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Long term behaviour of cement concrete containing discarded tire rubber

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ABSTRACT

Disposal of waste tire rubber has become one of the major environmental issues in 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. It was estimated that, almost 1000 million tires end their service life every year and more than 50% are discarded without any treatment. One of the possible solutions for the use of waste tire rubber is to incorporate into cement concrete, to replace some of the natural aggregates. This paper presents the results of an experimental research to analyse the suitability of waste tire rubber as a partial substitute for natural fine aggregates in cement concrete. For the first time, three sizes of crumb rubber were mixed in definite percentages and replaced for fine aggregates from 0% to 20% in multiples of 2.5%. Tests were done to determine the mechanical properties, water absorption, resistance to sulphate attack, carbonation and porosity of these concrete samples. It was observed that the values of compressive strength, flexural tensile strength, pull-off strength and sulphate attack of rubberized concrete were lower than that of control mix; but up to a certain percentage, they gave better resistance to water absorption, and carbonation. It was concluded that there is a promising future for the use of discarded tire rubber as a partial substitute for fine aggregates in concrete, which can result in huge environmental and sustainability benefits.

1. Introduction

With urbanization, industrialization and technological innovations in different fields, large amount and variety of solid waste materials have been generated by the industrial, agricultural, mining and domestic activities. Recycling of these non-biodegradable wastes is very difficult. In the year 2002, it was estimated that the amount of waste generation was 12 billion tonnes annually (1.6 billion would be municipal solid waste and 11 billion could be industrial waste). By the year 2025, the amount would be 19 billion tonnes annually. The land requirement for the disposal of these waste materials is a big challenge for the civil and environmental engineers (Asokan et al., 2007; Krishna et al., 2014; Thomas et al., 2013, 2015).

Due to the huge increase in the population and the uplift in the living standards of people, there was a big growth in the number of vehicles. As a result of this, lots of tires are ending as waste every day. Disposal of waste tire rubber has become a major environmental issue in all parts of the world. It was estimated that 1.5 billion tires are manufactured in the world per annum (Rafat and Tarun, 2004; Pelisser et al., 2011, 2012). Every year millions of tires are discarded, thrown away or buried all over the world, representing a very serious threat to the ecology. It is estimated that every year almost 1000 million tires end their service life and out of that, more than 50% are discarded to landfills or garbage, without any treatment. By the year 2030, the number would reach to 1200 million yearly. Including the stockpiled tires, there would be 5000 million tires to be discarded on a regular basis (Azevedo et al., 2012). If the Indian scenario is considered, it is estimated that the total number of discarded tires would be 112 million per year after retreading twice (Mukul, 2010).

The Discarded vehicle tires which are disposed to landfills constitute one important part of solid waste. The tires are bulky and 75% space that a tire occupies is void and these spaces provide the potential sites for the breeding of rodents. There is a tendency for the tires to float or rise in a land-fill and come to the surface (Neil and Ahmed, 1994; Rhyner et al., 1995). Stockpiled tires also present many types of, health, environmental and economic risks through air, water and soil pollution (Neil and Ahmed, 1994; Bashar et al., 2012). The tires store water for a longer period because of its

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particular shape and impermeable nature providing a breeding habitat for mosquitoes and various pests. Use of discarded tires as a fuel has been banned due to environmental issues (Gregory, 2001; Al-Tayeb et al., 2013; Rahman et al., 2012; Richardson et al., 2012).

Tire burning, which was the easiest and cheapest method of disposal, causes serious fire hazards (Benazzouk et al., 2007; Mehmet and Erhan, 2007; Thomas et al., 2014). Temperature in that area rises and the poisonous smoke with uncontrolled emissions of potentially harmful compounds is very dangerous to humans, animals and plants. The residue powder left after burning pollutes the soil. Once ignited, it is very difficult to extinguish as the 75% free space can store lot of free oxygen. Tires melt due to the high temperature and generate oil that pollutes soil and water (Neil and Ahmed, 1994; Pacheco-Torgal and Jalai, 2011).

For the last some years, construction industry is taking 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 aggregates in concrete. One of the possible solutions for the use of waste tire rubber is to incorporate into cement concrete, to replace some of the natural aggregates. This attempt could be environmental friendly (as it helps to dispose the waste tires and prevent environmental pollution) and economically viable as some of the costly natural aggregates can be saved (Khalid and Mathew, 2012; Azevedo et al., 2012).

2. Literature review

Eldin and Senouci (1993) were the first to study on aggregates derived from used tires. They replaced fine aggregates (1 mm tire crumb) and coarse aggregates (6 mm, 19 mm, 25 mm and 38 mm). It was reported that the particular concrete had lower workability, compressive and tensile strength, and greater tenacity. The decrease in mechanical properties was attributed to the loss of adherence between the surface of rubber particles and the cement matrix. The loss in compressive strength increased with the size of the tire derived aggregated.

