Construction and Building Materials 162 (2018) 816–829

Contents lists available at ScienceDirect

Construction and Building Materials

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

The combined effect of crumb rubber and synthetic fibers on impact resistance of self-consolidating concrete

Basem H. AbdelAleem *, Mohamed K. Ismail, Assem A.A. Hassan

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

HIGHLIGHTS

- The impact resistance and mechanical properties of SCRC with SFs were investigated.
- The behavior of SLFs was also presented for comparison.
- Different SFs types, sizes, and contents were investigated.
- Increasing the CR content significantly improved the mixtures impact resistance.
- Using SFs in SCRC further improved the impact resistance and mechanical properties.

ARTICLE INFO

Article history:
Received 13 March 2017
Received in revised form 11 November 2017
Accepted 9 December 2017

Keywords:
Self-consolidating concrete
Crumb rubber
Synthetic fibers
Impact resistance
Drop-weight impacts

ABSTRACT

This study was conducted to evaluate the impact resistance and mechanical properties of self-consolidating rubberized concrete (SCRC) mixtures reinforced with synthetic fibers (SFs). In particular, the investigation aimed to maximize the impact resistance and energy absorption of SCRC mixtures by optimizing the mixture proportions and by using the most appropriate types and volumes of SFs. The study also presented the effect of steel fibers (SLFs) on the impact resistance and mechanical properties of SCRC for comparison. The tested fibers consisted of three types of flexible SFs (19-mm, 38-mm, and 50-mm), two types of semi-rigid SFs (27-mm and 54-mm), and two types of hooked-end SLFs (35-mm and 60-mm). The results indicated that increasing the CR content had a negative effect on the mechanical properties of SCRC mixtures, while the ductility and impact resistance were significantly improved. Using SFs in SCRC mixtures further increased the impact resistance and appeared to alleviate the reduction in splitting tensile strength (STS) and flexural strength (FS) that resulted from adding CR. Although using longer SFs had a negative impact on the fresh properties of SCRC, it greatly improved the mechanical properties and impact resistance of the mixtures. The results also indicated that in the absence of the challenge of achieving self-compactibility, it was possible to develop vibrated rubberized concrete with higher percentages of CR and SFs, which in turn resulted in higher improvements in STS, FS, impact resistance, and further reduction in the self-weight of concrete.

1. Introduction

Rubberized concrete is a relatively new building material, which has proven to have better ductility, energy absorption, and impact resistance compared to normal concrete [1,2]. Many structural applications require high-impact resistance and more energy absorption capacity, such as foundation pads of machinery, shock absorbers, airport runways, railway buffers, and highway pavement [3]. Rubber aggregates are one of the mixture components that have a lower stiffness and can contribute to enhancing the ductility, energy absorption, and impact resistance of the concrete composite [4–6]. Topcu 1995 [7] studied the elastic and plastic energy capacity of concrete by replacing the course and fine aggregates by course and fine rubber chips. It was found that replacing aggregates with rubber chips decreased the elastic energy and increased the plastic energy capacity of concrete. Khaloo et al. 2008 [2] investigated the effect of adding up to 25% crumb rubber (CR) as a partial replacement for coarse and fine aggregates. They reported that the toughness recorded its higher value at 25% CR replacement. Moreover, Gupta et al. 2015 [4] observed that using up to 25% CR as a partial replacement of fine aggregate appeared

---

* Corresponding author.

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

https://doi.org/10.1016/j.conbuildmat.2017.12.077
0950-0618/

to improve the impact absorption energy of vibrated rubberized concrete (VRC) mixtures.

Despite the advantages of adding rubber to concrete in enhancing the ductility, toughness, energy absorption, and impact resistance, utilizing rubber in concrete proved to have a negative effect on the mechanical properties of concrete such as compressive strength, splitting tensile strength (STS), and flexural strength (FS) [6,5,4,8]. Therefore, alleviating the reductions in mechanical properties of concrete mixtures can maximize the benefits that come from adding rubber to concrete. Using fibers is one of the options that helps to improve the STS and FS of concrete mixtures, which can compensate for the reductions in the mechanical properties resulting from adding high percentages of CR [9–11]. In addition, using fibers to reinforce concrete mixtures exhibited positive effects on the impact resistance and energy absorption capacity [12–14]. Banthia et al. 2003 [15] found that the use of fibers in normal vibrated concrete mixtures enhanced the post-fracture stress transfer capability, which in turn improved the resistance to impact loads. They attributed their results to the superior effect of fibers in bridging matrix cracks. Choi and Yuan 2005 [16] observed that the addition of polypropylene fibers to normal vibrated concrete increased the STS by 20–50%. Song et al. 2005 [17] found that using 0.1% nylon and polypropylene in vibrated concrete mixtures increased the STS by 17% and 10%, respectively. They also found that the inclusion of nylon and polypropylene fibers increased the impact resistance. For example, adding 0.1% nylon fibers to fiber-reinforced concrete mixtures increased the first crack and failure crack by 19% and 30.5%, respectively, while these increases reached up to 11.9% and 17% when polypropylene fibers were added.

Developing self-consolidating concrete (SCC) with CR and fibers can contribute to achieving concrete with distinct structural performance, including high-impact resistance, toughness, energy absorption, and ductility. However, due to the negative effect on the fresh properties resulting from adding fibers to self-consolidating rubberized concrete (SCRC) mixtures, developing such mixtures is a challenge and requires a balance between achieving adequate viscosity and acceptable fresh properties [18,19].

