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Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete

K. Ganesan [a,*], K. Rajagopal [a], K. Thangavel [b]

[a] Department of Civil Engineering, Alagappa Chettiar College of Engineering and Technology, Karaikudi 630004, India
[b] Concrete Corrosion Division, Central Electro Chemical Research Institute, Karaikudi 630006, India

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Abstract

In this study, rice husk ash (RHA) prepared from the boiler burnt husk residue of a particular rice mill has been evaluated for optimal level of replacement as blending component in cements. The physical, chemical and mineralogical characteristics of RHA were first analysed. The properties of concrete investigated include compressive strength, splitting tensile strength, water absorption, sorptivity, total charge-passed derived from rapid chloride permeability test (RCPT) and rate of chloride ion penetration in terms of diffusion coefficient. This particular RHA consists of 87% of silica, mainly in amorphous form and has an average specific surface area of 36.47 m^2/g. Test results obtained in this study indicate that up to 30% of RHA could be advantageously blended with cement without adversely affecting the strength and permeability properties of concrete. Another interesting observation emanating from this study is the linear relationship that exists among water sorptivity, chloride penetration and chloride diffusion.

Keywords: Rice husk ash; Blended cement; Concrete; Compressive strength; Transport properties

1. Introduction

Rice husk is an agricultural residue obtained from the outer covering of rice grains during milling process. It constitutes 20% of the 500 million tons of paddy produced in the world [1]. Initially rice husk was converted into ash by open heap village burning method at a temperature, ranging from 300 °C to 450 °C [2]. When the husk was converted to ash by uncontrolled burning below 500 °C, the ignition was not completed and considerable amount of unburnt carbon was found in the resulting ash [3]. Carbon content in excess of 30% was expected to have an adverse effect upon the pozzolanic activity of RHA [4]. The ash produced by controlled burning of the rice husk between 550 °C and 700 °C incinerating temperature for 1 h transforms the silica content of the ash into amorphous phase [5,6]. The reactivity of amorphous silica is directly proportional to the specific surface area of ash [7,8]. The ash so produced is pulverized or ground to required fineness and mixed with cement to produce blended cement.

Several papers have been published on the performance of RHA blended concrete. However, only limited information is available on the permeability characteristics. The objective of the present investigation is to evaluate the rice mill boiler burnt rice husk residue as supplementary cementitious material with reference to strength and permeability properties of hardened concretes and identify the optimal level of replacement. In the present context, optimal level refers to the maximum favorable percentage of replacement of OPC with RHA up to which the strength and permeability properties of blended concrete are equivalent or more than that of unblended OPC concrete. Towards this end, experiments were carried out in two phases as per standard test procedures. In the first phase, chemical composition, physical properties, and characterization of RHA were carried out. This included evaluation of standard consistency, initial setting time, final setting time

* Corresponding author. Tel.: +91 4565 224144; fax: +91 4565 224528.
E-mail address: ganesanhari@yahoo.com (K. Ganesan).

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and compressive strength of RHA blended cements. In the second phase, studies on concrete specimens were conducted. This included tests on compressive strength, splitting tensile strength, water absorption, coefficient of water absorption, sorptivity, resistance to chloride ion penetration and diffusion coefficient. All the experiments were carried out in triplicate and mean values are reported.

2. Materials and methods

2.1. Materials used

Ordinary Portland cement (OPC) conforming to Indian standard code IS 8112-1995 was used. Graded river sand passing through 1.18 mm sieve with fineness modulus of 2.85 and specific gravity of 2.55 was used as fine aggregate. Locally available crushed granite aggregate, passing through 12.5 mm sieve while being retained on 4.75 mm sieve with fineness modulus of 6.26 and specific gravity of 2.7. (Conforming to IS 383-1970) was used as coarse aggregate.

Boiler-fired rice husk residue was collected from a modern rice mill at Puduvayal, Sivaganga district in TamilNadu, India. The uncontrolled fired husk residue ash was black in colour obviously due to excess amount of carbon content. The mill fired husk residue ash was further burnt in an industrial furnace at a temperature of 650 °C over a period of 1 h as described below.

The uncontrolled fired husk residue collected from the mill was placed in the furnace. The temperature of the furnace was increased at a rate of 200 °C per hour until it reached the required temperature of 650 °C over a period of 3 h and 15 min. At 650 °C, the temperature was kept constant for a burning time of 1 h; under controlled condition and then cooled. The material was pulverized to a mean grain size of 3.8 μm before it was used as a cement replacement material.

2.2. Physical and chemical analysis of OPC and RHA

Particle size distribution of OPC and RHA was determined using HORIBA LA– 910 particle size analyzer. Mineralogical analysis of RHA was carried out by X-ray diffraction analysis. Specific surface area of OPC was measured as per IS 4031 (part 2)-1995 using Blain's air permeability apparatus. Specific surface area of RHA was measured using BET's method by nitrogen adsorption. Physical properties such as specific gravity, bulk density, and fineness of OPC and RHA were determined as per IS 4031 (parts)-1995 and IS1727-1995. Chemical analysis for oxide composition of OPC and RHA was determined as per IS 4032-1985 and IS 1727-1995.

2.3. Blended cements

RHA blended cements were prepared by replacing OPC with different amount of RHA (5%, 10%, 15%, 20%, 25%, 30% and 35% by weight of cement) in dry condition. The mixtures were thoroughly homogenized and kept in polythene bottles.

2.4. Consistency and setting time of blended cement

Standard consistency of RHA blended cements was determined in accordance with IS 4031 (Part 4)-1995. Pastes having standard consistency were used to determine the initial setting time and final setting time in accordance with IS 4031 (Part 5)-1995.

2.5. Compressive strength of blended cement mortar cubes

The compressive strength of RHA blended cement mortar cube specimens of 70.6 mm size with a water binder ratio appropriate to standard consistency measurement was determined after 1, 3, 7 and 28 days of moisture curing as per IS 4031(Part 6)-1995. Mortar mixes were designated as M0 for control and M1-M7 for RHA blended mortars. The RHA blended cement mortar mix proportions are presented in Table 1.

2.6. Mix proportions and casting of concrete specimens

In the second phase, eight different proportions of concrete mixes (RHA ranging from 5% to 35% by weight of cement) including the control mix were prepared with a water to binder W/(C + RHA) ratio of 0.53 for a design cube compressive strength of 25 MPa. These mixes were designated as R0 for control and R1–R7 for RHA concretes. The mix proportions are presented in Table 2.

The concrete was mixed for 5 min in a laboratory drum mixer. For mixes R0 through R7, twelve cube specimens of 100 mm size were cast from each mix for compressive strength testing. Three cylindrical specimens of 150 mm diameter and 300 mm height were also cast from each mix for determining the splitting tensile strength. Thirty cylindrical specimens of 100 mm diameter and 50 mm height were cast from each mix for water and chloride penetration tests. After casting, all the specimens were left covered in the casting room for 24 h. The specimens were then demoulded and transferred to moisture curing room until the time of testing.

2.7. Compressive strength of concrete

Compressive strength of RHA blended cement concrete cubes was determined as per IS 9013-1997 after 7, 14, 28 and 90 days of moisture curing.

2.8. Splitting tensile strength of concrete

Splitting tensile strength test was conducted on RHA blended concrete cylinders as per IS 5816-1999 after 28 days of moisture curing.