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Effect of bacteria on strength, permeation characteristics and micro-structure of silica fume concrete

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HIGHLIGHTS

- Effect of bacteria on strength and permeation properties of concrete is presented.
- Concrete is made with 0, 5, 10, and 15% silica fume as cement replacement.
- Economic study of bacterial SF concrete is also covered.

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ABSTRACT

Influence of bacteria on strength and permeation characteristics concrete incorporating silica fume (SF) as a substitution of cement has been investigated in this study. The cement was partially substituted with 5, 10 and 15% SF and with constant concentration of bacterial culture, 10^5 cfu/mL of water. Cement was substituted with silica fume in concrete by weight. At 28 d, nearly 10–12% increase in compressive strength was observed on incorporation of bacteria in SF concrete. At 28 d, the compressive strength of concrete increased from 32.9 to 36.5 MPa for SF, 34.8 to 38.4 MPa for SF5, 38.7 to 43.0 MPa for SF10 and 36.6 to 40.2 MPa for SF15 on addition of bacteria. Water absorption, porosity and capillary water rise reduced in the range of 42–48%, 52–56% and 54–78%, respectively, in bacterial concrete compared to corresponding nonbacterial samples at 28 days. Reduction in chloride permeability of bacterial concrete was observed and the total charge passed through bacterial concrete samples reduced by nearly 10% compared to nonbacterial concrete samples at 56 d of age. At 28 d, total charge passed through concrete reduced from 2525 to 1993 C for SF, 1537 to 1338 C for SF5, 961 to 912 C for SF10 and 1186 to 1174 C for SF15 on addition of bacteria. Calcite precipitation on addition bacteria and confirmed by SEM and XRD analysis is considered as the reason for improvement in properties of concrete. Economic study of bacterial SF concrete has also been carried out in the present work. The Benefit/Cost Ratio of bacterial SF concrete got reduced with the increase in SF quantity. Compared to control concrete, bacterial SF concrete containing 10% silica fume demonstrated highest benefit in improvement in its properties and corresponding highest Benefit/Cost Ratio.

1. Introduction

Supplementary cementing materials (SCMs) are extensively used in enhancing concrete properties. Waste/by-product materials used as SCM in concrete constructions not only check the environmental contamination but also enhance the concrete properties in fresh as well as in hardened state. Silica fume (SF) is generated by silicon metal or ferrosilicon alloys producing industry and has

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pozzolanic properties. High strength concrete are made with the use of SF as supplementary cementitious materials. ACI Committee [1], in its report has illustrated various possible application and limitations of use of SF in concrete. Very high strength concrete having 28-d compressive strength of 100 MPa and higher can be produced with the use of SF as SCM material. Yogendran et al. [2] suggested that with respect to improvement in strength properties of high strength concretes (28 d compressive strength ranging from 50 to 70 MPa),use of 15% SF was the optimal substitution level. Maximum improvement in compressive strength of concrete incorporating SF as SCM occurs between 7 and 28 d of curing period [3]. Zhou et al. [4] concluded that replacement of 10–15% cement with silica fume in high strength concretes with higher water binder ratio (28-d compressive strength between 80 and 115 MPa) has more influence on its compressive strength. The use of SF has great effect on durability properties of concrete as well, significant reduction in porosity and chloride permeability of SF concrete have shown [5–11].

The durability properties of concrete can further be enhanced by applying bacterial induced carbonate precipitation (BICP) techniques in addition to use of SCM's. The concept of utilization of microbiologically induced calcite ($CaCO_3$) precipitation was first introduced by Ramakrishnan et al. [12] and they used it in repairing the cracks and fissures in concrete. They observed that bacteria when used in concrete, continuously precipitated calcite layer over already existing concrete layer. The precipitated calcite layer was insoluble in water, impermeable and was adhered to the existing surface of concrete in the form of scales. Bacterial technique when used in fresh concretes results in calcite precipitation in voids and consequently improves the strength and lowers permeability of concrete. De Muynck et al. [13] reported that surface calciteprecipitation reduced water absorption in the range of 65–90% depending on specimen porosity. They also observed decrease in sorptivity and permeability of concrete specimens due to surface precipitation of calcite by the bacterium. Wiktors and Jonkers [14] and Wang et al., [15] observed that gas and water permeability of bacterial concrete reduced after activation of the bacteria and filling the cracks with the deposited $CaCO_3$ crystals.

