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Performance of high strength rubberized concrete in aggressive environment

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HIGHLIGHTS

- Waste tyre rubber creates environmental pollution.
- Concrete was designed with water–cement ratio 0.3.
- Waste tyre rubber (crumb rubber) was partially replaced for fine aggregates.
- Rubberized concrete shows better resistance to acid attack.
- Chloride penetration and carbonation are comparable to that of control mix.

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ABSTRACT

Due to the huge increase in the population and number of vehicles, lots of tyres are ending as waste every day. It was estimated that every year almost 1000 million tyres end their useful life and more than 50% are discarded without any treatment. One of the possible solutions for the effective use of waste tyre rubber is to incorporate into cement based materials, to replace some of the natural aggregates. In this study, waste tyre rubber in the form of crumb rubber was used as a partial replacement for natural fine aggregates in high strength cement concrete. Crumb rubber was replaced for fine aggregates from 0% to 20% in multiples of 2.5%. Tests were done to determine the depth of carbonation, water absorption of acid attacked specimens, compressive strength of acid attacked specimen, variation in weight of acid attacked specimen and chloride penetration of these concrete samples. From the test results it could be concluded that the high strength rubberized concrete are highly resistant to the aggressive environments.

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. 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 challenge for the civil and environmental engineers [1–4,15–17].

Waste tyre rubber is one of the solid waste materials that pollute the environment. Every year millions of tyres 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 tyres end their useful life and more than 50% are discarded without any treatment. By the year 2030, the number would reach to 1200 million tyres yearly. (Including the stockpiled tyres, there would be 5000 million tyres to be discarded on a regular basis.) If the Indian scenario is considered, it is estimated that the total number of discarded tyres would be 112 million per year (after retreading twice) [8,10–12,15].

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 tyre rubber is to incorporate into cement based materials, to replace some of the natural aggregates. This attempt could be environmental friendly (as it helps to dispose the waste tyres and prevent environmental pollution) and economically viable (as some of the costly natural aggregates can be saved) [14,16,27,29,30].

Oikonomou and Mavridou [31] studied on the chloride ion penetration resistance of mortars which are modified by the waste

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rubber from automobile tyres. Rubber particles were used to replace fine aggregates by weight, from 0% to 15% in multiples of 2.5%. Water absorption by immersion of rubberized concrete had given better results when compared to the control mix. Benazzouk et al. [10] reported that the resistance to chloride ion penetration was enhanced due to the addition of rubber particles in concrete. Up to the substitution of 15% of rubber particles, the chloride ion penetration had decreased. For 5% substitution with rubber particles, the reduction was 14.22% lesser than that of the control mix and for 15% substitution, it was 35.85%. The best results were obtained in the mixture with 12.5% rubber particles and a bitumen emulsion. It exhibited better mechanical properties and the chloride ion penetration was decreased by 55.89% when compared to the control mix.

Azevedo et al. [7] observed that the increase in percentage of rubber resulted in serious loss in compressive strength. The concrete mix containing 5% tyre rubber, 15% flyash and 15% metakaolin for cement replacement gave the results similar to that of control mix. The capillary water absorption was lower in the specimens where rubber was substituted up to 15%. Mohamed [29] studied on high strength rubberized concrete containing silica fumes. Tyre-rubber particles were used to replace the total weight of the fine mineral aggregate by 10%, 20%, 30%, and 40%. The fresh rubberized concrete exhibited lower unit weight and acceptable workability when compared to plain concrete. Considerable reductions were noticed in axial strength, flexural strength, and tangential modulus of elasticity. Cube Drop tests showed good resilience of the rubberized concrete.

Many studies on normal strength rubberized concrete were reported in literatures. A proper study is essential on the properties of high strength rubberized concrete. In this study, concrete was designed with water–cement ratio of 0.3. Crumb rubber (waste tyre 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. Various tests like chloride penetration, compressive strength of acid attacked specimen, variation in weight of acid attacked specimen, water absorption of acid attacked specimen and test for carbonation resistance was performed on the concrete samples.

