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Contribution Of Rice Husk Ash To The Properties Of Cement Mortar And Concrete

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Abstract

In the last decade, the use of supplementary cementing materials has become an integral part of high strength and high performance concrete mix design. These can be natural materials, by-products or industrial wastes, or the ones requiring less energy and time to produce. Some of the commonly used supplementary cementing materials are fly ash, Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBFS) and Rice Husk Ash (RHA) etc. RHA is a by-product material obtained from the combustion of rice husk which consists of non-crystalline silicon dioxide with high specific surface area and high pozzolanic reactivity. It is used as pozzolanic material in mortar and concrete, and has demonstrated significant influence in improving the mechanical and durability properties of mortar and concrete. This paper presents an overview of the work carried out on the use of RHA as partial replacement of cement in mortar and concrete. Reported properties in this study are the mechanical and fresh properties of mortar/concrete. The optimal level of replacement of RHA in cement is also reported in this paper.

Keywords:*Rice Husk Ash, Pozzolan, Durability, Setting time, Porosity.*

1. Introduction

All Concrete is widely used construction material for various types of structures due to its structural stability and strength. All the materials required producing such huge quantities of concrete come from the earth's crust. Thus, it deflects its resources every year creating ecological strains. On the other hand, human activities on earth produce solid waste in considerable quantities of over 2500/MT per year, including industrial waste, agricultural waste and waste from rural and urban societies. Recent technological development has shown that these materials are valuable as organic and inorganic resources and can produce various useful products. Amongst the solid wastes, the most prominent ones are fly ash, blast furnace slag, rice husk ash, silica fume, and demolished construction materials. The current cement production rate of the world, which is approximately1.2 billion tones/year, is expected to grow exponentially to about 2 billion tones per year by 2015. Most of the increase in cement demand will be meant by the use of supplementary cementing materials. Considerable efforts are being taken worldwide to utilise natural waste and bye –product as supplementary cementing materials to improve the properties of cement concrete. Substantial energy and cost savings can result when industrial by-products are used as a partial replacement for the energy-intensive portland cement. The presence of mineral and chemical admixtures in concrete is known to impart significant improvement in workability and durability. Among the different existing residues and by-products, the possibility of using rice husk ash in the production of structural concrete is very important for India. India is second largest rice paddy cultivating country in the world. Both the technical advantages offered by structural concrete containing rice husk ash and the social benefits' related to the decrease in number of problems of ash disposal in the environment have simulated the development of research into the potentialities of this material. Rice plant is one of the plants that absorbs silica from the soil and assimilates it into its structure during the growth (Smith et al., 1986). Rice husk is the outer covering of the grain of rice plant with a high concentration of silica, generally more than 80-85% (Siddique 2008). It is responsible for approximately 30% of the gross weight of a rice kernel and normally contains 80% of organic and 20% of inorganic substances. Rice husk is produced in millions of tons per year as a waste material in agricultural and industrial processes. It can contribute about 20% of its weight to Rice Husk Ash (RHA) after incineration (Anwar et al., 2001). RHA is a highly pozzolanic material (Tashima et al., 2004). The non-crystalline silica and high specific surface area of the RHA are responsible for its high pozzolanic reactivity. The utilization of RHA as a pozzolanic materials in cement and concrete provides several advantages such as improve strength and durability properties, reduce materials cost due to cement saving and environmental benefits related to disposal of waste materials.

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2. Properties of rice husk ash

Rice husk essentially consists of amorphous silica(90% SiO_2), carbon (5% C) and potassium-oxide(2% K_2O). Some of the useful properties are described below:

2.1. High silica content

Many of RHA's most practical applications stem from its high amorphous silica content. RHA contains around 85 to 90 percent silica. Applications which take advantage of RHA's high silica content include cement and concrete mixes, glaze and release agents for ceramics, specialty paints, and flame retardants. In the cement industry, RHA acts as a much more economical alternative to micro-silica and silica fume, which are imported from China, Norway and Burma. Also, exposing RHA to temperatures exceeding 1,500 degrees Fahrenheit transforms the silica to its crystalline form, which in itself has a number of practical applications, including microelectronics and solar cells.

