

Review article:

## Contribution of Rice Husk Ash to the Properties of Mortar and Concrete: A Review

Alireza Naji Givi <sup>1</sup>, Suraya Abdul Rashid <sup>2</sup>, Farah Nora A. Aziz <sup>3</sup>, Mohamad Amran Mohd Salleh <sup>2</sup>

<sup>1</sup> Institute of Advanced Technology, Universiti Putra Malaysia, Malaysia

<sup>2</sup> Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia

<sup>3</sup> Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia

<sup>2</sup> Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia

[najigivi@yahoo.com](mailto:najigivi@yahoo.com)

**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, durability and fresh properties of mortar/concrete. [Journal of American Science 2010;6(3):157-165]. (ISSN: 1545-1003).

**Key words:** Rice husk ash; concrete; mechanical properties of concrete; durability of concrete

### 1. Introduction

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. RHA has been used in lime-pozzolana mixes and could be a suitable partly replacement for Portland cement (Smith et al., 1986; Zhang et al., 1996; Nicole et al., 2000; Sakr 2006; Sata et al., 2007; etc).

RHA concrete is like fly ash/slag concrete with regard to its strength development but with a higher pozzolanic activity it helps the pozzolanic reactions occur at early ages rather than later as is the case with other replacement cementing materials (Molhotra, 1993).

#### 1.1. Properties of rice husk ash

The typical chemical composition and physical properties of RHA are given in Table 1 (Mehta 1992; Bui et al., 2005; Zhang et al., 1996).

#### 1.2. Advantages of using rice husk ash in concrete

The use of RHA in concrete has been associated with the following essential assets:

- Increased compressive and flexural strengths (Zhang et al., 1996; Ismaila 1996; Rodriguez 2005)
- Reduced permeability (Zhang et al., 1996; Ganesan et al., 2007)
- Increased resistance to chemical attack (Chindaprasirt et al., 2007)
- Increased durability (Coutinho 2002)
- Reduced effects of alkali-silica reactivity (ASR) (Nicole et al., 2000)
- Reduced shrinkage due to particle packing, making concrete denser (Habeeb et al., 2009)
- Enhanced workability of concrete (Coutinho 2002; Habeeb et al., 2009; Mahmud et al., 2004)
- Reduced heat gain through the walls of buildings (Lertsatitthanakorn et al., 2009)
- Reduced amount of super plasticizer (Sata et al., 2007)
- Reduced potential for efflorescence due to reduced calcium hydracids (Chindaprasirt et al., 2007)

**Table 1:** Chemical and physical properties of RHA<sup>a</sup> (Wt. %)

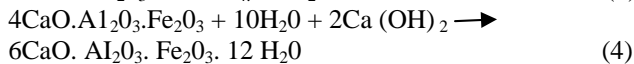
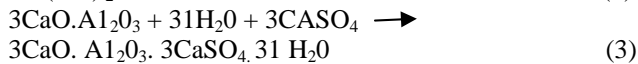
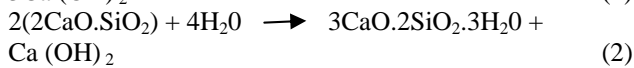
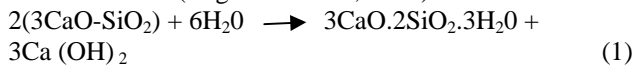
Chemical properties									
Constituent	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	Loss on ignition
Mehta (1992)	87.2	0.15	0.16	0.55	0.35	0.24	1.12	3.68	8.55
Zhang et al. (1996)	87.3	0.15	0.16	0.55	0.35	0.24	1.12	3.68	8.55
Bui et al. (2005)	86.98	0.84	0.73	1.40	0.57	0.11	2.46	-----	5.14
Physical properties									
	Specific gravity (g/cm <sup>3</sup> )			Mean particle size (μm)			Fineness: passing 45μm (%)		
Mehta (1992)	2.06			-----			99		
Zhang et al. (1996)	2.06			-----			99		
Bui et al. (2005)	2.10			7.4			---		

<sup>a</sup>Rice husk ash

## 2. Reaction mechanism

### 2.1. Pozzolanic reaction

A pozzolanic reaction occurs when a siliceous or aluminous material get in touch with calcium hydroxide in the presence of humidity to form compounds exhibiting cementitious properties (Papadakis et al., 2002). In the cement hydration development, the calcium silicate hydrate (C-S-H) and calcium hydroxide (Ca (OH)<sub>2</sub>, or CH) are released within the hydration of two main components of cement namely tricalcium silicate (C3S) and dicalcium silicate (C2S) where C, S represent CaO and SiO<sub>2</sub> (Omotosoa et al., 1995). Hydration of C3S, C2S also C3A and C4AF (A and F symbolize Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>) respectively, is important. Upon wetting, the following reactions occur (Englehard et al., 1995):

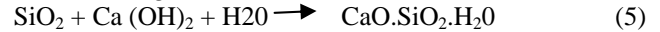


The C-S-H gel generated by the hydration of C3S and C2S in equations (1) and (2) is the main strengthening constituent. Calcium hydroxide and Ettringite (3CaO·3CaSO<sub>4</sub>·31H<sub>2</sub>O, equation 3) that are crystalline hydration products are randomly distributed and form the frame of the gel-like products. Hydration of C4AF (equation 4), consumes calcium hydroxide and generates gel-like products. Excess calcium hydroxide can be detrimental to concrete strength, due to tending the crystalline growth in one direction.

