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Performance evaluation of Khyber Pakhtunkhwa Rice Husk Ash (RHA) in improving mechanical behavior of cement

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HIGHLIGHTS

- Study of RHA in KPK at higher temperature.
- The chemical composition of RHA varies with source.
- RHA content up-to 15% increase the compressive and flexure strength at later ages.
- Incorporation of RHA in cement mortar inhibit the ASR.
- Burning of RHA at higher temperature transform amorphous silica to crystalline silica.

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ABSTRACT

The rice husk (RH) as an agro-waste materials having low nutritional properties as a provender, when burnt under controlled temperature produce great quantity of Rice Husk Ash (RHA). The use of RHA as a supplementary cementitious materials have much importance in construction industry especially in the countries of high rice production. This paper discus the collection of rice husk (RH) from different regions of Khyber Pakhtunkhwa (KPK), the properties of Rice Husk Ash produced from these RH by different combustion methods of high temperature and their effect on mechanical behavior of cement. To evaluate the chemical composition and quantification of crystalline silica in RHA of various regions of KP, EDX and XRD tests were performed. Consistency, setting time, compressive, flexural strength and Alkali silica reaction tests were also performed for various replacement level of RHA i.e. 5%, 15% and 25% in cement paste and in mortar. Results show an obvious variation in the silica content with variation in sources. A partial transformation of amorphous silica to crystalline silica was observed at 800 °C (method **A**) and mostly at a temperature of 1000 °C (method **B**). RHA by method **A** and **B**, as a partial replacement of cement increase linearly the consistency and setting time but decrease the alkali silica reaction. Also the RHA by method **A** increased the compressive and flexural strength up-to 15% at later ages but a slight increase was observed up-to 5% replacement of RHA by method **B**.

1. Introduction

Globally, a net rice production of 678 million tones was observed during 2009 season by Food and Agriculture organization [1,2] and from such amount of rice, a rice husk of 20% is obtained [3]. This amount is considered as waste materials according to industrial point of view. After incineration of Rice husk, the Rice Husk Ash is remain as waste materials [3,4].

The need of limiting the content of carbon produced during the production of cement drove the scientific research toward the use of industrial by-products to be incorporated as a supplementary cementitious materials (SCMs) [5]. According to Islam et al. [6], cement factory normally released approximately one tone of CO_2 for the net production of one tone of cement. A substantial research has been also carried out on the use of Rice Husk Ash (RHA) as a pozzolonic SCMs. The biodegradability of rice husk is very less as compared to wheat straw and other agro waste product and also it has been observed that burning of Rice husk took a longer time and consequently environmental annoyance produced [5]. The Rice Husk Ash normally contain up-to 20%

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amorphous silica which is considered as the highest amount of silica in residue of plants [7], and this silica content with high reactivity may be enhanced under controlled combustion conditions [8].

RH that burnt under controlled environment to convert into ash accomplished the chemicals composition and physical characteristics of minerals admixtures [9]. Pozzolonic behavior of RHA mainly depends upon the size of ash particles, the surface area of the ash [10–13], the crystallization phase of silica and the silica content in RHA. Under controlled temperature, the combustion of RH produces amorphous silica content and particles of large surface areas [14]. To obtain good quality ash, special type of furnace or incinerators for burning and grinding techniques for RH are adopted. The burning procedure of RH was developed from the burning in the open air in 1970s to liquidized layers technique in 1990s [9]. In the liquidized technique, controlled temperature and time of combustion was considered as the best achievement in the combustion technology [15]. In this method, a moderate temperature for a short time is mandatory to obtain a good content of ash. However, many researchers collect RHA directly from rice mills [9,16].

In literature, the use of RHA as a supplementary cementitious materials due to its pozzolonic nature with economical and environmental benefits are available [15,17].

Of all the residues of plants, the ash obtained from the incineration of RH has highest amount of silica content [7]. The rice crop normally ingest orthosilicic acid in large quantity from ground water and this acid is further polymerized in the husk, ultimately contribute to amorphous silica [18]. RHA can be used as a partial replacement of Portland cement in mortar and concrete due to its pozzolanic nature [11] and to lower the cost of construction and to make a sophisticated contribution to the construction industry by providing low cost building materials and subsequently an economical shelter [7,19] RHA not only increase the basic strength properties but also enhance the durability of mortar and concrete [18] and to produce high performance cement [20].