Mehmet and Erhan (2007) investigated on the strength development and chloride penetration of rubberized concretes. They pointed out that the unit weight of rubberized concrete decreased with increasing percentage of rubber added. There was reduction in unit weight up to 18%. The strength development patterns for plain and rubberized concrete between 3 and 7 days were relatively high, slower rate was noticed between 7 and 28 days, and relatively slower rate was observed between 28 and 90 days. The compressive strength reduced systematically as the percentage of rubber was increased irrespective of the w/c ratio and curing period. There was a systematic increase in the depth of chloride penetration for increase in the rubber content, with and without silica fumes.

Eshmaiel et al. (2009) investigated on the usage of tire rubber as an aggregate and as filler in concrete. Chipped rubber was used for coarse aggregate replacement and powdered rubber was used for cement replacement in concrete in 5%, 7.5% and 10% by weight. It was observed that, up to 5% replacement, the mechanical properties were similar to the control mix and beyond that, there were considerable differences. Al-Mutairi et al. (2010) explained that the use of 5% silica fumes in rubberized concrete helped to minimize the loss in compressive strength at elevated temperatures. At elevated temperature of above 400 °C, the compressive strength was similar to that of control concrete. Guleria and Dutta (2011) explained that the unconfined compressive strength of rubberized concrete can be increased by treating the tire chips with carbon tetrachloride and sodium hydroxide.

Arin and Nurhayat (2009) observed decrease in the water absorption upon increase in size of the rubber particles in the concrete. Miguel and Jorge (2012) have reported that the water absorption (by the process of immersion) of rubberized concrete increases as the percentage of rubber and the particle size of replaced rubber increases. When the capillary water absorption test was done, the results were not conclusive. Azevedo et al. (2012) explained that it is possible to maintain a low capillary action even at the rubber content of 15% in concrete.

Camille and George (2013) studied on the use of recycled crumb rubber as fine aggregates in concrete. They have noticed good compressive strength for less than 25% replacements of crumb rubber (for fine aggregates) and huge drop beyond 25% of crumb rubber. For 25% substitution, almost 8% reduction in concrete density was noticed. James and Masanobu (2013) mentioned that the bonding between the cement paste and the crumb rubber can be improved by the addition of silica fumes in concrete, which is proven by the increase in compressive strength of the rubberized silica fume concrete.

In this regard, an attempt may be done to control the environmental pollution and to save the natural resources by using the discarded tire rubber for partial replacement for fine aggregates in cement concrete.

3. 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.

3.1. Raw materials

Ordinary Portland Cement of grade 43, conforming to IS: 8112-1989 was used. (Specific gravity was 3.15, Normal consistency as 34%, Initial setting time 99 min and Final setting time 176 min). Natural river sand confirming to zone II as per IS: 383-1970 was obtained from river banas (Specific gravity 2.63, free surface moisture 1%, fineness modulus 2.83). Coarse aggregates, 10 mm size was used 40% by weight of total coarse aggregates (fineness modulus-5.573) and 20 mm size was used in 60% by weight (fineness modulus-7.312). Crushed stone were used as coarse aggregates with an average specific gravity-2.63. Tire rubber was grinded into three sizes (powder form of 30 mesh, 0.8–2 mm, 2–4 mm). 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 (2–4 mm size in 25%, 0.8–2 mm size in 35% and rubber powder in 40%) to bring it to zone II. This was performed in the best of our knowledge, for the first time as it was noticed in any literature. The chemical composition of Crumb Rubber, physical properties and chemical composition of cement are given in Thomas et al., 2014.

3.2. Preparation of test specimens

Concrete mix was designed as per IS: 10262-2010 and IS: 456-2000 with water-cement ratio 0.4. Water-cement ratios of 0.45 and 0.5 were also studied to study the variations in different properties. Crumb rubber was replaced for natural fine aggregates from 0% to 20% in multiple of 2.5%. The mixture proportions are given in Table 1. Super plasticizer was used as the admixture to arrive at the desired workability (above 0.91). In these mixes, nine cube specimens of size 100 mm were casted for 7, 28 and 90 days compressive strength test. Three concrete cube specimens each were casted for water absorption test, sulphate attack test and carbonation test. Nine concrete beams of size 100 mm × 100 mm × 500 mm were casted for 7, 28, and 90 days flexural tensile strength test. The mixtures were prepared and casted at indoor temperature of 25–30 °C. Moulds were covered with plastic sheets, soon after casting and de-moulded after 24 h. Curing was done for 28–90 days in water tank, with controlled temperature of 25–27 °C.