Journal of Cleaner Production 188 (2018) 264–277

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Replacement of silica fume with thermally treated rice husk ash in Reactive Powder Concrete

M. Vigneshwari*, K. Arunachalam, A. Angayarkanni

Department of Civil Engineering, Thiagarajar College of Engineering, Madurai, Tamilnadu, 625015, India

ARTICLE INFO

Article history:
Available online 3 April 2018

Keywords:
Reactive powder concrete (RPC)
Ultra high performance concrete (UHPC)
Silica fume (SF)
Rice husk ash (RHA)
Compressive strength
Flexural strength

ABSTRACT

Reactive Powder Concrete (RPC) is a type of Ultra High Performance Concrete (UHPC) having advanced mechanical and durability properties. Silica Fume (SF) is a chief constituent in RPC for pozzolanic reaction and for improving the packing density of granular materials. However, the high cost and limited availability of SF constrain the RPC application in modern construction industry, especially in developing countries like India. Therefore in this research work, Rice Husk Ash (RHA) an agricultural waste has been used as a partial substitute for SF with 10%, 20%, 30%, 40% and 50% to determine its effect on the mechanical and durability properties of RPC under normal curing and steam curing. Test results showed that RPC containing RHA has satisfactory mechanical and durability performance under both normal curing and steam curing. Hence RHA can be used as an alternative material for SF to produce RPC without compromising the required qualities.

1. Introduction

Reactive Powder Concrete (RPC) is a new class of material developed due to the advancements of modern concrete technology. Richard and Cheyrezy, 1995 stated that RPC is having the combination of Portland cement, silica fume, quartz flour with very fine grained silica sand and very low water-binder ratio with the use of high range water reducing admixtures possesses exceptional mechanical and durability properties. RPC is a highly ductile concrete in addition to its higher compressive strength of more than 150 MPa; it is possible due to the inclusion of small sized steel fibers as reported by Abbas et al. (2015); Shi et al., 2015; Van Tuan et al., 2011a,b; Wang et al., 2012. Yazici et al., 2013 suggested that this modern material can be used very effectively in many practical applications like nuclear waste containment structures, high rise buildings, skyscrapers, long span bridges, and walkways.

One of the most important constituents of RPC is Silica Fume (SF). Because of its extreme fineness and high amorphous silica content, it enhances the pozzolanic reaction by reacting with calcium hydroxide resulting from primary hydration as reported by Richard and Cheyrezy (1995); Van Tuan et al., 2011a,b. Moreover the use of SF in concrete production, especially in developing countries, is very limited due to its high cost and limited availability of its constituent materials. In view of this, some other pozzolanic materials having similar functions are being investigated as cost effective alternatives.

Various researchers like Raman et al., 2011; Van et al., 2014; Van Tuan et al., 2011a,b have found that the Rice Husk Ash (RHA), which is obtained by burning rice husk, an agricultural residue can be a possible alternative for SF. Rice is one of the major crops grown throughout the world**.** India is one of the major rice producing country and the annual rice production in India is approximately 200 million tons. Industries use rice husk as fuel for power generation and in boilers. Among the different types of biomass used for gasification, rice husk has a high ash content varying from 18 to 20%; stated by Ganesan et al. (2008); Raman et al., 2011**.** About 20 million tons of RHA are produced annually in India. This RHA is a great environment threat causing damage to the land and the surrounding area in which it is dumped. Lots of ways are being thought of for disposing them by making commercial use of this RHA since silica is the major constituent of RHA; this issue has already been reported by Ferraro and Nanni (2012). With such a large ash content and silica content in the ash, it becomes essential and economical to extract silica from the ash, which has wide market and also takes care of ash disposal issues.

RHA is generally obtained by controlled combustion of rice husk in appropriate conditions; the RHA contains 90–96% silica in an

* Corresponding author.
E-mail addresses: m.vigneshwari87@gmail.com (M. Vigneshwari), karcivil@tce.edu (K. Arunachalam).

https://doi.org/10.1016/j.jclepro.2018.04.008
0959-6526/

amorphous form. Various researches are made to utilize RHA as a supplementary cementitious material for cement in conventional concrete. The compressive strength is increased with the addition of RHA in conventional concrete (Gursel et al., 2016). Also in High Strength Concrete, RHA is used as a replacement material for SF because of its similar functions as that of SF. There are very few researches made to use RHA in the production of RPC. Nehdi et al., 2003 studied the performance of RHA produced in controlled combustion and concluded that RHA enhanced the compressive strength of concrete by up to 40%. Ganesan et al., 2008; Saraswathy and Song, 2007 found that RHA up to 30% could be beneficially used as blending component in cement without affecting the strength and durability characteristics. Also the incorporation of RHA up to 30% replacement improves the corrosion resistance properties. Chao-Lung et al., 2011; Zain et al., 2011 reported that the grinding process and duration are important factors to improve the pozzolanic reactivity of RHA in concrete. The reactivity also depends on the amorphous silica content, size of the particle and the surface area of the RHA particles (Sua-Iam and Makul, 2014).

