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Experimental and modelling studies on high strength concrete containing waste tire rubber

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ABSTRACT

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. A series of laboratory investigations were undertaken to evaluate the performance of concrete mixtures incorporating discarded tire rubber as aggregate. Numerous projects have been conducted to on the replacement of aggregates by crumb rubber, but scarce data are found in literature on high strength rubberized concrete. In this study, crumb rubber was partially substituted for fine aggregates from 0% to 20% in multiples of 2.5%. 6% silica fumes were added by weight of cement. The properties of concrete like compressive strength of sulphate attacked specimen, water absorption of sulphate attacked specimen, variation in weight of sulphate attacked specimen, macro cell current measurement, half cell potentials and modelling in Abacus was performed and the results were analyzed. The results showed that there was gradual decrease in the compressive strength of the specimens when compared to the control mix. Water absorption of sulphate attacked specimens showed a trend similar to that of the control mix. Macrocell corrosion and half cell potential measurements showed that there was no presence of corrosion. The analytical results from Abaqus followed the pattern of the results obtained from laboratory experiments.

1. Introduction

Solid waste disposal is a worldwide problem. Recycling of these non-biodegradable waste materials is very difficult and a great challenge to the environmental engineers. Fly ash, marble sludge waste, incineration ash, rice husk-bark ash, bagasse ash, bottom ash, plastic waste, stone wastes, ceramic waste, copper slag, agricultural wastes, copper tailings, carbon steel slag, coal waste, mine waste, construction and demolition waste, ceramic waste, foundry slag, limestone waste, wood ash, furnace slag, welding slag, phosphogypsum slag, ISF slag, wollastonite, waste tire rubber, etc., are some of the some of the examples of municipal and industrial waste materials that pollute the environment. Mohammed, Anwar Hossain, Ting Eng Swee, Wong, and Abdullahi (2012), Nayef, Al-Rukaibi, and Bufarsan (2010), Onuaguluchi and Panesar (2014), Oikonomou and Mavridou (2009), Pelisser, Barcelos, Santos, Peterson, and Bernardin (2012), Al-Tayeb, Abu Bakar, Ismail, and Md Akil (2013), Azevedo, Pacheco-Torgal, Jesus, Aguiar, and Camoes (2012), Cuong Ho, Turatsinze, Hameed, and Chinh Vu (2012), Benazzouk et al. (2007), Garrick (2001), Guneyisi, Ozturan, and Gesoğlu (2007), Yilmaz and Degirmenci (2009).

Proper waste management initiatives can stimulate innovation in recycling and reuse, limit land filling, reduce losses of resources and create incentives for behavioural change. It was estimated that in EU, about five tonnes of waste per person per year is generated on average, and little more than a third of that is effectively recycled. The European Zero Waste Programme aims to eliminate maximum waste materials by recycling and reuse, that will allow for a overall savings potential of €630 billion per year for European industry and the creation of 580,000 new jobs until 2030 (SWD 2014-206).

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. (Pacheco-Torgal, Ding, & Jalali, 2012; Pelisser, Zavarise, Longo, & Bernardin, 2011; Richardson, Coventry, & Ward, 2012; Thomas, Damare, & Gupta, 2013). It is estimated that every year almost 1000 million tires end their service life and more than 50% are discarded without any treatment. By the year 2030, the number would reach to 1200 million tires yearly. (Including the stockpiled tires, there would be 5000 million tires to be discarded on a regular basis.) If the Indian

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Table 1
Mixture proportions of fresh concrete.

Cement (kg/m^3)	Water (kg/m^3)	Silica fumes (kg/m^3)	Coarse aggregate 10 mm (kg/m^3)	Coarse aggregate 20 mm (kg/m^3)	Fine aggregates (kg/m^3)	Admixture (%)
450.0	140.0	27.0	355.0	848.0	666.0	2

scenario is considered, it is estimated that the total number of discarded tires would be 112 million per year (after retreading twice). Rahman, Usman, and Al-Ghalib (2012), Thomas, Chandra Gupta, Kalla, and Csetenyi (2014), Thomas and Gupta Chandra (2015), Thomas, Chandra Gupta, Mehra, and Kumar (2015).

