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Properties of high strength concrete containing scrap tire rubber

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A B S T R A C T

Disposal of waste tire rubber has become a major environmental issue in all parts of the world representing a very serious threat to the ecology. One of the possible solutions for the use of scrap tire rubber is to incorporate it into concrete, to replace some of the natural aggregate. This paper presents the results of an experimental research to analyse the suitability of scrap tire rubber as a partial substitute for natural fine aggregate in high strength cement concrete. Crumb rubber replaced natural fine aggregate from 0% to 20% in multiples of 2.5%. Tests were performed to determine the compressive strength, flexural tensile strength, pull-off strength, abrasion resistance, water absorption and water penetration of these concrete samples and their microstructures were observed using Scanning Electron Microscopy (SEM). It was observed that the compressive strength, flexural tensile strength, pull-off strength and depth of water penetration of the rubberized concrete were less than that of the control mix, while the abrasion resistance and water absorption (up to 10% substitution) exhibited better results than that of the control mix concrete. Rubberized concrete may be used in structures where there are chances of brittle failure. Crumb rubber may be utilized in high strength concrete as a partial substitute for fine aggregate up to 12.5% by weight for obtaining strength above 60 MPa.

1. Introduction

Disposal of waste tire rubber has become a major environmental issue in all parts of the world. Every year millions of tires are discarded, thrown away or buried all over the world, representing a very serious threat to the ecology (Richardson et al., 2012; Thomas et al., 2013; Pelisser et al., 2012). By the year 2030, the number of discarded tires would reach to 1200 million tires yearly (including the stockpiled tires, there would be 5000 million tires to be discarded on a regular basis). In India alone, the total number of discarded tires would be an estimated 112 million per year (after retreading twice) (Al-Mutairi et al., 2010; Yilmaz et al., 2009; Ho et al., 2012; Gesoglu and Erhan, 2007).

The vehicle tires which are disposed to landfills constitute one important part of solid waste. Stockpiled tires also present many types of, health, environmental and economic risks through air, water and soil pollution. The tires store water for a long period because of its particular shape and impermeable nature providing a breeding habitat for mosquitoes and various pests (Eldin and Senouci, 1994; Mohammed et al., 2012; Thomas et al., 2015a, b). Tire burning, which was the easiest and cheapest method of disposal, causes serious fire hazards (Gosoğlu and Guneyisi, 2011; Wang et al., 2013). Once ignited, it is very difficult to extinguish as the 75% free space can store lot of free oxygen. In addition, the residue powder left after burning pollutes the soil. The oil that is generated from the melting of tires can also pollute soil and water (Eldin and Senouci, 1994).

Tire rubber can be used in a variety of civil and non-civil engineering applications such as geotechnical works, road construction, fuel for cement kilns, incineration for production of electricity, feedstock for carbon black manufacturing, reefs in marine environments, and aggregate in cement-based products. Still, millions of tires are being buried, thrown away or burnt all over the world (Segre and Joekes, 2000; Oikonomou and Mavridou, 2009). Recently, construction industry has taken up the challenge to incorporate sustainability in the production activities by searching for more environmental friendly raw materials or by the use of solid waste materials as aggregate in cement concrete (Shu and Baoshan, 2014; Thomas et al., 2014; Pelisser et al., 2011). One of the possible solutions for the use of waste tire rubber is to incorporate into cement based materials, to replace some of the natural aggregate. This attempt could be environmentally friendly and economically viable (Pappu et al., 2007; Mohammed et al., 2012; Thomas et al., 2015a, b; Thomas and Gupta, 2015a, b).

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Guneyisi et al. (2004) studied the properties of rubberized concrete that contains silica fumes. Crumb rubber and tire chips were used to replace fine and coarse aggregate respectively from 2.5% to 50% by volume. Silica fume was used to replace cement from 5% to 20% and water to cement ratios of 0.6 and 0.4 were adopted. It was observed that the rubberized concrete with and without silica fumes were workable to a certain degree. The use of silica fumes in rubberized concrete helped to minimize the rate of strength loss. The concrete with compressive strength of 40 MPa was produced with 15% rubber content and 0.4 water to cement ratio.

Pelisser et al. (2011) studied the effect of alkaline activation and silica fume usage on concrete made with waste rubber particles (10% as a substitute for fine aggregate). The crumb rubber was washed with sodium hydroxide and silica fumes were added in 15% by mass to act as a surface modifier. Three water-cement ratios (0.4, 0.5 and 0.6) were used. The rubberized concrete without silica fumes had shown a reduction in strength up to 67% when compared to control mix, while that with silica fumes had shown only 14% reduction in strength. Onuaguluchi and Daman (2014) studied the properties of concrete containing pre-coated crumb rubber and silica fumes. They observed significant increase in the compressive and tensile strengths of the concrete. Considerable improvement was also noticed in the resistance to chloride penetrability due to the action of silica fumes in rubberized concrete.

Huang et al. (2013) studied the properties of rubberized concrete after performing two stage surface treatments on tire rubber. Rubber was coated with cement and silane, a coupling agent. It was observed that silane helped develop a chemical bond between rubber particles and cement paste, and minimized the loss in density and compressive strength. The two stage treatment was found more effective in improving the properties of the rubberized concrete. Dong et al. (2013) observed that the chloride ion penetration resistance of the concrete containing coated rubber and that of control concrete was similar. Energy absorption capability of concrete with coated rubber was better than that of concrete with uncoated rubber.

