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Evaluation of mechanical and durability properties of crumb rubber concrete

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HIGHLIGHTS

- Waste crumb rubber is used in PPC based concrete as a replacement of fine aggregates at optimum (4–5.5%) percentages.
- Concrete of mean target strength 31.6 N/mm^2 was designed with water/cement ratio 0.40.
- Voids are generated due to fineness of crumb rubber which led to fall in mechanical properties.
- Microstructural study shows generation of voids and cracks.
- Crumb rubber may be utilized as a substitute for fine aggregates up to 4% replacement level.

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ABSTRACT

Due to rapid growth of automobile sector, disposal of waste rubber is becoming a major issue. In this study, effort has been made to reduce this problem by utilizing waste rubber in the form of crumb rubber in Portland pozzolana cement concrete as a substitute of fine aggregates in varied percentages. Experimental work has been conducted to evaluate compressive strength, flexural strength, density and durability properties like water absorption and abrasion resistance for the different proportions (0%, 4%, 4.5%, 5% and 5.5%) of crumb rubber in concrete. Micro-structural study using XRD, SEM and optical microscopy have also been carried out in the present study. It has been observed that with an increment of crumb rubber, workability of concrete decreases. The output of compressive and flexural strength show slight decrease with 4% replacement of fine aggregates by crumb rubber. Water absorption and abrasion resistance were also marginally affected at the same substitution level of crumb rubber in concrete. Hence, it can be concluded that 4% of fine aggregates can be replaced by crumb rubber to manufacture concrete for non-structural elements.

1. Introduction

A tyre is a composite of elastomeric formulations which includes steel fiber cord [1]. Generally for several years, old tyres are disposed by landfilling which reduces accessible areas [2]. Tyre being non-biodegradable in nature, on burning produces toxic gases which are harmful to humans. Hence, re-use of discarded rubber can protect barren lands and associated health problems [3]. Waste tyres may be recycled in various applications, production of concrete being one of them.

Concrete prepared with rubber which is often referred as Rubberized Concrete (RC), promotes utilizing an alternative for natural fine aggregate. The primarily used applications are in the construction processes, used as aggregate in structural works, chiefly used for road pavements as well as for earthquake resistance structures, retaining walls and estuaries. The other applications include synthetic reefs for fishery improvement and as granulate for football ground [4]. Such utilization of rubber in concrete would reduce the environmental problems as mentioned above.

1.1. Literature review

Numerous studies have already been carried out for an alternative substitution of fine aggregates through rubber. Gupta et al. [5] substituted rubber ash (0.15 to 1.9 mm) from 0% to 20% in steps of 5% with replacement of fine aggregates. They concluded that as the content of rubber ash increases, concrete workability decreases. Batayneh et al. [6] also reported similar observation when crumb rubber (4.75–0.075 mm) of varying percentage from 0% to 100% was incorporated in concrete. Oikonomou and Mauridou [7] proved that as the rubber content increases up to 15% workability

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decreases. The usage of crumb rubber in concrete prolongs setting time and increase the viscosity of concrete. The use of fly ash in concrete reduces this undesirable outcome with crumb rubber which reduces viscosity [8]. The complete study was carried out for different mix proportions with constant w/c ratio.

Al-Tayeb et al. [9] and Dong et al. [10] reported that with rise in proportion of crumb rubber content, compressive strength decreases. Wang et al. [11] used crumb rubber (4.75 mm) at a varying percentage up to 40% with a step size of 10% as a substitute of fine aggregates. They observed that compressive strength decreases with increase in the proportion of crumb rubber. Yung et 1al. [12], Xue and Shinozuka [13] also presented the similar results for different proportions up to 20% replacement of fine aggregates by crumb rubber.

However, with regard to flexural strength, contradicting results have been reported. Increase in flexural strength was reported by Yilmaz and Degirmenci [14] by using 0.25, 0.5, and 1 mm sizes of rubber fibers up to 30% replacement of fine aggregates. Segre and Joekes [15] also reported an increase in flexural strength by undertaking NaOH pre-treatment to rubber particles. Wu et al. [16], Akhras and Smadi [17] and Ganesan [18] also observed similar results for increase in flexural strength. Some studies also show that flexural strength decreases as the proportion of the rubber content increases. This contradiction in behaviour depends on size of waste rubber utilized [19,20]. Gupta et al. [5] reported a decrease in flexural strength for rubber ash concrete. Ganjian et al. [21] observed the similar trend of decrease in flexural strength for crumb rubber (0.425–4.75 mm), shredded rubber (length 300–430 mm and width 100–230 mm), and ground rubber (0.075–0.475 mm) at 5%, 7.5% and 10% replacement of fine aggregates.