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 and preparation of test specimens

Ordinary Portland Cement of grade 43, conforming to IS: 8112-1989 [26] 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 [22] (Specific gravity 2.63, free surface moisture 1%, fineness modulus 2.83). Crushed stone coarse aggregates, 10 mm size (fineness modulus-5.573) was used 40% by weight of total coarse aggregates and coarse aggregates, 20 mm size (fineness modulus-7.312) was used 60% of total coarse aggregates. The average specific gravity of the coarse aggregates was 2.63. Tyre 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 by weight (2–4 mm size in 25%, 0.8–2 mm size in 35% and rubber powder in 40%) to bring it to zone II.

To investigate the suitability of discarded tyre rubber as a substitute for fine aggregates in concrete, concrete was designed (As per IS: 10262-2010) [24] with water–cement ratio 0.3. The ratio of cement, fine aggregates and coarse aggregates were 1:1.48:2.67 by weight (1 part of cement, 1.48 parts of fine aggregates and 2.67 parts of coarse aggregates). 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 15 concrete cubes each of size 100 mm were cast for 28, 56 and 84 days acid attack test, 6 concrete cubes each of the above size for carbonation and chloride penetration test. The mixtures were prepared and cast 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 to 90 days in water tank, with controlled temperature of 25–27 °C. The IS codes used for this experimentation work is given in Refs. [5,6,18–26].

3. Laboratory testing program

3.1. Chloride ion penetration

Silver nitrate spraying test was used to study the depth of chloride penetration as per Refs. [32,33]. The test specimens (100 mm concrete cubes) after 28 days of water curing, were subjected to continuous soaking for 91 days in 4% NaCl solution. The test specimen were periodically withdrawn at 28, 56 and 91 days from the soaking tank and tested for depth of chloride permeability. The cubes were split into two halves from the middle and the freshly split pieces were sprayed with 0.1 N silver nitrate ($AgNO_3$) solution. The $AgNO_3$ reacts with the free chloride on the concrete surface and form a white precipitate of silver chloride (AgCl). In the places where the free chlorides are absent, $AgNO_3$ reacts with hydroxide to form a brown precipitate of silver oxide (AgO). Thus, the boundary of colour change indicates the depth of chloride permeability as shown in Fig. 2.

The depth of chloride penetration was obtained by measuring the average depth of penetration in three samples. The formation of silver chloride (white colour) occurs only when the concentration of free chloride ion is greater than 0.15% by weight of cement.

The graph showing variation in the chloride ion penetration with respect to the percentage of crumb rubber is given in Fig. 1. The depth of chloride penetration of the mixes with crumb rubber up to 10% of fine aggregates was lesser than or similar to the values of the control mix. The mixes with crumb rubber 12.5–20% had shown more depth of chloride penetration than that of the control mix. The chloride ion penetration exhibited reduction for the mixes with 0–7.5% crumb rubber. Gradual increase in the depth of chloride ion penetration was observed for the mixes with 10–20% crumb rubber. In 28 days of exposure, the chloride penetration value of the control mix was 8 mm, that of the mix with 10% crumb rubber was 7 mm and for the mix with 20% crumb rubber was 9 mm. Similar trend was observed at 56 days and 91 days of immersion. At 91 days, the value of control mix was 16 mm. Minimum value of 15 mm was obtained for the mix with 2.5% and 5% crumb rubber and the maximum value of 20 mm was obtained for the mix with 20% crumb rubber.

Table 1
Mixture proportions of fresh concrete.

Cement kg/m^3	Water kg/m^3	Silica fumes kg/m^3	Coarse aggregates 10 mm kg/m^3	Coarse aggregates 20 mm kg/m^3	Fine aggregates kg/m^3	Admixture %
450.000	140.000	27.000	355.000	848.000	666.000	2