This study mainly focused on developing fiber self-consolidating rubberized concrete (FRSCRC) mixtures using different types and volumes of SFs and maximized percentage of CR and fibers to ensure higher ductility, energy absorption, and impact resistance. The study also included the development of SCRC mixtures with steel fibers for comparison. Fiber-vibrated rubberized concrete (FRVRC) with maximized percentage of CR and SFs were also developed in this study.

2. Research significance

Combining fibers with CR can reduce the negative effect of CR on the mechanical properties (especially the STS and FS) of concrete. In addition, adding fibers to SCRC helps to develop sustainable concrete with enhanced ductility, toughness, energy absorption, and reduced self-weight. The literature review includes limited research investigating the effect of CR and steel fibers (SLFs) on the impact resistance of VRC. However, there are no available studies that investigated the effect of combining CR with SFs on the mechanical properties and impact resistance of SCC mixtures. In this research, FRSCRC mixtures with different types, sizes, and volumes of SFs were developed and optimized. The authors believe that this research will be very useful for researchers/engineers who are interested in developing concrete with high-impact resistance and reduced self-weight.

3. Experimental program

3.1. Materials

General use Portland cement [20], metakaolin (MK) [21], and fly ash (FA) (ASTM C618 Type F) were used to develop the mixtures. Natural crushed stone with a maximum size of 10 mm and natural sand were used for the coarse and fine aggregates, respectively. Each type of aggregate 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, a 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. Three types of flexible SFs, two types of semi-rigid SFs, and two types of hooked-ends SLFs were used (Fig. 2). The fibers used were chosen based on the types commercially available on the world market. The physical and mechanical properties of the fibers used are shown in Table 1. A polycarboxylate-based high-range water-reducer admixture (HRWRA) similar to ASTM C494 Type F [22] was used to achieve the required slump flow of mixtures.

3.2. Mixture development

Developing SCRC and FRSCRC mixtures requires a balanced viscosity to improve the particle suspension and decrease the risk of segregation without affecting the mixtures' flowability. Therefore, several trial mixtures were performed to determine the minimum water-to-binder (w/b) ratio, total binder content, coarse-to-fine aggregate ratio (C/F), and type of supplementary cementing materials (SCMs) required to develop mixtures meeting the acceptable fresh properties limits of SCC according to the EFNARC (2005) [23] without overdosing the HRWRA. The trial mixtures stage targeted a class of SCC having a slump flow diameter of 700 ± 50 mm meeting the SCC conformity criteria given by the EFNARC (2005) [23]. The optimum results were obtained by combining 550 kg/m^3 binder content, 0.4 w/b ratio, and 0.7C/F aggregate ratio. In addition, it was necessary to replace 50% of the cement content by 30% FA and 20% MK (as resulted from the trial mixtures stage). The FA was used to increase the fluidity of SCC, while MK was used to achieve high particle suspension, avoiding the risk of segregation. MK was also used to increase the mechanical properties of the mixtures [24,25] achieving adequate strengths for structural applications. Varied amounts of HRWRA were added to the developed mixtures until the targeted slump flow diameter of 700 ± 50 mm was achieved.

Table 2 shows all the developed mixtures. In stage 1, mixtures 1–7 were developed to evaluate the effect of varying the percentage of CR from 0% to 30% (by volume of fine aggregate) on the mechanical properties and impact resistance of SCRC mixtures. In stage 2, mixtures 8–24 were developed to investigate the influence of adding different types and/or lengths of fibers on improving the impact resistance and mechanical properties. It is worth noting that further increases in fiber percentage beyond the maximum percentage used in this stage (0.2% for SFs and 0.35% for SLFs) led to a significant drop in the L-box value below the acceptable limits given by EFNARC (2005) [23]. In stage 3, mixtures 25–31were designed to investigate the development of vibrated concrete in order to allow the use of higher percentage of CR (30%) and larger volumes and lengths from different types of synthetic and steel fibers (1%). The use of higher percentages of CR and SLFs in the developed mixtures in this stage was intended to investigate mixtures with further enhancement in the ductility, energy dissipation, tensile strength, impact resistance, and reduced self-weight. The selection of 30% CR and 1% fiber in this stage was based on a preliminary trial mixtures stage to obtain acceptable mixture consistency (no visual sign of CR or fiber clumping) and reasonable compressive strengths for structural application (more than 25 MPa). During this trial mixture stage, using percentages of fibers higher than 1% usually resulted in a formation of fiber balls while using percentages of CR higher than 30% significantly reduced the compressive strength.

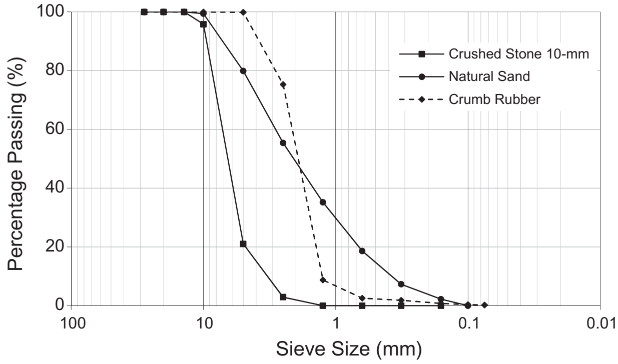

Fig. 1. Grading curves for fine, coarse, and crumb rubber aggregates.