Albano, Camacho, Reyes, Feliu, and Hernandez (2005) studied on the properties of concrete in which waste tire rubber (crumb rubber with size 0.29 mm and 0.59 mm) was substituted for 5% and 10% of fine aggregates by weight. Untreated and treated scrap rubber was used. The purpose of treatment with a solution of sodium hydroxide and a coupling agent silane was to increase the interfacial adhesion between the concrete and rubber. It was noticed that the particle size, density, compressive and splitting tensile strength of concrete decreased. The treatment with sodium hydroxide and silane does not produce any significant improvement in the mechanical properties of concrete. As the percentage of substitution increased, the ultrasonic pulse velocity decreased.

Guneyisi, Gesoğlu, and Ozturan (2004) studied on the properties of rubberized concrete containing silica fumes. Crumb rubber and tire chips were used to replace fine and coarse aggregates respectively from 2.5% to 50% by volume. Silica fumes were used to replace cement from 5% to 20% and water–cement ratios of 0.6 and 0.4 was 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 rubber content 15% and water–cement ratio 0.4.

Gesoğlu and Guneyisi (2007) investigated on the strength development and chloride penetration of rubberized concretes and 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 between 7 and 28 days, and relatively slower rate between 28 and 90 days. The compressive strength reduced systematically as the percentage of rubber was increased irrespective of the water–cement 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.

Xue and Shinozuka (2013) have studied on the dynamic and static performance of rubberized concrete. They have used the rubber crumb (maximum size 6 mm) for coarse aggregate replacement in 5–20% by volume of aggregates. A part of cement was replaced with silica fumes. It was observed that the addition of rubber crumb to concrete increased the damping ratio to 62% more than the control mix. Also the seismic force on the rubberized concrete was lesser by 27% than the control mix. Addition of silica fumes to rubberized concrete had helped to increase the strength by improving the bonding between the rubber crumb and the cement paste.

In this study, concrete was designed with water–cement ratio of 0.3. Crumb rubber (waste tire rubber mechanically grinded into rubber crumbs) was partially substituted for fine aggregates from 0% to 20% in multiples of 2.5%. 6% silica fumes were added by weight of cement. The properties of concrete-like compressive strength of sulphate attacked specimen, water absorption of sulphate attacked specimen, variation in weight of sulphate attacked specimen, macro cell current measurement, half cell potentials and modelling in Abacus was performed.

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.

2.1. Raw materials

Ordinary Portland Cement of grade 43, conforming to 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; void content 34% as per ASTM C 29, 2009 (specific gravity 2.63, free surface moisture 1%, fineness modulus 2.83). Coarse aggregates, 10 mm size was used 40% (fineness modulus – 5.573) and 20 mm size was used 60% (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.

2.2. Preparation of test specimens

To investigate the suitability of discarded tire rubber as a substitute for fine aggregates in concrete, concrete was designed (As per IS: 10262-2010) with water–cement ratio of 0.3. The ratio of cement, fine aggregates and coarse aggregates are 1:1.48:2.67 by weight (1 part of cement, 1.48 parts of fine aggregates and 2.67 parts of coarse aggregates). 6% silica fumes were added by weight of cement. Crumb rubber was replaced for natural fine aggregates from 0% to 20% in multiple of 2.5%. The mixture proportion is given in Table 1. Super plasticizer was used as the admixture to arrive at the desired workability (above 0.91). In these mixes 9 cubes of size 100 mm were casted for sulphate attack test, concrete specimens of size 250 mm × 200 mm × 120 mm for corrosion test. The mixtures were prepared and casted at indoor temperature of 25–30 °C. Compacting factor tests were done on fresh concrete to determine its workability. 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. All the tests were performed as per the relevant ASTM and IS codes as given in the references. (ASTM C 267-97, IS, 1199-1959, IS 456-2000, IS: 1237-1980, IS: 516-1959, IS: 2386-1963, IS 6441-1972, IS 6441-1989, etc.)

3. Laboratory testing programme

Sulphate attack test was performed according to ASTM C 1012-89. The test specimens (100 mm concrete cubes) after 28 days of water curing, was taken oven dried weight and then subjected to continuous soaking for 3 months in 3% $MgSO_4$ solution. Three types of tests were done on the sulphate attacked specimens. The specimens were periodically withdrawn at every 28, 56 and 91 days