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Potential of rice husk ash for mitigating the alkali-silica reaction in mortar bars incorporating reactive aggregates

Safeer Abbas [a,*], Syed M.S. Kazmi [b], Muhammad J. Munir [b]

[a] Department of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan
[b] Department of Civil Engineering, Mirpur University of Science and Technology, Mirpur, AJK, Pakistan

HIGHLIGHTS

- Effect of RHA in mitigating the ASR expansion was investigated.
- SEM and EDS analysis were conducted to study the micro-structural behavior due to ASR.
- Incorporating RHA as a pozzolan can be helpful for mitigating the ASR expansion.

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ABSTRACT

Alkali-silica reaction (ASR) in concrete structures is very common problem around the globe. In this study, the potential of rice husk ash (RHA) in mitigating the ASR expansion was investigated. For this purpose, aggregates from reactive source were selected. RHA was acquired from local industry. Mortar bar specimens were prepared with various RHA proportions (10%, 20%, 30% and 40% by cement weight) to evaluate the ASR expansion in accordance with ASTM C1260. The pozzolanic reactivity of RHA was also evaluated using strength activity index and thermal analysis. Results showed satisfactory level of pozzolanic reactivity when cement was partially replaced with RHA. Mortar bars expansion results showed 23% and 50% decrease in expansion for specimen incorporating 10% and 40% of RHA, respectively. Scanning electron microscopy (SEM) also showed cracking due to ASR in control specimens; however, no cracks were observed in mortar bar specimens incorporating RHA. Moreover, energy disperse X-ray spectroscopy (EDS) analysis of mortar bars incorporating RHA showed low calcium to silica ratio with higher amount of alumina which may resulted into alkali reduction due to alkali absorption and dilution process leading to reduce the ASR expansion. Therefore, the incorporation of RHA as a pozzolanic material can be helpful in binding alkalies and mitigating the ASR expansion.

1. Introduction

Due to alkali silica reaction (ASR), a gel is formed. ASR gel is considered harmless itself; however, its water absorbing property may cause problems for concrete. Gel expands in the presence of moisture and causes pressure on the surrounding concrete leading to excessive cracking. Normally, presence of alkalies in the pore solution, reactive aggregates and moisture are considered as essential factors for ASR to initiate [1]. In many parts of the world, ASR was observed after several years of construction [2]. For instance, in 1990, Elgeseter Bridge in Norway damaged due to ASR [3]. Similarly, twenty bridges in Netherland were affected because of ASR [4]. A hydroelectric plant in Atlantic Canada showed a serious distress due to ASR in concrete after ten years of construction [5]. Moreover, cracks due to ASR were also observed in spillway of Tarbela and Warsak dams in Pakistan [6].

Various researchers have studied the utilization of supplementary cementitious materials (SCMs) and waste materials as a measure to control the ASR. For example, fly ash, slag, silica fume, *meta*-kaolin have been used to control the ASR expansion in concrete [7–15]. Distress in concrete due to ASR can be controlled by SCMs mainly because of higher strength as a result of pozzolanic reaction, reduction in alkali content due to their replacement with cement and decrease in silica dissolution rate from the surface of aggregates [16]. Moreover, SCMs improve the porosity of concrete leading to decrease the moisture access for reaction to initiate [17].

Rice hush ash (RHA) is one of the waste material having pozzolanic properties. In many parts of the world, the major sources of biomass for fuel generation are the rice husk and sugarcane

* Corresponding author.
E-mail address: safeerabbas26@gmail.com (S. Abbas).

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[18]. Asian countries like India, China, Cambodia, Philippines, Indonesia and Thailand used rice husk for the gasification of power generation [19–21]. After combustion/burning of rice husk, an ash is produced known as rice husk ash (RHA). Disposal of RHA can cause a lot of space and environmental problems. RHA can be used in concrete as a replacement of cement leading to reduce the carbon dioxide emission. Zerbino et al. [22,23] studied the utilization of RHA against ASR. No significant reduction in expansion was observed with RHA because of utilization of natural RHA having unburnt particles [22,23].

Controlling ASR expansion through waste utilization will not only help in mitigating the problem but also leads towards the sustainable and economical construction. Although literature showed that the mechanical and durability properties were improved due to the addition of RHA. However, still investigations are required to study the effect of RHA in controlling the ASR expansion.

