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Experimental Investigation Of Mechanical Performance Of Rubberized Fiber Reinforced Concrete Made Of Recycled Plastics

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Abstract – This paper investigates the mechanical properties of rubberized fiber-reinforced concrete (RuFRC) incorporating synthetic macro-structural fibers made of recycled plastics and waste tyre rubber shreds. The effects of different percentages of fiber doses 0%, 0.25%, 0.5% and 1% on the compressive, tensile and flexural strength of RuFRC are examined. In addition, tyre rubber shreds are used to replace coarse aggregate by 10%, 20% and 30% by volume. It is found that the mechanical properties of RuFRC are significantly affected due to the variation of the fiber doses and rubber percentages. While the inclusion of fiber and rubber together decreases the compressive strength of concrete, the tensile strength of concrete is found to increase significantly.

Keywords: *Rubberized concrete; fiber-reinforced concrete, compressive strength, tensile strength, flexural strength.*

1. Introduction

Concrete is one of the most used construction materials in the world. However, due to the surge of construction across the globe, the demands for natural sands and aggregates have significantly increased which led to the depletion of these natural resources [1]. Previously, researchers studied the applicability of crumb rubber sourced from recycled tyres as a sustainable aggregate for concrete. The application of crumb rubber in concrete not only solves the problem associated with the scarcity of natural aggregates but also finds a sustainable solution to reuse waste tyre. Around 1000 million tyres reach the end of their service life each year among which a significant amount ends up in a stockpile or landfill such as 3000 million in the EU, and 1000 million in the USA [2]. Tyre landfilling is a great ecological concern due to the toxic and soluble materials it contains. Rubber shreds produced from the waste tyre can be used as coarse aggregates whereas crumb rubber can be used as fine aggregates. Existing studies showed that the workability and the mechanical properties of rubberized concrete decreased as the rubber percentages increased [3, 4]. However, existing test results show that the inclusion of tyre rubber in concrete increases the energy dissipation of the concrete beams under dynamic loading [5]. In addition, the literature indicates that rubberized concrete has better durability than traditional concrete [6]. It was reported that rubber as aggregate increases the electrical resistivity of concrete and thus enhances durability [7, 8]. Therefore, rubberized concrete has been used in protective structures to absorb significant energy dissipation resulting from explosion or impact.

Synthetic macro-fibers are made of carbon, acrylic, polyolefin or aramid and can be virgin and recycled polypropylene (PP), polyethylene terephthalate (PET) fibers or high-density polyethylene (HDPE). Synthetic macro-fibers decrease the width of the cracks in concrete, thus, preventing water from entering into the concrete matrix and corroding the reinforcement bars [9]. In addition, macro-fibers prevent crack tip propagation, thus, eliminating most micro-cracks. By effectively controlling and arresting cracks in concrete, macro-fibers prevent plastic and dry shrinkage of concrete and retain the integrity of the concrete. Macro-fibers also improve the post-cracking performance of concrete. Polypropylene (PP) is one of the most used plastics in our modern civilization, widely used in packaging, stationery and automotive components to name a few. Macro-fibers made of PP have higher resistance against the alkaline environment as well as have higher tensile strength and elastic modulus; however, offer ease of production and lower cost to manufacture. Kazmi et al. [10] investigated the effects of different percentages of fibers (0, 0.5% and 1%) and three different percentages of recycled aggregates (0%, 50% and 100%) on the mechanical performance of fiber-reinforced concrete (FRC). It was found that with the increase of the fiber doses, the peak stress, strain and ultimate strain of concrete increased. However, this effect was more noticeable in concrete with a higher percentage of recycled aggregates. Fallah and Nematzadeh [11] studied the effects of 0 to 0.5% fiber doses with an increment of 0.1% on the mechanical performance of high-strength concrete containing silica fume and nano-silica. It was found that the compressive strength decreases with the increase of the fiber doses. Similarly, the tensile strength of FRC decreased for the increase of the fiber doses beyond 0.3% fiber doses. The maximum increase of the tensile strength was recorded as 12.81% for concrete with 0.2% fiber dose.