2.2. Small particle size

RHA's particle size ranks second among its most useful properties. RHA powders normally measure about 25 microns, giving it a very high surface-area-to-volume ratio and making it an excellent absorbent for oil and chemical spills. It also plays an important role in concrete mixes. Cement, which has a particle size of 35 microns, leaves voids in the concrete after curing, reducing the latter's strength. RHA's small particle size allows it to fill the spaces between cement particles.

2.3. Moisture resistance

RHA's water resistance makes it a good additive for waterproofing materials, reducing water penetration by nearly 60 percent when incorporated in sealants and specialty paints. In concrete, a study conducted by the Civil Engineering Department of the Universidade Estadual Paulista Júlio de Mesquita Filho in Brazil, learned that substituting a portion of cement with 10 percent RHA lowers its water absorption by about 40 percent. Increasing the ratio of RHA to cement to an allowable extent increases concrete's water resistance without compromising its quality. Practical applications include concrete pilings for bridges and other marine environments.

2.4. Heat resistance

RHA's heat resistance allows it to be of important use as an insulation powder in steel mills, especially during casting, as reported by the Rice Husk Ash website. Without an RHA coating over the molten metal, transferring the latter from the ladle to a mold would cause an abrupt 300-degree Fahrenheit temperature drop, which damages the cast. RHA prevents the rapid cooling of the metal, preserving the cast's quality. Also, RHA's heat resistance is used in concrete mixes for high-temperature environments, such as nuclear power plant.

3. Fresh properties of mortar / concrete

3.1. Workability

It is defined as per ACI:116R-90, the properties of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. The workability property is measured by conducting slump cone test or compacting factor test. While observing the characteristics of fresh concrete of different mixes, it was noted that in concrete matrix when cement was replaced in different proportions of RHA, the workability decreases with increasing quantity of RHA. This happened because the quantum of fine materials in the concrete mixes decreased and it become difficult to have the same level of workability even using plasticizers. The dosage of super plasticizer increases with the increase in replacement level of RHA. This may be due to partial replacement of cement by RHA with higher fineness and porosity could attribute to increased surface area of matrix to absorb more water.

3.2. Consistency and setting time

It was observed that the consistency values of RHA blends varied from 31 to 42%. Initial and final setting time tests were shown to yield different results on plain cement paste and pastes having rice husk ash (Dakroury et al., 2008). The studies by Ganesan et al. (2008), Cook (1986), and Bhanumathidas etal. (2004) showed that RHA increases the setting time of pastes. Just like other hydraulic cement, the reactivity of rice husk ash cement depends very much upon the specific surface area or particle size. The rice husk ash cement with finer particles exhibits superior setting time behavior. Research has shown the increase in the initial setting time by raising the RHA level in the cement mixture over those of plain cement paste.

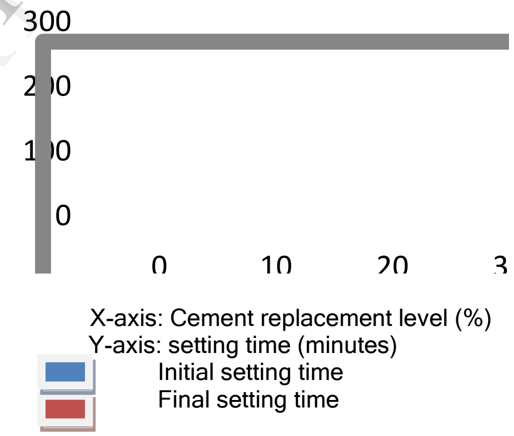

Figure 1. Initial and final setting time of RHA-OPC blends.

