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Mechanical properties of high strength concrete with scrap tire rubber

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HIGHLIGHTS

- The first study to investigate the properties of high strength rubberized concrete.
- The first study of both the viscous and hysteretic damping of rubberized concrete.
- The compressive strength is reduced with the increase of the rubber content.
- Energy dissipation and damping are increased with increasing rubber content.
- The mix design CS is recommended for further study in seismic applications.

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ABSTRACT

Green construction has been a very important aspect in the concrete production field in the last decade. One of the most problematic waste materials is scrap tires. The use of scrap tires in civil engineering is increasing. This article investigates the effect of using scrap tires in high strength concrete on both the mechanical and dynamic properties. Two different rubberized concrete mixtures were designed. The first set; variable slump (VS) was intended to study the effect of rubber replacement of sand on the workability of concrete. The other set; constant slump (CS) was designed to keep the workability the same. The compressive strength of the concrete was reduced by the use of rubber with more severe loss of strength for VS compared to CS. The viscous damping ratio was investigated using free vibration tests with impact hammer on simply supported beams. The replacement of up to 30% of sand with rubber resulted in an increase in damping with the increase being more in the CS beams as well. The hysteresis damping for cylinders under cyclic loading was also investigated and the average hysteresis damping was found to increase. The results of this article give an insight on the properties of high strength concrete with scrap tire rubber.

1. Introduction

Green construction has been an important aspect in the concrete production field in the last decade or so. The use of waste products in concrete manufacturing is beneficial both economically by replacing some of the components with waste materials and environmentally by clean disposal of waste materials. One of the most problematic waste materials is scrap tires; if improperly handled, scrap tires can be a threat to environment. Exposed scrap tires can be a breeding space for mosquitoes that carry disease. Scrap tire piles can be easily set on fire which is difficult to put out, and produces heavy smoke and toxic run off to waterways [Rubber manufacturers association 2014].

The addition of shredded scrap tires to concrete provides some favorable characteristics for concrete and alters some of concrete properties. The ordinary cement-based concrete is generally brittle; however, the addition of rubber to concrete, producing what is called rubberized concrete, can increase its ductility and impact resistance [1–4]. Rubberized concrete is used in many applications such as concrete pavements, sidewalks, and road barriers where concrete is subjected to dynamic loading from moving vehicles or people walking on sidewalks.

The mechanical properties of normal strength rubberized concrete have been extensively investigated [5–8]. An extensive literature review for the mechanical properties of normal strength rubberized concrete can be found in [9]. Past research concluded that the addition of high percentage of shredded rubber to concrete reduces the compressive strength and workability of fresh concrete. However, these effects vary according to many factors such as the size and distribution of the rubber particles, the type of aggregate

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to be replaced (coarse aggregate or fine aggregate), and the percentage of rubber content in a rubberized concrete mixture. Youssf et al. [4] investigated the FRP confinement effects on rubberized concrete.

The dynamic properties of rubberized concrete have not yet received the attention it deserves. Hernandez-Olivares et al. [10] reported an increase of 23–30% of the dissipated energy of rubberized concrete having low rubber contents of 3.5% and 5% compared to conventional concrete. Zheng et al. [11] investigated the dynamic properties of rubberized concrete. A more recent study [12] investigated methods for increasing the damping capacity of concrete by replacing up to 20% of the fine aggregate with shredded rubber. Generally, these researchers reported an increase in damping and decrease in compressive strength was reported.

While there have been some investigations of the dynamic properties of rubberized concrete [10–12], the mechanical and dynamic properties of high strength concretes with scrap tires, to the best knowledge of the authors, have not been studied yet. In this manuscript, the mechanical and dynamic properties of high strength concrete (concrete with compressive strength of greater than 65 MPa) having scrap tire rubber as a substitution for fine gravel were studied. Furthermore, past research on dynamic properties of normal strength rubberized concrete either focused on measuring viscous damping [11] or hysteretic damping [10,12]. This study represents the first study to carry out comprehensive evaluation of the viscous and hysteretic damping of rubberized concrete. Different percentages of replacement of sand ranging from 0% to 30% by volume were investigated. The dynamic properties of high strength rubberized concrete are also investigated using an impact hammer. The dissipated energy and hysteresis damping are also investigated.

2. Experimental investigation

2.1. Material characteristics

Two sets of rubberized concrete mixtures were designed and used during the course of this study. The first set, hereafter called variable slump (VS), was used to test the properties of concrete having 0%, 5%, 10%, 15%, 20%, and 30% volume replacement of sand with shredded rubber. The second set, hereafter called constant slump (CS), is similar to VS set but with variable amounts of superplasticizer to maintain the same workability of the fresh concrete regardless of the rubber percentages. The materials used for sets VS, and CS are shown in Tables 1 and 2, respectively. The mixture nomenclature in Tables 1 and 2 consists of mixture set (VS or CS) followed by the percentage of sand replacement with rubber by volume.

