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Experimental investigation on compression toughness of rubberized steel fibre concrete

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HIGHLIGHTS

- Compressive properties with inclusion of crumb rubber aggregate into plain and steel fibre concrete were studied.
- Compression toughness improved by addition of crumb rubber to plain and steel fibre concrete.
- ACI equation could be used directly to obtain modulus of elasticity for rubberized steel fibre concrete.
- Crumb rubber could be satisfactorily utilized with steel fibre into concrete under compression loading.

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ABSTRACT

In this study, the compression toughness of steel fibre concrete (SFC) with the inclusion of crumb rubber by partial replacement of fine aggregate was investigated. Crumb rubber was incorporated at different percentages of 5%, 10%, and 15% by volume. The compression properties (compression strength, modulus of elasticity and stress–strain diagrams) showed a possible interaction between steel fibre and crumb rubber to enhance such properties of concrete.

Results obtained showed improvement in the compression toughness by increase of crumb rubber content up to 15% and change into the behaviour of normal concrete to ductile instead of brittle. The toughness index and the specific compression toughness of concrete specimens indicated crumb rubber could be satisfactorily utilized with steel fibre to present a good performance under compressive loading and to keep the environment clean and healthy by recycling of waste tire.

1. Introduction

Developed countries consider recycling of waste materials to achieve different economic and environmental aspects. For instance, recycling of discarded tires has received attention. The discard of tires to land as stockpiles represents one of the threats to the environment and health [1]. To solve this problem, studies related to the use of waste tire in a form of rubber particles or rubber crumbs into concrete have been widely conducted. In the earlier investigations of its mechanical properties, crumb rubber concrete showed a reduction in compressive and splitting tensile strengths and an improvement in ductile behaviour [2]. However, subsequent studies are required to investigate the toughness of rubberized concrete.

The toughness or energy-absorbing capacity of concrete can be defined as the area under the stress–strain curve. Rubberized concrete is found to enhance plastic energy capacity, which leads to an increase in the energy absorbed [3–6]. The effect of waste tire chips incorporated into concrete by replacing aggregate was discussed by Eldin and Senouci [2]. They observed enhanced toughness of rubberized concrete, although compressive and tensile strengths decreased. Li et al. [7] found that the toughness of rubberized concrete (fibres or chips) increased significantly. The rubberized cylindrical samples tested with splitting tensile test were also found to be difficult to break in opposite to control mixture. The fibres from waste tires were recognized to have a better performance in transferring loads than the chips in this study. The capability of rubberized concrete to absorb dynamic loading was generally better than that of plain or ordinary concrete. Khaloo et al. [8] presented a study on the behaviour of rubberized concrete consisting of tire chips, crumb rubber, and a blend of them by replacing a portion of aggregate volume. Different ratios of 12.5%, 25%, 37.5%, and 50% were considered for each type of rubber particles. A large

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reduction in compressive strength and tangential modulus of elasticity was observed, while the rubberized concrete presented ductile behaviour with respect to rubber content. The optimum rubber ratio related to the maximum toughness index was 25%. Other results obtained showed crack width, and its propagation in rubberized concrete was slower than that in ordinary concrete.

Fibres especially steel (industrial or waste), are commonly used to enhance different concrete properties, such as impact resistance, toughness ratio [9,10] and ductility [11,12]. Steel fibres and crumb rubber concrete have recently been widely investigated by researchers to utilize the positive synergy between them. A preliminary investigation was presented by Turatsinze et al. [13] to enhance the cracking resistance of concrete. The rubberized particles that were used comprised metal steel fibre, and a positive synergy between them was found through the improvement in strain capacity. A thin crack aperture was also observed, with a delay in shrinkage cracks. Xie et al. [6] investigated the effect of incorporation of crumb rubber into steel fibres recycled concrete aggregate on the compressive and flexural properties. The utilization of recycled concrete aggregate instead of normal concrete aggregate with crumb rubber was concluded through the outcome of this work. This conclusion was due to that the reduction rate of this type of concrete was smaller than that of normal concrete aggregate when crumb rubber was added. Recently, an improvement in the permeability resistance was observed in such type of concrete by treatment of crumb rubber aggregate surface to enhance the interface with cement matrix [14]. In general, the combination of steel fibre with crumb rubber for any type of concrete aggregate is generally promising in many concrete engineering applications that hopefully would expand the horizon of manufacturing such type of concrete in the future. Park et al. [15] conducted a study to investigate the improvement of the structural behaviour (strength and ductility) of concrete pipes with partial replacement of fine aggregate (by volume) with crumb rubber. Five mixtures, namely, reinforced concrete, rubberized concrete, steel-fibre-reinforced rubberized concrete, polypropylene-fibre-reinforced rubberized concrete, and hybrid-fibre-reinforced rubberized concrete, were considered for the dry casting of concrete pipes. The results obtained showed that the hybrid fibre reinforcements (both steel and polypropylene fibres) presented a better enhancement in the strength and ductility of concrete pipes than the single-type incorporation of fibre when added to rubberized concrete pipes. However, selecting a proper amount of crumb rubber in rubberized-fibre-reinforced concrete pipes was recommended to effectively improve the strength and ductility.