Figure.1 shows the setting time of cement paste with RHA in various proportion of replacement. RHA addition tends to increase the initial setting time of cement. The rate of increase in initial setting time varies depending upon the addition rate of RHA. The rate increases with RHA replacement up to 20% and then it decreases. Unlike other pozzolanic materials, RHA tends to shorten the final setting time. The rate of retardation of final setting time decreases continuously with increase in RHA content up to 30%.

4. Properties of hardened mortar / concrete

4.1. Pore size distribution

There is a consensus among several researchers that with partial replacement of cement by pozzolans, porosity decreases in concrete. Blended (or pozzolanic) cements are being used worldwide to produce more homogenous hydration products by filling and segmentation of the capillary voids and produce ultimately more denser and impermeable concrete (Guneyisi et al., 2006). Figure 2 shows the effect of RHA content on the total porosity of RHA-hardened cement paste. When the percent of the RHA is increased, the total porosity is decreased. This decrease in the total porosity is attributed to the change occurring in the pore size distribution as a result of using RHA which could react with the calcium hydroxide to form C-S-H gel (Dakroury et al., 2008). Results due to the intensification mechanism of RHA blended concrete confirmed that the average pore size of concrete incorporating RHA is decreased compared to that of control concrete (Sugita et al., 1997).

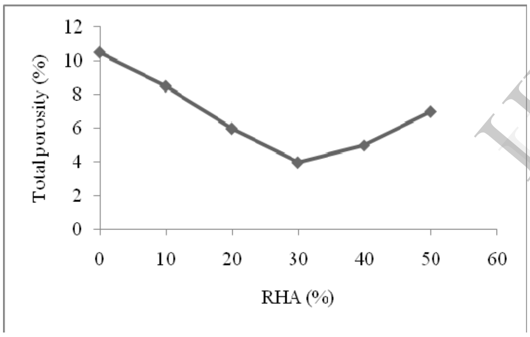

Figure 2. Total porosity of RHA hardened cement paste (Dakroury et al., 2008).

4.2. Water absorption and sorptivity

One of the main sources of contamination of concrete in structures is water absorption which influences durability of the concrete and also has the risk of alkali aggregate reactions (Ithuralde 1992). The more impermeable the concrete, the greater will be its resistance to deterioration. The incorporation of pozzolan such as fly ash reduces the average pore size and results in a less permeable paste (Poon et al., 1997; Chindaprasirt et al., 2005). Literature studies have identified that commonly permeability of blended cement concrete is less than plain cement paste. It was observed that the incorporation of RHA in the composites could cause an extensive pore refinement in the matrix and in the interface layer, thereby decreasing water permeability (Rodrigues et al., 2006). The radial expansion of Portland cement hydration products in pozzolanic particles would have a pore modification effect therefore reduces the interconnectedness among pores (Cook et al., 1987). This occurrence can be coupled with perfection on the interfacial transition zones among the cement matrix and aggregate (Toutanji et al., 2004). The permeability will decrease rapidly with the progress of the hydration. The presence of pozzolan leads to greater precipitation of cement gel products (Feng et al., 2004) than occurs in Portland cement alone, which more effectively block the pores helping to reduce permeability. Saraswathy et al. (2007) studied the effect of partial replacement of cement with RHA at different replacement levels on the porosity and water absorption of concrete and reported that the coefficient of water absorption for rice husk ash replaced concrete at all levels was less than control concrete.