2. Experimental program

The main objective of this study was to investigate the pozzolanic activity of rice husk ash (RHA) and its effectiveness in controlling the ASR distress. The experimental program was divided into two phases. Firstly, the material characterization of used materials was performed in order to determine its physical and chemical properties. Various mortar mixtures (Table 1) incorporating different proportions of RHA were examined for evaluating the pozzolanic reactivity of RHA. Furthermore, effect of RHA on the fresh properties of mortar mixtures was also investigated. In the second phase, the role of RHA in mitigating the ASR was inspected using the expansion test performed according to ASTM C1260 (Standard test method for potential alkali reactivity of aggregates) [24] on mortar bar specimens. Moreover, scanning electron microscopy (SEM) and energy disperse X-ray spectroscopy (EDS) on selected specimens were performed in order to examine its micro-structure due to ASR distress.

2.1. Materials

Ordinary Portland cement was used. Aggregates used in this study, were acquired from Muzaffarabad, Azad Kashmir. These aggregates were obtained from dolomite-limestone parent rock through blasting. Furthermore, wet technique was adopted to crush the aggregates in the required sizes. Dolomite-limestone rock type is considered as alkali-silica reactive [26,33]. Aggregates despite of being alkali-silica reactive are commonly used for local concrete construction. To explore the suitability in controlling the ASR expansion, rice husk ash (RHA) from local industry was used. Outer cover of rice kernel (rice husk) is burnt as a fuel in many industries, leading to generation of RHA. Generally, it is considered that RHA particles of size 10–75 μm exhibits pozzolanic behavior [25]. Therefore, ash was ground for one hour in a ball mill. Ground rice husk ash with particle size less than 75 μm was used. For mortar mixing, clean tap water was utilized.

Table 1
Mixture proportions used to prepare specimens.

Mixture	Cement (%)	RHA (%)
C	100	0
RHA10	90	10
RHA20	80	20
RHA30	70	30
RHA40	60	40

2.2. Mixture proportions

Mortar cube and bar specimens were casted using various proportions of RHA (10%, 20%, 30% and 40% by cement weight). Specimens were prepared in a proportion of 1–2.25 (cement to aggregate ratio). Mortar bar specimens were prepared using constant and varying water-cement ratios. Initially, water-cement ratio was 0.47 (as recommended by ASTM C1260 [24]). The flowability (flow diameter) of control mixture without RHA was 115 mm. However, it was observed that due to addition of RHA, the workability (flowability) of the mortar mixture decreased. Therefore, in order to achieve a constant flow (115 mm), varying w/c was used depending on the RHA contents. For instance, mixture incorporating 30% of RHA, 0.53 w/c was used in order to achieve a constant flow of 115 mm.

3. Test methodologies

3.1. Raw materials

To study the chemical composition of cement and RHA, X-ray fluorescence (XRF) and X-ray diffraction (XRD) were performed. Specific gravity of both cement and RHA was also determined in accordance with ASTM C188 (Standard test method for density of hydraulic cement) [26]. Fineness of raw material was evaluated through ASTM C184 (Standard test method for fineness of hydraulic cement by the 150-μm (No. 100) and 75-μm (No. 200) sieves) [27] and ASTM C204 (Standard test method for fineness of hydraulic cement by air-permeability apparatus) [28]. Furthermore, expansion of cement was determined in accordance with ASTM C151 (Standard test method for autoclave expansion of Portland cement) [29]. Mineralogical composition of aggregates was determined through petrographic examination following ASTM C295 (Standard guide for petrographic examination of aggregates for concrete) [30].

To evaluate the alkali-silica reactivity potential of aggregates, chemical test was also performed in accordance with ASTM C289 (Standard test method for potential alkali-silica reactivity of aggregates (chemical method)) [31]. Water absorption and specific gravity of aggregates were evaluated in accordance with ASTM C127 (Standard test method for specific gravity and absorption of coarse aggregate) [32]. Void contents and bulk density were measured according to ASTM C29 (Standard test method for bulk density (unit weight) and voids in aggregate) [33]. Abrasion value of aggregates were evaluated through ASTM C535 (Standard test method for resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles machine) [34]. Crushing and impact value of aggregates were determined in accordance with BS 812–110 (Testing aggregates: methods for determination of aggregate crushing value (ACV)) [35] and BS-812-112 (Testing aggregates: method for determination of aggregate impact value (AIV)) [36]. Weight loss due to soundness was also measured in accordance with ASTM C88 (Standard test method for soundness of aggregates by use of sodium sulfate or magnesium sulfate) [37].

3.2. Fresh properties of mortar

To evaluate the performance of fresh mortar incorporating various proportions of RHA and reactive aggregates, various tests were performed in accordance with ASTM standard procedures. Consistency and setting time tests were performed according to ASTM C187 (Standard test method for normal consistency of hydraulic cement) [38] and ASTM C191 (Standard test methods for time of setting of hydraulic cement by vicat needle) [39], respectively.