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Studies on performance enhancement of recycled aggregate by incorporating bio and nano materials

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HIGHLIGHTS

- RA and RAC were improved using bacteria induced precipitation and nanosilica.
- Bacteria and nanosilica treated RA/RAC showed reduction in water absorption, volume of voids (%) and enhancement in density parameters.
- Bio and nano modified RA/RAC visualized by FESEM which showed improvement in both, old as well as new ITZs.

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ABSTRACT

This paper investigates the modification effect of nanosilica and ureolytic/non-ureolytic bacteria at the interfacial transition zone (ITZ) of RA and recycled aggregate concrete (RAC).The improved RA showed reduction in water absorption (43% in non-ureolytic bacteria, 64% in ureolytic bacteria and 21% in nano modified RA) and increase in specific gravity (~29% in non-ureolytic bacteria, 30% in ureolytic bacteria and 18% in nano modified RA). The studies also proved that properties of RA and RAC on the macroscale were highly improved by the soaking approach than the direct mixing approach. ITZ studies were carried out using Field Emission Scanning Electron Microscopy (FESEM) and Energy-dispersive X-ray spectroscopy (EDX) analysis, which revealed that, biogenic calcite and nano mediated accelerated hydration products densified both the ITZs (old and new), leading to substantial improvement in macroproperties of RAC. Thus, the proposed modification techniques, seems promising for the performance enhancement of recycled aggregate.

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1. Introduction

Increasing demand and dependence on natural aggregate (NA), has posed the need for a sustainable alternative to replace a fraction or all of the NA in concrete mixture. Abundance of recycled aggregate (RA) from construction and demolition waste makes it a suitable substitute for replacement with NA, however; high water absorption and weak bonding to the new matrix are the limiting factors that restricts its utilization in fresh concrete. Various methodologies have been adopted to combat the issue of water absorption related to RA, for instance, to remove the adhered old mortar by chemical treatment, heat treatment and mechanical grinding [1]. High energy consumption and cost are some disadvantages of these methods, which have motivated various researchers around the world to explore methods which focus on strengthening the adhered old mortar rather than removing it. Therefore methodologies like sodium silicate treatment [2], polymer impregnation [3], carbonation treatment [4] have been adopted to improve the quality of adhered old mortar. The sodium silicate treatment might introduce alkalis which increases the risk of alkali silica reaction. Likewise, in polymer impregnation method, the longer time period and compatibility of polymer with concrete are some major concerns. In concrete, made of recycled aggregate, the number of ITZs are more, as it contains old ITZ between old mortar and aggregate as well as new ITZ between old mortar and new mortar [5]. Modification of these ITZs and specifically old ITZ having adhered old mortar, can therefore be targeted to substantially decrease the water absorption of RA, to make it comparable to NA in recycled aggregate concrete (RAC).

To overcome the challenge of high water absorption value of RA in RAC, fly ash and volcanic ash have therefore been incorporated and durability properties of mixes have been studied [6]. In order to improve the microstructure of both ITZs in RAC, silica fume

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has also been used [7]. The authors proposed two-stage mixing approach (TSMA) to treat RAC, which resulted in significant strengthening of ITZs between RA and new mortar. A novel triple mixing method based on TSMA has been proposed which when compared with TSMA, could further improve the properties of the RA, the microstructure of ITZs and the RAC [8]. Besides, the incorporation of pozzolanic mineral admixtures, modification of RAC with nanomaterials, has also been accomplished by surface treatment of RA. The studies reveals reduction in 7 and 28 days compressive strength of fully RAC by ~12–14%, while addition of 3% nanosilica in RAC improves the strength which is comparable with NAC [9,10]. Addition of nano silica is found to significantly improve compressive strength of concrete containing 25% RCA at all ages; however, no such improvement is observed in concrete containing 50% RCA [11]. The better efficiency of ITZ due to presoaking (for 24 h) in nanosilica incorporated RAC (RAC replacement of 25% and 50% of NAC) has been experimentally verified through compressive strength, durability properties and microstructure analysis [12]. Treatment with two different nanoslurries, resulted in macroscale property improvement of both RA as well as RAC. The width of the new ITZs reduced in modified RAC and the elastic modulus obtained from nanoindentation tests proved to improve significantly [13]. The effects of nano-silica and nano-limestone on the crack propagation and microstructure properties of RAC have been investigated using SEM and MIP. Nanosilica is found to be more effective in improving the microstructure as well as reducing the water absorption (~20%) and porosity (~24%) in comparison to RAC [14]. Moreover, studies were done on surface treatment of recycled aggregate using nanoslurry (nSi + nCa) and the nanoindentation results reveal enhanced new ITZs between old and new cement mortars as well as surface strengthening of old mortars. Furthermore, the macroscale properties such as compressive strength and resistance to chloride diffusion were also improved [15].