Rubberized fiber-reinforced concrete (RuFRC) can combine the benefits of both rubberized concrete and FRC. However, until today, no research has been performed to investigate the effects of different rubber percentages on FRC with various fiber doses. This study reports a series of tests carried out to investigate the mechanical performance of RuFRC. The fiber doses were varied from 0%, 0.25%, 0.5% and 1% whereas rubber shreds were used to replace coarse aggregate by 10%, 20% and 30% by volume. Tests on axial compression, split tensile testing and flexural testing were carried out and reported herein.

2. Experimental Program

2.1. Specimens and mix design

The effects of fiber doses and rubber shreds on the compressive, tensile and flexural strength of RuFRC are investigated. A control batch without fibers and rubber shreds for each test was also cast for comparison purposes. The compressive strength of the concrete was measured using cylindrical samples of 100mm × 200mm. The tensile strength was measured using 150mm × 300mm cylindrical samples using split tensile testing. The flexural strength was measured using 400mm × 150mm × 150mm rectangular samples. The mechanical properties of RuFRC were measured based on the average results of three samples for each test. In the naming of the specimens, C0-0 is the control specimen with no fibers and rubber shreds. For RuFRC, the first number represents the specification of the fiber dose followed by the number that represents the percentage of rubber shreds used to replace the coarse aggregates.

The mix design provided by Flexiroc Australia was used to prepare samples to study the mechanical properties of RuFRC. Ordinary Portland Cement (OPC), fine sand, coarse aggregates,water-to-cement ratio and water reducer were used according to the mix design. The fiber doses varied from 0.25% to 0.5%, 0.75% and 1%. Rubber shreds were used to replace coarse aggregate by 10%, 20% and 30% by volume. Synthetic macro fibers made of recycled plastics called 'eMesh' as shown in Fig. 1(a) with a minimum tensile strength of 350 MPa and fiber length of 47 mm were used. The rubber shreds were sourced from the waste tyres supplied by Flexiroc Australia as shown in Fig. 1(b).

The aggregates, sands and rubbers were pre-soaked and then surface dry prior to mixing. A 70L mixer was used to mix the batch. In the beginning, aggregates, sands, rubber shreds and fibers were mixed for 2 minutes before adding cement and mixed it for another 1 minute. Half of the water was first poured and mixed for 1 minute before gradually adding the remaining water in addition with a plasticizer.

After completing the mixing, a slump test was carried out for each mix according to AS 1012.3.1:2014 [12]. The cylindrical molds prepared for compression and tensile testing and molds prepared for flexural tests were then cast. A vibrator table was used to vibrate the samples to ensure proper compaction. The samples were then cured for 24 hours before removing the molds and left at normal temperature to cure for 28 days before testing.


(a) (b)

Fig. 1: Images of (a) eMesh fiber [13], (b) tyre shreds

2.2. Test setup

The compressive strength of RuFRC was measured under axial compression using the specification recommended by AS 1012.9.1:2014 [14]. The tensile splitting tests were carried out according to AS 1012.10-2000 [15] to measure the tensile strength of RuFRC. The flexural strength of RuFRC was measured using four-point bending test as specified by AS 1012.11-2000 [16]. The test setup of RuFRC subjected to compression, tensile splitting test and flexural test are shown in Fig. 2.

(a) Compression test (b) tensile test (c) flexural test

Fig. 2: Test setups of RuFRC under different loading conditions.

3. Test results and discussions

It was observed from Fig. 3 that the slump for the control specimen was close to 160mm. However, as the rubber and fiber doses increased, the slump decreased as expected. The lowest slump measured at 35mm was observed for the batch containing 1% fiber and 30% rubber. The higher doses of fibers were found to hold the slump, resulting in poor workability.

The failure of the RuFRC subjected to different loading conditions is shown in Fig. 4(a). The common failure of the samples subjected to compression test was due to the shear type failure and the loss of concrete from the core section. The samples subjected to the tensile splitting test exhibited fracturing in two sections close to the central line, as shown in Fig. 4(b). In specimens subjected to flexural load, it was found that RuFRC specimens exhibited more ductile failure compared to the control specimens.


(a) (b)

Fig. 3. Measured slump for (a) plain concrete and (b) RuFRC.