The usage of rubber as aggregates, affects the density of concrete also. With increase in percentage of rubber in concrete up to 20%, decrease in unit weight of rubberized concrete has been observed by Sukontasukkul and Chaikaew [22]. Some experimental studies also depict that, this reduction of concrete density was due to the low specific gravity of rubber used [6,7]. Yilmaz and Degirmenci [14] and Ganjian et al. [21] presented an increase in water absorption capacity when rubber aggregates were used as a substitute of coarse aggregates. Abrasion resistance of the rubberized concrete is less as compared with reference concrete [5,22]. Literature also shows that as the proportion of the rubber increases, change in volume occurs in the form of the thickness of cube [5].

The above studies have tested the suitability of rubber waste as fine aggregates in Ordinary Portland Cement (OPC) based concrete mixes except for the study reported by Yilmaz and Degirmenci [14]. This is the only study where inclusion of rubber enhances the properties of cement composite mortar. Hence in line with this outcome, in this study, Portland Pozzolana Cement (PPC) was used to make concrete mixes where crumb rubber of size 0.600 mm was used. Using a size of 0.600 mm reduces the effort of mechanical grinding when compared to 0.250 mm size of crumb rubber. The substitution of fine aggregates by crumb rubber was made in proportions of 0%, 4%, 4.5%, 5% and 5.5%. These variations are fixed based on literature reviewed earlier where substitution greater than 5% significantly deteriorates concrete properties.

The novelty of this paper is to illustrate the effect of crumb rubber (0.600 mm) on varying percentages (0%, 4%, 4.5%, 5% & 5.5%) with use of Portland pozzolana cement in concrete. Different tests were conducted such as workability, compressive strength, flexural strength, density for same w/c ratio. This study also aims to examine the durability properties such as abrasion resistance and water permeability.

Table 1
Physical and mechanical properties of cement, aggregates and crumb rubber.

Analysis	Results
PPC cement	
Setting time	Initial time – 115 min
	Final time – 248 min
Compressive	3 Days – 24.5 MPa
Strength	7 Days – 34.5 MPa
	28 Days – 45.2 MPa
Water absorption	
Coarse aggregate	0.5%
Fine aggregate	0.5%
Crumb rubber	0.3%

2. Methodology

2.1. Materials

The Portland pozzolana cement having specific gravity of 3.11 is used in present work. Fine aggregates (natural sand) with specific gravity 2.66 conforming to zone 2 as per IS: 383-1970 [23] is used. Coarse aggregates having the nominal size 20 mm & 10 mm of specific gravity 2.59 have been used in this study. Crumb rubber with a size of 0.600 mm having specific gravity 1.05 utilized in the present work. Crushed crumb rubber of size 0.600 mm was produced from scrap tyre rubber by mechanical grinding. A polycarboxylic ether polymer based superplasticizer is used to attain the required workability. Table 1 lists the properties of cement, fine aggregate, coarse aggregate and crumb rubber. Fig. 1 depicts the size distribution of sand. Table 2 shows the chemical composition of crumb rubber. In the concrete mixes, crumb rubber was used as an alternative of fine aggregate. Fig. 2 presents Scanning Electron Micrograph (SEM) of crumb rubber which shows the irregular shape and smooth texture. The phase identification of crumb rubber was performed by X-ray diffraction (XRD) technique for scan range of 10–80° with a step size of 10° as shown in Fig. 3. It has been observed from Fig. 3 that carbon content is maximum in crumb rubber.

2.2. Mix proportions

The replacement of fine aggregates from crumb rubber is used to prepare concrete mix at different percentages of 0%, 4%, 4.5%, 5% and 5.5% as shown in Table 3. A constant w/c ratio of 0.40 is considered. Substitution of fine aggregates with crumb rubber was made by weight basis. The dosage of superplasticizer was varied from 1.5% to 2.4% to achieve compaction factor of 0.9. Ingredients were mixed, cast and cured according to relevant specifications.

3. Experimental program

To investigate the fresh property of the concrete, compaction factor test was conducted according to IS: 1199-1959 [24]. The compressive strength test was conducted using a hydraulic compression testing machine on three 100 mm cube samples of each concrete mix after 28-day of curing [25]. The loading rate on the cubes was 140 kg/cm^2/min. The third point loading arrangement was used to evaluate flexural strength on UTM using three 100 × 100 × 500 mm specimen of each concrete mix after 28-day of curing. The loading rate on the beam was 180 kg/cm^2/min capacity as per BIS 516 [25]. The density, voids and water absorption of concrete was determined on three specimens as per ASTM C 642-13 [26].

The abrasion test was performed after 28-day of curing as per Indian Standard BIS: 1237-2012 [27]. Three 100 mm concrete cube specimens of each mix were oven dried at temperature 110 ± 5 °C for 24 h and after that specimen are initially weighed (w_1) and (w_2)