Zhang and Li (2012) studied the abrasion resistance of concrete in which silica fumes and crumb rubber were used as additives. It was reported that the addition of crumb rubber reduced the compressive strength but increased the abrasion resistance of the concrete. The addition of silica fume enhanced both compressive strength and abrasion resistance of rubberized concrete. Concrete with silica fumes had a better abrasion resistance than control concrete and the rubberized concrete had better resistance to abrasion when compared to the silica fume concrete. The abrasion resistance of rubberized concrete increased with the increase of rubber content. Sukontasukkul and Chaikaew (2006) mentioned that the crumb rubber blocks exhibited less abrasion resistance than the control mix specimens. The concrete blocks containing a mixture of different sizes of crumb rubber performed better than those with single size rubber aggregate. Gesoglu et al. (2014) explained that the abrasion resistance of pervious concrete increased with increasing amount of rubber from 0 to 20%. Fine crumb rubber (passing 1 mm sieve) exhibited more resistance to abrasion than tire chips and crumb rubber. The depth of wear reduced from 0.91% to 0.17% when the amount of fine crumb rubber was increased from 0% to 20%.

Although there are some studies focusing on the usage of waste tire in concrete technology, performance of discarded tire rubber has not been evaluated in high strength concrete in the recent past. Therefore the purpose of this study was determining the feasibility of using waste tire rubber in the production of high strength concrete and the resulting effects on its physical, mechanical and durability properties.

2. Material properties and preparation of test specimens

The properties of the raw materials and the methods of preparation of the specimens for testing are described below.

Ordinary Portland cement of grade 43, conforming to Indian Standards (IS): 8112-1989 was used (Specific gravity 3.15, Normal consistency 34%, Initial setting time 99 min, Final setting time 176 min). Natural river sand confirming to zone II as per IS: 383-1970 (Specific gravity 2.63, free surface moisture 1%, water absorption 1.5%, fineness modulus 2.83). Coarse aggregate, 10 mm size was used 40% (fineness modulus-5.573, water absorption 0.3%) and 20 mm size was used 60% (fineness modulus-7.312, water absorption 0.25%). Crushed stone were used as coarse aggregate with an average specific gravity-2.63. Crumb rubber was supplied by a local industry. Tire rubber was ground into three sizes after removing the steel and textile fibers (powder form of 30 mesh, 0.8–2 mm, 2–4 mm). The difference in specific gravity of river sand and crumb rubber was taken into consideration while replacing. The ratio of specific gravity of rubber to the specific gravity of sand was taken and that was multiplied to the mass of fine aggregate to be replaced. It gives the exact weight of rubber to be taken for replacement. The specific gravity of rubber powder was 1.05 and that of the other two sizes were 1.13. The three sizes of crumb rubber were mixed in definite percentages (25% of 2–4 mm size, 35% of 0.8–2 mm size and 40% rubber powder) to bring it to zone II.

The Scanning Electron Microscopy (SEM) image of cement is given in Fig. 9. The image of silica fume is given in Fig. 10. The images of cement and silica fumes show a spherical and shiny appearance. The images of crumb rubber and fine aggregate (river sand) passing through a 300 μm sieve are given in Figs. 11 and 12 respectively. When the surface of the crumb rubber and river sand is observed, the former seems to have a smooth, hard surface while the latter has a rough, irregular one.

To investigate the suitability of discarded tire rubber as a substitute for fine aggregate in concrete, M60 grade concrete was designed (as per IS: 10262-2010 and IS 456, 2000) with a water-cement ratio of 0.3. The mixture proportion is given in Table 1. The ratio of cement, fine aggregate and coarse aggregate are 1: 1.48: 2.67 by weight (1 part of cement, 1.48 parts of fine aggregate and 2.67 parts of coarse aggregate). Crumb rubber replaced natural sand by weight from 0% to 20% in multiple of 2.5%. Only the fine aggregate was replaced with crumb rubber, while all the other parameters were kept constant. To enhance the interfacial transition zone bonding, 6% silica fumes by weight of cement were added to the concrete. Silica fume can contribute to the increment in strength of concrete by creating dense packing and as a pore filler of cement paste. At ordinary temperatures and in the presence of moisture, silica fume is more reactive than fly ash. A super

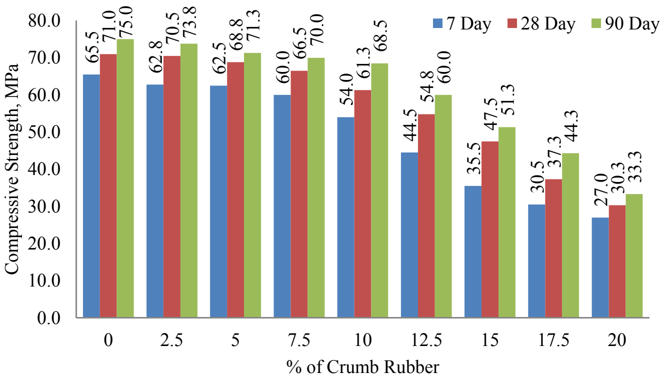

Fig. 1. Results for compressive strength test.

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