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Properties of bacterial rice husk ash concrete

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HIGHLIGHTS

- Calcite producing bacteria improved strength of RHA concrete.
- Water absorption, porosity and chloride permeability reduced with RHA and bacteria.
- Abrasion loss was minimum in RHA-bacterial concrete.
- SEM and XRD analysis indicated the formation of calcite in bacterial concrete.

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ABSTRACT

Influence of bacteria on the properties of concrete made with rice husk ash (RHA) is presented in this paper. For this purpose, control concrete was designed to have 28-d strength of 32.8 MPa. In the control concrete, cement was partially replaced with (0%, 5%, 10%, 15% and 20% by weight) RHA. Then, bacterium *Bacillus aerius* (10^5 cells/mL) was mixed in water during making of concrete. Tests were performed for compressive strength, water absorption, porosity, chloride permeability and abrasion resistance up the age of 56 d for all concrete mixtures with and without bacteria.

Results indicated that inclusion of bacteria in RHA-concrete enhanced its compressive strength at all ages. However, best performance was achieved with 10% RHA wherein 28-d compressive strength was 36.1 MPa, and with bacteria, it was 40.0 MPa. Inclusion of bacterium in RHA concrete reduced its water absorption, porosity, and permeability at all ages, due to calcite precipitation, which in turn improves these properties. SEM and XRD analysis exhibited the formation of ettringite in pores, calcium silicate hydrate (CSH) and calcite which made the concrete denser. Findings of this investigation indicated the use of RHA and bacterium enhances the durability properties of concrete.

1. Introduction

Approximately, yearly concrete production is about 10 billion cubic meters [1]. Cement is a very important constituent of concrete, and approximately 4180 million tons of cement were produced in 2014 globally [2]. Production of one ton of cement releases approximately one ton of CO_2 which makes up 7% of all CO_2 emissions produced globally [3]. Hence, there is necessity to use supplementary cementitious materials (SCMs) as partial replacement of cement in concrete. Utilization of SCMs reduces the consumption of Ordinary Portland cement, and thereby reduces the energy consumption and green house gas emissions associated with cement production.

As per Food and Agriculture Organization (F.A.O) statistics, world production of rice has risen from about 150 million tons in 1960 to over 740 million tons in 2013. Paddy consists of about 72% rice, 5–8% bran, and 20–22% husk [4]. In 2014, global production of paddy was 741.3 million tons, and consequently resulting in 148 million tons of rice husk [5]. Rice husk when properly burnt in incinerators at temperature lower than 700 °C generates rice husk ash containing highest proportion of reactive amorphous silica [6,7]. Generally, each tone of husk produces about 0.18–0.20 tons of ash [8].

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RHA due to its fine size (3–10 μm) mainly serves as a micro-filler, pozzolanic, and viscosity modifier in concrete. RHA behaves as a reactive pozzolanic material because of its extreme surface fineness and high silica content [9]. RHA reacts with calcium hydroxide and produces additional CSH gel. Micro-filling effect and pozzolanic activity of RHA results in refining the pore structure of the matrix and interfacial transition zone.

Inclusion of up to 15% (95 μm RHA) and 20% (5 μm RHA) RHA improved the compressive strength of concrete [10]. RHA concrete exhibited excellent improvement (30.8%) in compressive strength with 10% replacement, and up to 20% of cement could be valuably replaced with RHA without adversely affecting the compressive strength [11]. Saraswathy and Song [12] observed that with increase in RHA content (0–30%), chloride penetration decreased. Similar results were also observed between 90 and 100 d; where maximum reduction of 81.4% in charge passed was exhibited by specimens having 0–10% RHA [13]. Concretes made with 10% RHA exhibited about 72% reduction in 28-d chloride permeability [14]. Chloride-ion permeability of RHA blended concrete decreased with increase in RHA content up to 30% [15]. Water absorption of concrete decreased with increase in RHA content [10,15]. At 90 d, binary concrete containing 10% RHA content had lower water absorption than the control concrete [16]. Several other studies also reported that RHA enhanced the strength and durability properties of concrete [17–20].

SCMs improves the strength and durability of concrete however, the micro-cracks remained the main cause of concrete durability [21,22]. Various available traditional repair systems are chemical based which are expensive and hazardous to environment and health [21]. For the last 10–15 years, the interaction between microorganisms (particularly bacteria) and concrete structures is gaining ground in research for improvement in the durability of concrete [23–29]. Several researchers have proposed bacterial induced calcite precipitation (BICP) as an alternative approach to self-healing of concrete cracks by incorporating dormant but viable spores of alkali-resistant urease producing bacteria that convert organic compounds to inorganic mineral precipitates i.e. calcite [30–35]. Ramakrishnan et al. [23,24] and Van Tittelboom et al. [27] found that calcite precipitation by *Bacillus pasteurii* and *Bacillus sphaericus* was effective in plugging the cracks of concrete. Apart from *B. pasteurii* and *B. sphaericus*, other bacillus species such as *Bacillus pseudofirmus* and *Bacillus cohnii* [31], *Bacillus alkalinitrilicus* [33], and other genera such as *Shewanella* species [26,27], *Acinetobacter johnsonii* [36,37], *Pseudomonas aeruginosa* [38], *Myxococcus xanthus* [39], *Proteus mirabilis* and *Proteus vulgaris* [40] have also been studied extensively for calcite production in concrete.