The cement used in all mixtures is type I Portland cement meeting ASTM C150 specifications. Limestone washed coarse aggregate with nominal maximum size of 1 in was used. The sand used was Missouri river sand. The rubber used was ground rubber with three different sizes of 8–14, 14–30, and 30- where the first number represents the sieve number of the passing particles and the second number represents the sieve number of the retained particles. Different trial mixtures including different grading of the shredded rubber were prepared and the grading that had the best workability and consistency was selected for all mixtures. Fig. 1 shows the grading of the sand, coarse aggregate and ground rubber used during the course of this research. Fig. 2 shows the used ground rubber. The material characteristics of the sand, coarse aggregate and rubber are shown in Table 3.

2.2. Concrete mixing

The mixing procedure of the concrete was started by dry mixing the coarse aggregate, sand, and rubber for about 1 min to insure distribution of the aggregates and then the cement and fly ash were added and the concrete was dry mixed for another minute. The superplasticizer was added to the water and the water was then added to the mixture and the concrete was mixed for 2 min and then let stand for 1 min; then, mixed for another 2–3 min until consistency was observed. For the CS mixtures, the slump test was performed after the mixing and superplasticizer was carefully added if the slump was not satisfied.

2.3. Test specimens

Six concrete beams of each set, VS and CS, were cast with nominal dimensions of 150 mm × 150 mm × 900 mm; one for each percentage of rubber replacement and these were used to determine the dynamic modulus of elasticity and the damping ratio of each mixture. Mechanical vibration was performed for all the beams to insure proper placement and filling of the concrete. A total of thirty-six 100 mm × 200 mm cylinders for each set were cast in the same day with the beams to determine the compressive strength of the concrete at 7 and 56 days. The cylinders were also tested under axial cyclic loading at 56 days to determine the hysteretic damping of the different concrete mixtures. The beams and cylinders were demolded after 24 h and were moist cured in a controlled moisture room for 7 days. Then, they were removed from the curing room and left in the ambient temperature in the High-bay Lab at the Missouri University of Science and Technology.

2.4. Test setups

The compressive strengths of the concrete cylinders were determined using an MTS machine. The cylinders were grounded to assure the leveling of the surface and the two surfaces are parallel to each other. To determine the average axial strain of the concrete, two string potentiometers were placed on two opposite sides of each cylinder at a gauge length of one-third of the cylinder height. The average axial strains along a full specimen height were also measured using a Linear Variable Displacement Transducer (LVDT). The test setup for the compressive strength is shown in Fig. 3.

The cylinders were monotonically tested to determine the concrete compressive strength at 7 days. At 56 days, one group of the concrete cylinder specimens was monotonically loaded in a displacement control and another group was cyclically loaded using displacement control up to failure. The loading rate for both sets was 0.2 mm/min. The cyclic axial compressive loading, including loading/unloading cycles, was applied based on a prescribed pattern of progressively increasing levels of axial displacements until failure occurred. Three cycles of loading/unloading were applied at each axial displacement level. Finally, the cylinders were tested for compressive strength at 56 days to represent the actual compressive strength of the beams on the test day.

The dynamic properties of the rubberized concrete were determined using simply supported beams excited by an instrumented impulse hammer with a capacity of 22.5 kN. Fig. 4 shows the dynamic test setup. Four accelerometers were mounted on the surface of the beam. The beam was excited by hitting the beam at mid-span using the impact hammer. The accelerations were recorded using data acquisition system called Synergy box along with the instrumented hammer reading.

3. Dynamic properties analysis

The hysteresis is the property of systems to follow different loading and unloading paths. The hysteresis damping for the cyclic testing is calculated from the specific damping capacity (Y), which is the ratio between the energy dissipated per unit volume of the material, E_D, and the strain energy per unit volume stored in a linear elastic system, E_{S0}, as shown in Eq. (1).

$$Y = \frac{E_D}{E_{S0}} \tag{1}$$

A graphical representation of E_D and E_{S0} is shown in Fig. 5 [13].

The energy dissipated per cycle per unit volume, E_D, is measured as the area enclosed by a hysteresis loop drawn on axes of stress and strain. It can be calculated mathematically using Eq. (2).

Table 1
Mixture proportions for the control concrete and for VS set.

Materials (kg/m^3)	Water	Cement	Fly ash	Coarse aggregate	Super-plasticizer	Sand	R(8–14)	R(14–30)	R(30–)
Normal concrete	142.40	336.39	112.13	1057.22	1.07	576.66	–	–	–
VS 05	142.40	336.39	112.13	1057.22	1.07	544.63	10.09	3.20	0.70
VS 10	142.40	336.39	112.13	1057.22	1.07	519.00	20.18	6.41	1.41
VS 15	142.40	336.39	112.13	1057.22	1.07	490.16	30.27	9.61	2.11
VS 20	142.40	336.39	112.13	1057.22	1.07	461.33	40.37	12.81	2.82
VS 30	142.40	336.39	112.13	1057.22	1.07	403.67	60.55	19.22	4.23