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Technical note

Technical note on sorption and permeability of concrete containing rubber and quartz sandstone aggregates

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ABSTRACT

The presence of waste is a warning of overconsumption of materials and are not being used to its full potential. There has been a consistent decrease in environmental potential to absorb these wastes and a useful resource of matter and energy are lost due to the disposal of such wastes. The main problem associated is the excess production of wastes such as rubber and stones which could be utilised efficiently in many other ways. One of the sustainable utilisation of these wastes is by using them in the production of cement concrete. M30 concrete grade (water-cement ratio of 0.4) is designed as per Indian specifications with discarded tyre rubber as a partial replacement of fine aggregate and quartz sandstone as a partial replacement for coarse aggregates. The water absorption properties of concrete containing crumb rubber, quartz sandstone and a mixture of both were studied. Three sandstone replacement levels (0%, 50% and 100%) are taken and five rubber replacement levels (0%, 2.5%, 5%, 7.5% and 10%) were considered for the study. Concrete having quartz sandstones as coarse aggregates and crumb rubber as fine aggregates are recommended to be used at 50% substitution level of quartz sandstone. The maximum rubber replacement in the same mix can be limited to 7.5% to maintain the increase in sorption rate below 15%.

1. Introduction

The overall production of rubber tyres has increased to a greater extent and the automotive industry uses tyres which are highly durable and not easily recycled. The improper disposal of waste tyres is dangerous to the environment and human health [1]. Due to these environmental and health issues attributed from rubber waste, a broad area of research is focussed on the utilisation of them as a partial substitute for mineral aggregates. This considerable recycling of rubber wastes reduces the disposal problems and also lessens the use of natural mineral aggregates [2]. Rubber is a good absorber of shock and also possess moderate sound insulating properties. Although having its advantages, rubber, when utilised in concrete, shows a considerable decrease in mechanical strength with an increase in permeability [3,4]. The composition of cement paste being hydrophilic material and the rubber aggregates being a hydrophobic material makes it even more difficult for the resulting concrete to have an adhesive interlocking mechanism. Irrespective of reduced adhesion property, many researchers have found concrete with rubber aggregates showing better toughness and impact strength than concrete made with standard mineral aggregates [5–8].

On the other hand, sandstone being a consolidated sand is a well-known sedimentary type of rock. It is composed of rock fragments and silt-sized mineral grains which are held together by the cementing material. Kumar et al. (2016) observed an increase in water absorption of concrete as the quartz sandstone coarse aggregate was increased [9]. This phenomenon was observed due to the increase in microvoids between the interface of cement paste and foreign aggregate. The act of achieving consistent workability in concrete with sandstone aggregates is usually by increasing the dosage of super plasticisers [10].

The measurement of water absorption in concrete with different aggregates remains important for quantifying the interconnected pores. Also, the initial water absorption of an aggregate allows the casting person to determine the amount of excess water to be mixed before casting [11]. The rate of deterioration of concrete structures is directly related to moisture ingress. Also, the water permeability of concrete is a property that can alter the durability and serviceability of massive concrete structures [12,13]. The replacement and substitution of natural aggregates

Abbreviations: QS, quartz sandstone; QSC, quartz sandstone concrete; QSRC, quartz sandstone and rubber concrete; SEM, scanning electron microscope.

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by alternate source has become a widespread research in the area of construction sustainability. Thence it becomes necessary to reduce the excessive use of depleting construction materials and find new ones which are less aggressive towards the environment [14]. In the event of mixing one or more aggregates to produce concrete, gradation plays a vital role in attaining a good packing density. Fineness modulus and gradation of an aggregate play a vital role in determining the overall performance of fresh and hardened concrete [15]. This paper compares the water absorption characteristics of concrete with rubber, quartz sandstones and a mixture of both. The substitution of quartz sandstone as coarse aggregates was done at three levels (0%, 50% and 100%) and crumb rubber for fine aggregates at five levels (0%, 2.5%, 5%, 7.5% and 10%).