For the researchers, the incorporation of bacteria in concrete manufacturing is an important research area these days. Various researches have reported the improvement in durability properties of concrete on implementation of bacterial techniques [16–19]. In the present study, influence of bacteria addition in silica fume concrete on its strength and permeation properties has been investigated. In addition to properties of concrete, economic study of bacterial silica fume concrete has also been carried out.

2. Experimental program

2.1. Isolation and identification of bacteria

Alkaliphilic/alkalitolerant bacteria which can tolerate high pH was secluded from rhizospheric soil and from marble sludge. The specimens were put in sterilized solution made using NaCl (0.85%), properly diluted and plated on enrichment medium containing glucose (10.0 g/L), peptone (10.0 g/L), yeast extract (5.0 g/L), KH_2PO_4 (1.0 g/L), agar (15 g/L) and pH was attuned to 10.5 with 1 N NaOH solution.

2.2. Urease test

Urea agar medium was prepared using Peptone (1.0 g/L), sodium chloride (5.0 g/L), 0.2% phenol red, potassium dihydrogen phosphate (2.0 g/L),agar (20.0 g/L), and distilled water (1000 ml). The above constituents were dissolved in distilled water and the pH was maintained equal to 6.8. The prepared solution was autoclaved at 121 °C for 15 min then cooled down to room temperature. Then 1 g of glucose was added to the solution. The solution was steamed for one hour and subsequently, 20% aqueous 100 ml of urea was added to it. Following the sterilization of finally obtained solution by filtration, the slants were prepared. The isolated organisms splashed on the surface of the media was incubated at 37 °C and then media colour change from yellow to pink was observed. The isolate AKKR5 were studied for urease activity.

2.3. Study of bacteria

The bacterial strain morphology was determined using gram staining method. After staining the bacterial smear slide with crystal violet for 1–2 min, it was flooded with Gram's iodine for 1–2 min to remove colour, slide was slowly washed with acetone for 2–3 s. After decolourization, the slide was rinsed with water and then flooded with safranin counter stain for 2 min. Thereafter, the bacterial smear slide was first washed with water and then air dried.

XRD spectrums of bacterial samples were taken with the help of X'Pert PRO diffractometer and scanning 2 theta between 5° and 60°. The phases present in bacterial samples were identified with the help of X'pertHighScorePlus software.

2.4. Materials

Ordinary Portland cement (OPC) conforming to BIS: 8112-1989 [20] an equivalent to ASTM C - 150 – Type I [21] was used. Properties of SF were examined according to BIS 15388-2003 [22] and are given in Table 1. Coarse aggregate with nominal size of 12.5 mm having bulk density 1650 kg/m^3 was used in this work. Physical properties of coarse aggregates and fine aggregates are presented in Table 2.

2.5. Mix composition

Control concrete mix having 28-d compressive strength of 33.0 MPa was designed as per BIS: 10262-1982 [23]. Silica fume (5, 10 and 15% by weight) was used as partial replacement of cement. Constant concentration of bacterial culture (10^5 cfu/mL of water) was used in all the bacterial concrete mixes. The bacterial growth curve was prepared by observing optical density at 600 nm and cell concentration was determined from it. Mixes proportion details are presented in Table 3. The addition of bacteria has no effect on the slump value of concrete. As such slump results of BSF concrete are not presented in the Table 3.

2.6. Casting, curing and testing of specimens

Cubes (150 mm) were cast for compressive strength and water absorption measurement. Cylinders (100 × 200 mm) were made for permeability [24] and sorptivity [25] tests. Compressive strength was measured as per BIS: 516-1959 [26]. Water absorption and porosity measurement were done as per ASTM C 642-13 [27]. Concrete samples were studied with Scanning Electron Microscope (SEM).Specimens were first dried and then studied at accelerating voltage range of 20 kV by a SEM (JEOL, JSM 6510 LV). The concrete samples for SEM and XRD analysis were got from the inner core of the broken cube specimens. XRD spectra of powdered concrete samples were taken with the help of X'Pert PRO (PANalytical) diffractometer and scanning 2 theta between 5° and 60°. Phases in concrete were identified with the help of X'pertHighScorePlus software. All experiments were done in triplicate.