In this study, an experimental investigation on the behaviour of the rubberized steel fibre concrete subjected to compressive loading was conducted. The objective of this work was to evaluate the compression behaviour of different mixtures with partial replacement of fine aggregate with crumb rubber. An extensive discussion of the compression toughness of rubberized steel fibre concrete was included.

2. Experimental details

2.1. Materials and specimens preparation

The base paste material in this study consisted of Type 1 ordinary Portland cement. Coarse aggregate (crushed stone) had a maximum size of 14 mm. The specific gravity of the coarse aggregate was 2.65. River sand with fineness modulus of 3.4 and specific gravity of 2.64 was used as fine aggregate. The particle size distribution is shown in Fig. 1. The Steel fibres used were hooked–end fibres with a length of 60 mm and an aspect ratio of 80. Crumb rubber graded from 1.18 mm to 2.36 mm in size, with specific gravity of 0.73. A superplasticizer with advanced polycarboxylic ether was used to maintain the desired workability of concrete mixtures with steel fibre added by 0.3% of cement weight. Crumb rubber and steel fibre used in this study are shown in Fig. 2.

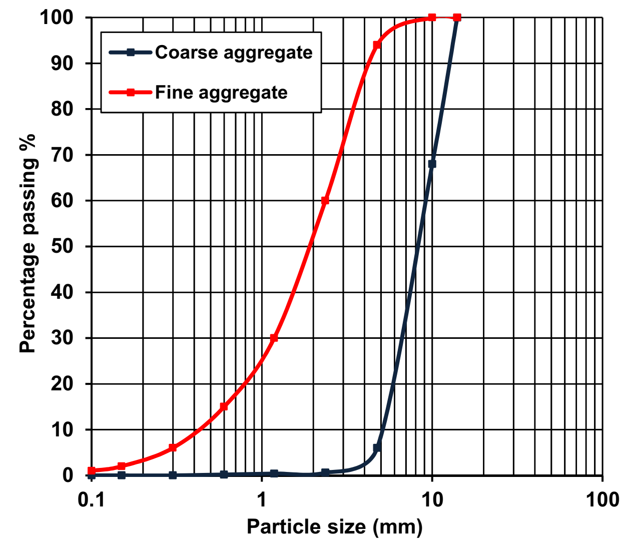

Fig. 1. Particle size distribution of fine and coarse aggregate.

The total number of mixtures prepared was eight. Each mixture differed in rubber and steel fibre ratios. Ordinary concrete as reference mixture designed with minimum strength of 40 MPa. A steel fibre concrete mixture containing 0.5% volume fraction of hooked-end steel fibre was prepared. The other series consisted of rubberized concrete with crumb rubber that had different replacement ratios (5%, 10%, and 15%) by partial replacement of fine aggregate (sand) by volume. Another series was considered in this study by combining crumb rubber with steel fibre at the same aforementioned replacement ratios. Table 1 shows the proportions of mixtures considered in this work. Each batch comprised six samples consisting of (200 × 100 mm) (Height × Diameter) cylinders prepared according to ASTM C192 [16] for compression and stress–strain behaviour. Another nine cubes of 100 mm side were adopted to determine the bulk density and compressive strength (7, 14 and 28). All mixtures were prepared in a pan mixer in a laboratory and then cast in steel moulds. After removing from the steel moulds 24 h later, the mixtures were cured in clean water at 26 °C until the age of test.

2.2. Tests setup

In order to determine the consistency of the rubberized mixtures, slump test was executed according to ASTM C143 [17]. The slump was determined by measuring the vertical difference between the top of the inverted mould and the centre of the top surface of the concrete specimen.

Compressive test was conducted using (200 × 100 mm) (Height × Diameter) concrete cylinders subjected to an axial load applied by a hydraulically operated machine with rate 0.3 N/mm^2/s until the failure of the specimen. The test conditions were according to ASTM C39 [18] and at age of 28 days. The stress–strain curves were determined by measuring loads that increased at a constant rate. For each stress value, the specified strain was measured and calculated immediately using the built – in system of the machine. Modulus of elasticity was calculated according to ASTM C469 [19]. For cubes specimens, the compressive strength tests were conducted on a hydraulic compression testing machine at 7, 14 and 28 days [20]. The tests results are average of three readings. The test set up of the cube and cylinder specimens is shown in Fig. 3.

3. Results and discussions

3.1. Slump

The slump was selected to be (30–60) mm in the design mix. For rubberized concrete, a reduction the slump was observed with respect to crumb rubber ratio as seen in Fig. 4 .With 15% substitution of sand by crumb rubber, the slump reduced by 14%. However, within this ratio, the concrete showed adequate consistency.

The reduction in the slump was discussed previously and attributed to the increase in the friction between the compounds of concrete which resulted from the roughness of the surface of rubber aggregate [21]. In addition, segregation could occur during the mixing with the increase in crumb rubber content. This is