2. Materials and properties

Ordinary Portland cement (OPC) of grade 43 was used for the casting. River sand conforming to zone II obtained from local sources were used as fine aggregates. Coarse aggregates of sizes 20 mm and 10 mm were procured and tested for specific gravity, water absorption, impact value test, Los Angeles abrasion test and gradation using sieve analysis. By sieve analysis, the ratio of mixing coarse aggregates (20 mm: 10 mm) was fixed to 55:45 for natural coarse and 60:40 for quartz sandstone coarse aggregates [10]. Discarded tyre rubber of sizes 0.8–2 mm, 2–4 mm and rubber powder was used based on the results of gradation for zone II fine aggregate confirmed with IS: 383-1970 [16,17]. To maintain a consistent workability, superplasticisers were added as a percentage by weight of cement in the range 0.8% - 1.6%. The properties of aggregates used are given in Table 1.The details of mix proportions for concrete containing solely rubber and quartz sandstone aggregates are same as given in Thomas et al. [17] and Kumar et al. [10]. The mix proportions of concrete containing both rubber and quartz sandstones together are given in Tables 2–4.

Table 1
Properties of aggregates.

Technical Information	Material	Results
Specific gravity (g/cc)	Fine aggregate	2.74
	Rubber	1.09
	Natural coarse aggregate	2.74
	Quartz sandstone	2.63
Water absorption (%)	Fine aggregate	0.11
	Rubber	2.45
	Natural coarse aggregate	0.14
	Quartz sandstone	1.64
Aggregate impact value test (%)	Natural coarse aggregate	29.92
	Quartz sandstone	36.74
Los Angeles abrasion test (%)	Natural coarse aggregate	37.92
	Quartz sandstone	47.24

3. Laboratory testing and results

The concrete samples having rubber and quartz sandstones were tested for sorptivity and permeability tests. The details of tests are as follows:

3.1. Water absorption test by sorptivity

The Sorptivity test was done as per ASTM C 1585-04 [18]. The test method is used to determine the rate of absorption (Sorptivity) of water in hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one of the sample surfaces is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water. The test was done on 28 days cured concrete cubes (which are oven dried at 65 ± 5 °C for 7 days) of 100 mm x100 mm x 100 mm. The side surface of each specimen is sealed with a suitable sealing material and the mass of the sealed specimen is noted. A support device is placed at the bottom of the pan and water is filled 1–3 mm above the top of the support apparatus (Fig. 1). The timing device is started immediately after the test surface of the specimen is placed on the top of the support device. The mass of specimen is noted at 1 min, 5 min, 10 min, 20 min, 30 min and 60 min and then every hour up to 6 h. The sorptivity values of concrete samples having various replacements of rubber and quartz sandstones are shown in Fig. 2.

The water sorption of concrete samples with quartz sandstones and rubber increased as the replacement level increased. This increase in the rate of water absorption can be related to the use of rubber and sedimentary sandstone aggregate. A maximum sorptivity of 0.55 mm was observed for concrete samples having 100% quartz sandstone and 10% rubber aggregates. Thomas et al., (2014) [17] observed a maximum sorptivity of 0.7 mm at 20% replacement on utilising crumb rubber as fine aggregates in concrete.

3.2. Water permeability by DIN 1048

To check the water permeability of concrete, water permeability test was performed. Three cubes of sizes 150 mm were oven dried. Before placing the cubes in the apparatus, weighing of the cube was done. The cubes were placed in such a manner that the direction of water pressure (0.5 N/mm^2) was normal to the direction of concrete filled in the mould for three days (Fig. 4). After three days, the pressure was released and cubes were taken out from apparatus. The cubes were weighed again. After weighing, split down the centre of the cube, with the facing which was exposed to water pressure facing down. Measure the maximum

Table 2
Mix proportions of concrete with 0% quartz sandstone.

Ingredients	Rubber replacement percentage				
	0%	2.5%	5%	7.5%	10%
Cement (kg/m^3)	340.13	340.13	340.13	340.13	340.13
Fine Aggregate(kg/m^3)	732.89	703.86	675.38	647.45	620.07
Water (kg/m^3)	136.05	136.05	136.05	136.05	136.05
Natural aggregate 10 mm (kg/m^3)	287.27	287.27	287.27	287.27	287.27
Natural aggregate 20 mm (kg/m^3)	351.11	351.11	351.11	351.11	351.11
Quartz Sandstone 10 mm (kg/m^3)	255.35	255.35	255.35	255.35	255.35
Quartz Sandstone 20 mm (kg/m^3)	383.03	383.03	383.03	383.03	383.03
Rubber (0.8–2 mm) (kg/m^3)	0	6.31	12.44	18.37	24.11
Rubber (2–4 mm) (kg/m^3)	0	4.51	8.88	13.12	17.25
Rubber powder (kg/m^3)	0	7.21	14.21	20.99	27.55