On the contrary, to enhance the property of RA/RAC on the microscale, biodeposition technique has been exploited by researchers to strengthen the bonding of adhered mortar on RAC. Ureolytic bacteria, *S. pasteurii* modified RA of particle size 6/8 mm showed reduction in water absorption of 14–20% and ~13% decrease for particle size 12/16 mm when a bacteria concentration of 10^7–10^8 cells/ml was applied [16]. Enhanced calcite precipitation on RA by increasing factors like bacterial (*S. pasteurii*) concentration, temperature, pH have been investigated and water reduction of 16% was observed in treated RA when application conditions were 35 °C, pH 9.5, 16.8 g/l of calcium content and10^8 cells/ml bacterial concentration [17]. Two times immersion treatment with *B. spahericus* for surface treatment of two different types of RA [18], proved the efficiency of MICP in improving the properties of RA/RAC by biogenic calcite deposition. The treated RA using 10^8 cells/ml showed an improvement in compressive strength of crushed concrete aggregate (CA) and mixed aggregate (MA) by 40%and 16%; reduction in water absorption by 27% for CA concrete, 20% for MA concrete. After using *B. subtilis (*10^6 cells/ml) treated RA, the compressive strength found to increase by 20% and a substantial decrease in capillary water absorption as well as drying shrinkage has been observed. The reason of this enhancement in durability properties is proved by morphological analysis which showed denser RAC formed by bacterial activity [19].

ITZ is relatively porous and contains voids and therefore it is attributed as the main reason for higher porosity than the other two components in concrete namely, cement paste and aggregate. Since, bacteria and nanomaterial mediated microstructure modification at ITZ in both RA and RAC is not studied in depth through electron microscopy till date, this area needs further exploration. In the present work, efforts are therefore, made to explicitly focus on the microstructure changes at ITZ of RA and RAC, densified by bio and nano material. A comparative study of ITZ of bio and nano treated and untreated RA and RAC is done. Moreover, the consequence of soaked and unsoaked RA on the water absorption, volume of voids and microstructure properties is also investigated. Thus in this study, the direct relation of microstructure modification at ITZ is established with the property improvement of RA/RAC. The past work on bacteria modified RA/RAC were done using ureolytic bacteria, namely, *B. pasteurii* and *B. sphaericus*. An attempt is therefore taken in the present work to study the effect of non-ureolytic bacteria (*B. cohnii*) in RA/RAC. Moreover, comparative study with ureolytic bacteria (*B. megaterium*) is done so as to identify the one having better biomineralization potential.

2. Experimental programme

2.1. Materials

2.1.1. Cement

The ordinary Portland cement (OPC) with Blaine fineness 390 m^2/kg, confirming to IS 8112:1989 [20,21] was used for the present study and its physical properties and chemical composition are shown in Table 1.

2.1.2. Fine and coarse aggregate

Local river sand with 4.75 mm maximum size was used for concrete studies and for coarse aggregates, crushed stone with maximum 16 mm graded aggregates (nominal size) was used. The physical characterization of aggregates, shown in Table 2, was carried out in accordance with IS 2386:1963 [22,23] and was found to be satisfying the criteria of IS 383:1970 [24,25].

2.1.3. Recycled aggregates

Recycled aggregates (RA) were obtained from IL & FS, Burari, India. The RA was screened by a 20-mm sieve to exclude any big particles. The properties of RA used in this research were determined as per ASTM C127-12 [26] and are given in Table 2.

Table 1
Chemical and Physical properties of ordinary Portland cement (OPC).

Composition	Mass %
SiO_2	19.3
Al_2O_3	5.8
Fe_2O_3	5.0
CaO	64.3
MgO	0.8
Alkalis (K_2O+Na_2O)	0.9
Others	1.5
Loss of ignition	4.0
Physical Properties	
Specific gravity	3.13
Fineness (m^2/kg)	315
Consistency (%)	27
Initial Setting time (min)	170
Final Setting time (min)	240

Table 2
Physical properties of aggregates used in this study.

Property	Fine aggregate	Coarse aggregate	Recycled aggregate
Water absorption (%)	0.57	0.65	1.4
Specific gravity	2.57	2.62	2.2
Fineness modulus	2.98	7.34	7.52
Grading zone	Zone-II	–	–
Crushing value (%)	–	20.06	26.51
Impact value (%)	–	20.32	26.89

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