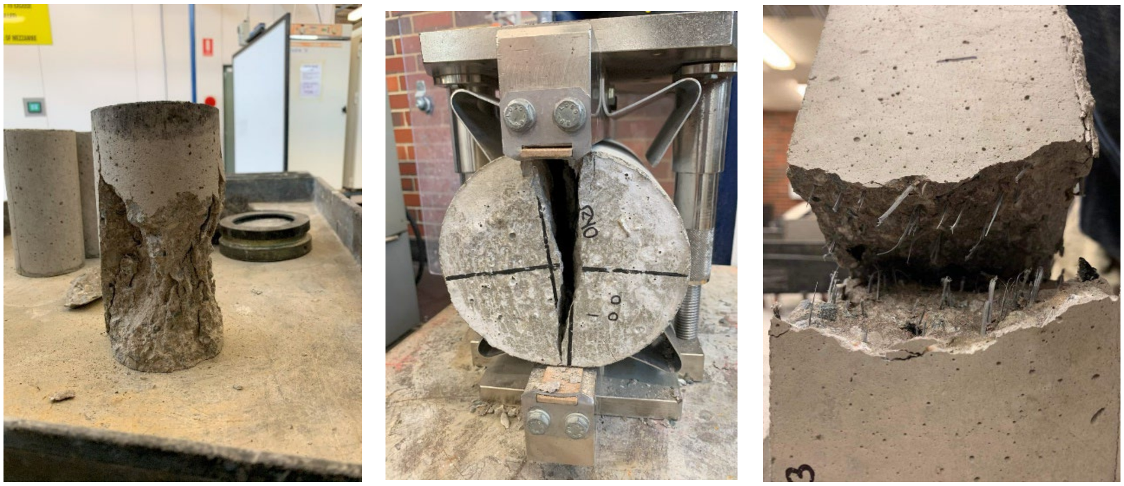
(a) Compression test (b) tensile test (c) flexural test

Fig. 4. Failure models of RuFRC subjected to different loading conditions.

The measured average compressive, tensile and flexural strengths of the tested specimens are shown in Figs. 5 to 7. The compressive strength of the control specimen was measured as 60.5 MPa. As expected, when the fiber dose was fixed, increasing the rubber percentage from 10 to 30% decreased the compressive strength of RuFRC. The compressive strength of RuFRC with 1% fiber dose and 10%, 20% and 30% rubber was measured as 40.4, 31.6 and 23.8 MPa, respectively. Interestingly, it was found that the percentage of the reduction of the compressive strength within a group of certain fiber doses due to the increase of the rubber percentage was very similar for groups with various fiber doses. For instance, when the fiber dose was 0.25%, increasing the rubber percentage from 0% (control specimen) to 10%, 20% and 30% decreased the compressive strength by 31%, 46% and 62%, respectively. Similarly, when the fiber dose was 1%, the reduction of the compressive strength was calculated as 33%, 48% and 61%. When investigating the effects of various fiber doses for a fixed percentage of rubber, it was found that generally, the compressive strength decreased with the increase of the fiber doses.

From Fig. 7, it is observed that generally, RuFRC specimens had higher tensile strength compared to the control specimen. However, generally, RuFRC specimens with 30% rubber had lower tensile strength than the specimens with 10% and 20% rubber content. For specimens with 1% fiber dose, 10% and 20% rubber content showed an increase of 22% and 21% of the tensile strength compared to the control specimen. This can be attributed to the fact that higher doses of fiber and rubber had poor compaction which resulted in reduced tensile capacity.

When investigating the flexural performance of RuFRC, it was found that the control specimen exhibited higher flexural strength than most RuFRC specimens. RuFRC with 30% rubber showed a considerable reduction of the flexural strength for all different fiber doses compared to the control specimen. This may be due to the fact that the combination of higher doses of rubber and fiber in concrete negatively impacts the flexural strength of RuFRC. However, when the fiber dose was o.25% and 0.75%, the specimen with 10% rubber exhibited 4% and 9% increase in flexural strength compared to the control specimen.