Highly reactive RHA can be produced by burning the RH at a temperature of 500 °C or lower for comparatively protracted time under oxidizing environment or for a slighter instant at a temperature of up-to 680 °C [8]. The burning of RH beyond this temperature may cause the conversion of amorphous silica to crystalline silica [10], firstly to cristobalite and as the temperature increase, it converted to tridymite [21]. The relevant research work of other investigators also confirm that combustion procedure and temperature affects the surface area of RHA particles, so a critical care must be taken in the processing of RH so that maximum reactivity of the ash can be achieved as a supplementary cementitious materials [4]. Combustion of RH at a temperature of 500–600 °C produced amorphous silica. At a temperature of 800 °C, Cristobalite was noticed in the ash [10] and after burning to a temperature of 1150 °C, tridymite with a huge of cristobalite was detected in the ash [22]. Nehdi et al. [4] reported some work of researchers and it is stated that combustion process of RH up-to a temperature of 900 °C produce ash with silica in amorphous state and at 1000 °C, yield crystalline silica when the duration of combustion cross the limit of 5 min. Bui et al. [23] reported that RH yield crystalline silica at a low temperature of 600 °C and even at 350 °C for 15 h exposure. A systematic research work was performed on the processing and reactivity of RHA by James and Rao and concluded that isothermal heating of RH at a temperature of 402 °C (675 K) completely oxidize the organic matter and yield silica content[23]. Della et al. [24] reported that combustion of RH at a temperature of 700 °C for 6 h duration produce about 95% amorphous silica powder. Abu Bakar et al. [25] demonstrated that less effect was observed on the production of silica at a temperature between 500 °C and 900 °C. Omatola et al. [26] have worked on the combustion process of RHA and elemental analysis and declare that amorphous silica is produced at a temperature of 600 °C to 1000 °C and also time of combustion have significant impact the production of amorphous silica. An optimum content of amorphous silica was recorded as 97% at an incinerated temperature of 700 °C with a presoaking duration of 3 h.

By using different procedure, it has been concluded that RHA shows positive pozzolonic behavior [3,27]. Due to this nature, RHA was used as a blended component in cement up-to 30% replacement, to evaluate the consistency and permeability and hence better results achieved [28,29]. The pozzolonic behavior, vast availability and due to low cost, the RHA has ignited the interest of researchers to be used for blending cement [26,27]. The fineness of RHA particles, structure of silica particles, silica content, loss on ignition and surface area of the particles are the main factors affecting the reactivity of RHA [32].

In Pakistan, rice is considered as one of the cash crop and about 6 million tonnes of good quality rice produce every year [33]. From the report of researchers, it is concluded that 20% of rice paddy is husk, it means that Pakistan produces nearly 1.2 million tonnes of rice husk every year. Out of 6 million tonnes, Khyber Pakhtunkhwa (KPK) produce approximately 80,000 tonnes of rice per annum and rice husk of about 16,000 tonnes produced normally [34]. This rice husk is normally burnt in the open field or in the mills. If this rice husk is burnt under controlled condition, it can be used beneficially in the construction industry.

Form the previous literature, It was observed that RHA was burnt in the range of 500 °C to 700 °C, with high content of quartzite silica was used is a partial replacement of cement in mortar and in concrete. The results shown an excellent behavior in enhancing the mechanical properties of cement mortar and concrete [23,35] but no specific literature was found on RHA with high crystalline silica content.

In this research work, rice husk was collected from the different regions of KPK and was burnt under different controlled high temperatures i.e. 800 °C and 1000 °C to categorize it. This prime focus of this study is to investigate the effect of crystalline silica (cristobalite and tridymite) on the mechanical properties of cement and mortar. Energy dispersive X-ray spectroscopy (EDX) analysis and X-ray diffraction (XRD) analysis was carried out on fine RHA powder to evaluate the chemical and structural composition of the particles. Also the consistency, setting time, strength behavior and alkali silica reaction is also checked for pozzolonic behavior by mixing various percentage of RHA as a partial replacement of cement in paste and in mortar. The selected percentage levels of RHA are 0%, 5%, 15% and 25%.

2. Materials and methods

2.1. Materials and mixtures

2.1.1. Cement

Ordinary Portland Cement (OPC) confirming to ASTM C-150 standard [36] of Cherat cement factory of Pakistan was used as received. The physical properties and chemical composition of OPC are shown in Tables 1 and 2 respectively.

Table 1
Physical properties of OPC.

Cement brand	Cherat Cement	ASTM Standards
Cement Type	Type 1 (OPC)	C 150
Density (g/cm^3)	3.14	C 77
Average Particle diameter (μm)	<31	C 204
Initial setting time (min)	152	C 191
Final setting time (min)	236	C 191
Consistency (%)	28	C 187
Compressive strength at 28 days (N/mm^2)	45.96	C 150