Chahal et al. [28] observed that inclusion of up to 30% fly ash along with 10^5 cells/ml of *S. pasteurii* in concrete exhibited "very low" chloride permeability values (762 C). Achal et al. [41] observed "low" chloride permeability (1000–2000 C) in concrete specimens containing *S. pasteurii* (Bp M-3) whereas control concrete specimens showed "moderate" chloride permeability. Inclusion of 0.33 mg/ml of bacterial cell wall (*Bacillus subtilis*) in saline solution significantly increased the 28-d compressive strength by 15.6% and decreased the porosity by 1.64% [42].

Several studies have been reported on the use of RHA as partial replacement to cement in the production of concrete [10,15,16] and use of calcite producing bacteria for remediation of concrete cracks [23,25,42] but no such work have been reported on the use of bacteria in concrete containing RHA as partial replacement to cement. The calcite producing bacterium has been used in this research work to study its effect on strength and permeation properties of concrete. The calcite produced by the bacteria in the concrete pores, densifies the matrix which results not only in improvement of compressive strength but also reduces the pore size, thereby, improving the permeation properties. Therefore, the present study was conducted to provide technical data about the strength and permeation properties of concrete containing RHA and calcite producing bacteria.

2. Materials and methods

A bacterium containing urease enzyme was isolated from marble sludge suspended in sterile saline solution (0.85% NaCl), serially diluted and plated on urea agar medium (Himedia) having pH of 6.8. Bacterial isolate was selected after incubation at 37 °C on the basis of changing the color of the medium from orange to pink. The selected bacterial isolate was then screened for calcite ($CaCO_3$) production, and grown in calcite broth medium (urea 20 g, sodium carbonate 2.12 g, ammonium chloride 10 g, nutrient broth 3 g, calcium acetate 25 g, and distilled water 1000 mL) with pH from 7.5 to 8.0. After incubation at 37 °C, X-ray diffraction (XRD; PANalytical X'Pro; using CuKα radiation ($\lambda = 1.5418$ Å); for diffraction angles 2 theta ranged between 5° and 60°) was used to analyze the precipitates in broth for the calcite production by bacterium. The XRD peaks were marked, compared and identified from the Joint Committee on Powder Diffraction Standards (JCPDS) data file. The isolate was identified using 16S rRNA gene sequencing technique and the 16S rRNA sequence was submitted to GenBank-NCBI. The 16S rRNA gene sequencing study was performed at Council of Scientific and Industrial Research - Institute of Microbial Technology (CSIR-IMTECH), Chandigarh, India. The 16S rRNA gene sequence of the strain AKKR5 was processed manually, analyzed at NCBI (National Centre for Biotechnology Information) server (http://www.ncbi.nlm.nih.gov) using BLAST tool and compared to the corresponding neighbor sequences from the GenBank-NCBI database. Ordinary Portland cement (OPC) having specific gravity, standard consistency, initial and final setting time as 3.10, 28%, 123 min and 270 min, respectively, was used as per Indian standard specification BIS 8112 [43]. Chemical analysis of OPC done by X-ray fluorescence (XRF) showed that cement was mainly composed of lime (CaO; 63.5%), silica (SiO_2; 21.25%), alumina (Al_2O_3; 4.74%), iron oxide (Fe_2O_3; 4.3%) followed by sulfur trioxide (SO_3), magnesium oxide (MgO), potassium oxide (K_2O), sodium oxide (Na_2O) and titanium oxide (TiO_2).

Natural sand (size 4.75 mm) and crushed stone (size 12.5 mm) were used as fine and coarse aggregate, respectively, and were tested for their suitability in concrete as per Indian Standard Specifications BIS: 383 [44]. Fineness modulus of fine aggregate was 2.58, whereas specific gravity and moisture content was 2.68 and 0.16%, respectively. Coarse aggregate had specific gravity of 2.7 and water absorption of 1.14%.

Table 1
Mix proportions.

Mixture	Cement (kg/m^3)	RHA (%)	RHA (kg/m^3)	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	W/C ratio	Water (kg/m^3)	Bacteria content (cfu/ml)	Slump (mm)
R0	390.0	0	0	569.0	1164.0	0.5	185.0	0	90
R5	370.5	5	19.5	569.0	1164.0	0.5	185.0	0	83
R10	351.0	10	39.0	569.0	1164.0	0.5	185.0	0	77
R15	331.5	15	58.5	569.0	1164.0	0.5	185.0	0	72
R20	312.0	20	78.0	569.0	1164.0	0.5	185.0	0	66
BR0	390.0	0	0	569.0	1164.0	0.5	185.0	10^5	–
BR5	370.5	5	19.5	569.0	1164.0	0.5	185.0	10^5	–
BR10	351.0	10	39.0	569.0	1164.0	0.5	185.0	10^5	–
BR15	331.5	15	58.5	569.0	1164.0	0.5	185.0	10^5	–
BR20	312.0	20	78.0	569.0	1164.0	0.5	185.0	10^5	–