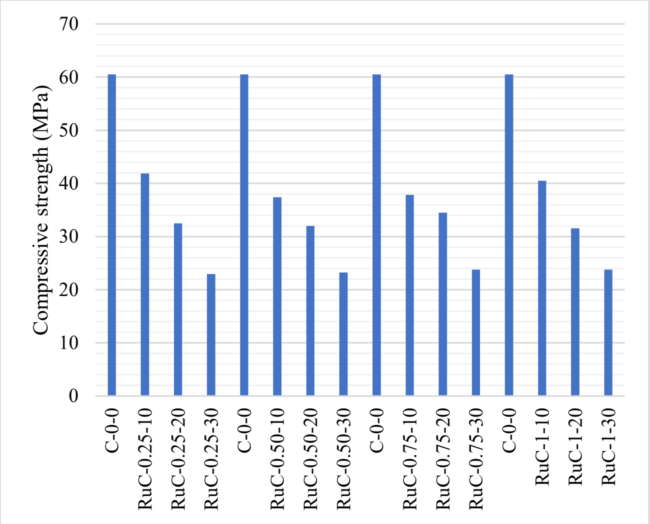

Fig. 5: Compressive strength of RuFRC.

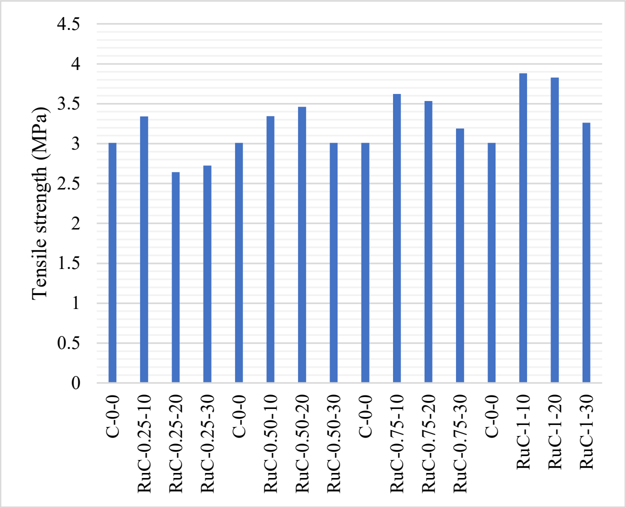

Fig. 6. Tensile strength of RuFRC

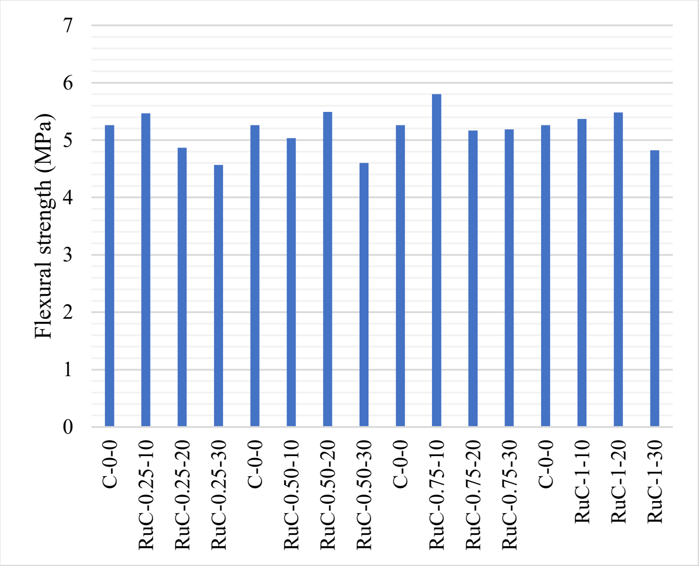

Fig. 7. Flexural strength of RuFRC

5. Conclusions

This paper reports a series of tests carried out to study the mechanical performance of RuFRC under different loading conditions. The effects of different fiber doses and the different percentages of crumb rubber on the compressive strength, tensile strength and flexural strength of RuFRC are studied. Results show that increasing the rubber percentage reduces the slump of the mix. Generally, the compressive strength of RuFRC decreased with the increase of the fiber doses. However, the percentage of the reduction of the compressive strength within a group of certain fiber doses due to the increase of the rubber percentage was very similar for groups with various fiber doses. The inclusion of fiber and rubber was found to increase the tensile strength of concrete. However, the tensile strength of RuFRC decreased when rubber percentages increased more than 20% to replace the coarse aggregates. Lastly, the flexural strength of RuFRC decreased significantly when the rubber percentage was 30%. A small percentage of rubber can increase the flexural strength of RuFRC as it was observed from the test results.

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