Van Tuan et al., 2011a,b explored the performance of UHPC by using RHA as a supplementary cementitious material as that of SF by minimizing the cement content in UHPC. Van et al., 2014 studied the effect of using RHA in UHPC without SF and test results indicated that it mitigates the autogeneous shrinkage problem that normally occurs in UHPC with SF. This advantageous effect is due to the porous structure of RHA which slows down the reduction in the internal relative humidity of UHPC and the same results are also reported by Wang et al. (2017) when recycled coral based materials are used in UHPC as they are also having porous structure similar to RHA.

Prior research showed that RHA could be used as a supplementary cementitious material in RPC as that of SF to enhance the mechanical and durability properties. However, only very limited data is available on the effect of partially replacing SF with RHA without reducing the cement content on the overall mechanical performance and durability of RPC. Hence, this research program is intended to bridge this gap in the existing knowledge. In this study, the effect of RHA on the mechanical performance of RPC was experimentally investigated by using RHA as a partial substitute for SF.

2. Experimental programme

2.1. Production of rice husk ash

The rice husk derived from the paddy harvested in the villages near Madurai was collected from the local rice mill in bulk quantity and it was processed in the laboratory and used as a single source material throughout the study. The rice husk was cleaned initially to remove the waste materials present in it. Known quantities of rice husk were taken in crucibles and were kept in the furnace for the removal of volatile matters and carbon from the sample. Samples were burnt at different temperatures of 550 °C, 600 °C, 650 °C and 700 °C. At each temperature, samples were burnt for 1hr, 2hrs, 3hrs and 4hrs duration and the collected samples were named based on their duration of burning and temperature maintained. After collecting all the samples they were tested for X-Ray Diffraction (XRD) and Energy Dispersive Spectroscopy (EDAX) analysis. The XRD and EDAX tests for RHA treated at 550 °C, 600 °C, 650 °C and 700 °C temperatures for the duration of 1hr, 2hrs, 3hrs and 4hrs were carried out. The raw rice husk and RHA after burning in controlled condition and grinding are shown in Fig. 1.

The XRD test results for various samples at different treatment conditions were analyzed using Origin 8 Pro software to identify the best suitable temperature and duration of treatment and are shown in Fig. 2. Using XRD graph, whether the particles are in amorphous state or in crystalline state can be identified based on the energy diffraction. If the arrangement of atoms in the diffraction of the chemical particles is in disorderly manner, it is an indication of amorphous state. If the arrangement of atoms is in orderly manner, it shows that there is a transition of amorphous state to crystalline state. Even if the silica content is more, the treatment process producing crystalline silica is not suitable.

From the XRD results as shown in Fig. 2(a, b, c, d), it was observed that the RHA was purely amorphous in nature at the burning temperatures of 550 °C, 600 °C, 650 °C and 700 °C and the burning duration of 1hr, 2hrs, 3hrs and 4hrs.

Using EDAX analysis, chemical composition of individual compounds present in the various samples of RHA at different treatment conditions is found. The major chemical compounds present in all the samples of RHA at different treatment conditions are given in Table 1. From EDAX test, sample is selected based on the maximum silica content with low carbon content to replace SF with RHA in RPC.

From EDAX test, RHA subjected to 600 °C temperature for 3hrs duration gave maximum silica content of 89.9% without carbon content and it is in amorphous state from XRD analysis. Hence this temperature and duration were selected for treating rice husk to obtain RHA which gave convincing results for the SF replacement in RPC. From this study, it can be inferred that RHA with its properties similar to SF can be used as an alternative supplementary cementitious material to produce RPC.

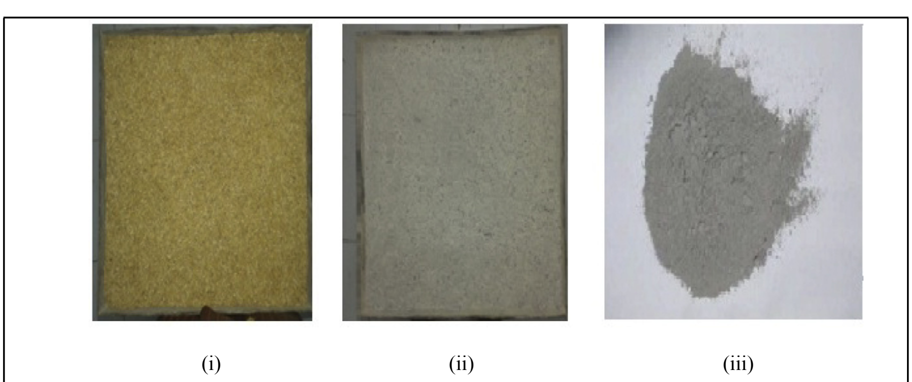

Fig. 1. (i) Raw Rice Husk (ii) Rice Husk Ash after burning (iii) Rice Husk Ash after grinding.