4.3. Compressive strength

Inclusion of RHA as partial replacement of cement enhances the compressive strength of concrete, but the optimum replacement level of OPC by RHA to give maximum long term strength enhancement has been reported between 10% up to 30%. All these replacement levels of RHA are in percentage by weight of the total binder material. Mahmud et al. (1996) reported 15% cement replacement by RHA as an optimal level for achieving maximum strength. Zhang et al. (1996) suggested 10% RHA replacement exhibited upper strength than control OPC at all ages. Ganesan et al. (2007) concluded that concrete containing 15% of RHA showed an utmost compressive strength and loss at elevated content more than 15%. Dakroury et al. (2008) reported that using 30% RHA as a replacement of part of cement could be considered optimum for all content of W/C ratios in investigated mortars because of its high value of compressive strength. Zhang et al. (1996) reported that achieving higher compressive strength and decrease of permeability in RHA blended concrete is perhaps caused by the reduced porosity, reduced calcium hydroxide and reduced width of the interfacial zone between the paste and the aggregate. The development of more CS-H gel in concrete with RHA may progress the concrete properties due to the reaction among RHA and calcium hydroxide in hydrating cement (Yu et al., 1999). It is apparent from the literature that generally RHA blended cement compared to OPC cement exhibited higher compressive strength than OPC. According to Rodriguez (2006) the RHA concrete had higher compressive strength at 91 days in comparison to that of the concrete without RHA. The increase in compressive strength of concretes with residual RHA may also be justified by the filler (physical) effect. It is concluded that RHA can provide a positive effect on the compressive strength of concrete at early ages. Besides, in the long term, the compressive strength of RHA blended concrete produced by controlled incineration shows better performance.

5. Optimum content of RHA

According to A. Muthadhi and S. Kothandaraman, all RHA concrete mixture showed improved compressive strength characteristics up to 20% RHA replacement. At 30% replacement level, all the mixtures attained strength nearly equal to that of respective reference mixtures. According to their cost analysis to fine the optimum dosage level of RHA (table 1),the production cost of RHA comes to be Rs. 16.50 per kg in laboratory conditions. When compared to the cost of microsilica available in the market, the use of RHA may reduce the cost of supplementary cementitious material by about 40%. The cost of binder materials for 20% and 30% RHA addition is calculated based on the average market rate of cement and RHA produced at laboratory conditions. The cost of binder content is increased to about 50% and 80% for 20% and 30% RHA addition respectively. It is inferred that, there is 30% increase in cost of binder materials for 30% RHA addition when compared to that of 20%. By taking into account all the factors, they reported 20% RHA addition is optimum dosage level to achieve maximum strength gain with economy.

Table 1. Cost analysis for the production of 1 kg of RHA:

S.No	Description	Total Cost(Rs.)
	Husk required to produce 1 kg of ash=(1/.2)=5 kg (Note: ash content in husk=20%)	
1.	Cost of raw material: 1 kg of husk =0.555 paise Cost of 5 kg of husk =5×0.55	2.75
2.	Transit cost: Transit cost for 5 kg of husk=5×0.80	4.00
3.	Cost of inceneration: Electrical energy consumed=3.33 kWh/1kg of ash One unit power of electricity(industrial purposes)= Rs.2.60/- Incineration cost=3.33×2.60	8.65
4.	Grinding cost: Electrical energy consumed for grinding = 0.375Kwh/kg of ash Grinding cost=0.3752.60	0.97
	Others (10% of total)	0.16
	Net total=	16.53

6. Conclusion

The employment of RHA in cement and concrete has gained considerable importance because of the requirements of environmental safety and more durable construction in the future. The use of RHA as partial replacement of cement in mortar and concrete has been extensively investigated in recent years. This literature review clearly demonstrates that RHA is an effective pozzolan which can contribute to mechanical properties of concrete. The reactivity of RHA varies depending upon its manufacturing process. RHA addition tends to retard the initial setting time and accelerate the final setting time. Additionally, RHA blended concrete can decrease the total porosity of concrete and modifies the pore structure of the cement, mortar, and concrete, and significantly reduce the permeability which allows the influence of harmful ions leading to the deterioration of the concrete matrix. RHA blended concrete can improve the compressive strength. RHA helps in enhancing the early age mechanical properties as well as long-term strength properties of cement concrete. Partial replacement of cement with RHA reduces the water penetration into concrete by capillary action.20% RHA addition is optimum dosage level to achieve maximum strength gain with economy. Finally, this literature search showed that the mechanical properties of concrete are enhanced when the substitution of Portland cement was done by RHA.

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