtures.

3.2. Mixture development

A total of 20 rubberized concrete mixtures were developed and tested in this study, with the main objective of evaluating the performance of SLF in developing/optimizing SCRC with high percentage of CR and minimized reduction of strength and stability. The study also aimed to compare the performance of other SCMs (MK, FA, and SG) in optimized SCRC mixtures with that of SLFSCRC.

Table 1 presents the tested mixtures and their composition. The first group of mixtures (mixtures 1–5) was designed to investigate the effect of increasing the percentage of CR on the SLFSCRC mixtures. The second set of mixtures (mixtures 6–8) was designed to compare SLFSCRC with the performance of other SCMs (MK, FA, and SG) in optimized SCRC mixtures with maximized percentages of CR. Mixture 9 investigated the effect of incorporating steel fibres on enhancing STS and FS of SLFSCRC. The third set of mixtures (mixtures 10–12) investigated the effect of binder content on enhancing and optimizing SLFSCRC mixtures with high percentages of CR. The fourth set of mixtures (mixtures 13 and 14) investigated the effectiveness of using MK in improving the properties of SLFSCRC in order to allow higher percentages of CR to be used in SLFSCRC mixtures. The fifth set of mixtures (mixtures 15–20) was designed to evaluate the properties of VRC compared to SCRC.

The optimum percentage used in each of SLF, MK, FA, and SG mixtures were 10%, 20%, 20%, and 30%, respectively. These percentages

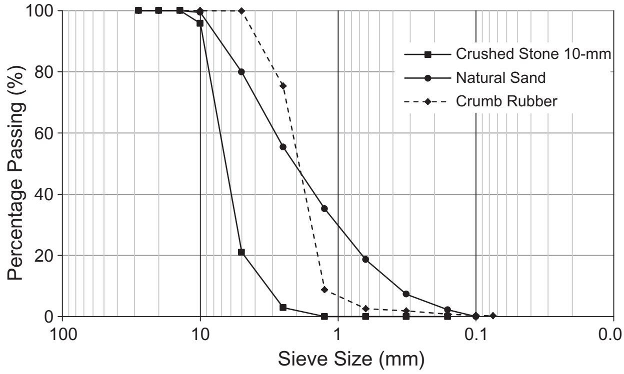

Fig. 1. Grading curves for fine, coarse, and crumb rubber aggregates.