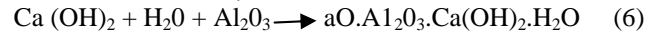
It is known that by adding pozzolanic material to mortar or concrete mix, the pozzolanic reaction will only start when CH is released and pozzolan/CH interaction exist (Villar Cocina et al., 2003). In the pozzolan-lime reaction, OH<sup>-</sup> and Ca<sup>2+</sup> react with the SiO<sub>2</sub> or Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> framework to form calcium silicate hydrate (C-S-H),

calcium aluminate hydrate (C-A-H), and calcium aluminate ferrite hydrate:

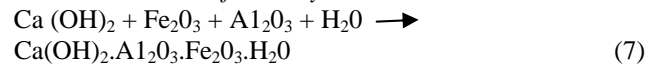
*Tobermorite gel:*



*Calcium aluminate hydrate:*



*Calcium aluminate ferrite hydrate:*



The crystallized compound of C-S-H and C-A-H, which are called cement gel, hardened with age to form a continuous binding matrix with a large surface area and are components responsible for the development of strength in the cement paste (Kassim et al., 2004). Pozzolan-lime reactions are slow, generally starting after one or more weeks (Englehard et al., 1995). The behavior of the delay in pozzolanic reaction will result in more permeable concrete at early ages and gradually becomes denser than plain concrete with time. This behavior is due to two reasons: Firstly, pozzolan particles become the precipitation sites for the early hydration C-S-H and CH that hinders pozzolanic reaction. Secondly, the strong dependency of the breaking down of glass phase on the alkalinity of the pore water which could only attain the high pH after some days of hydration. Pozzolan can partially replace cement in mortar or concrete mix without affecting strength development. The effect of the pozzolanic reaction produces more cement gel (i.e. C-S-H and C-A-H) reducing the pore size, blocks the capillary and produces denser concrete thus making it stronger and more durable.

### 2.2. Pozzolanic reaction of RHA

Data from reaction results between RHA and CH indicates that the amount of CH by 30% RHA in cement paste begins to decrease after 3 days, and by 91 days it reaches nearly zero, while in the control paste, it is considerably enlarged with hydration time (Yu et al., 1999). The addition of pozzolan decreases the formed CH by the pozzolanic reaction to produce more C-S-H gel that can improve the strength and durability of concrete (Aziz

et al., 2004). Amorphous silica that is found in some pozzolanic materials (Habeeb et al., 2009) reacts with lime more eagerly than those of crystalline form (Lin et al., 2003).

The most essential asset of RHA that identifies pozzolanic activity is the amorphous phase substance. The production of rice husk ash can lead to the formation of approximately 85% to 95% by weight of amorphous silica (Della et al., 2002). As a consequence of this characteristic, RHA is an extremely reactive pozzolanic substance appropriate for use in lime-pozzolan mixes and for Portland cement substitution. The reactivity of RHA associated to lime depends on a combination of two factors: namely the non-crystalline silica content and its specific surface (Dakrouy et al., 2008). Cement replacement by rice husk ash accelerates the early hydration of C3S. The increase in the early hydration rate of C3S is attributed to the high specific surface area of the rice husk ash (Feng et al., 2004). This phenomenon specially takes place with fine particles of RHA. Although the small particles of pozzolans are less reactive than Portland cements (Mehta et al., 1990), they produce a large number of nucleation sites for the precipitation of the hydration products by dispersing in cement pastes. Consequently, this mechanism creates the more homogenous and denser paste as for the distribution of the finer pores due to the pozzolanic reactions among the amorphous silica of the mineral addition and the CH (Isaia et al., 2003). Mehta (1987) reported that the finer particles of RHA speed up the reactions and form smaller CH crystals. Berry et al. (1994) revealed that high volume of not completely reacted pozzolanic particles in the cement paste may fill up the voids and enhance density of the paste. Cabrera et al. (2001) have exposed that pozzolanic reaction can be characterized by the Jander diffusion equation based on Fick's parabolic law of diffusion assuming the interface is a contracting sphere. The Jander equation for three dimensional diffusion in a sphere is  $(1 - (1 - x)^{1/3})^2 = (D/r^2)kt$  where  $x$  is the fraction of the sphere that has reacted,  $r$  is initial radius of the starting sphere, and  $k$  is the diffusion constant.

### 2.3. Temperature effect

Exothermal reactions occur during the cement hydration. Hydration heat is an essential aspect that influences the setting and characteristic behavior of Portland cements. This temperature variation, from the initial moment of setting until the hardening of the cement, may cause shrinkage which results in the cracks formation that can be seen in some constructions (Rojas et al., 1993). Cement blended with pozzolanic materials usually has decreased heat of hydration compared to pure cement during the period of C3S hydration (Mostafa et al., 2005). The rate of hydration heat of the cement added with pozzolanic material mainly depends on three factors, C3S hydration, aluminate hydration and pozzolanic reaction (Hewlet, 1998). Likewise, RHA demonstrate increase of

hydration heat behavior (positive values) during the first 12 h. The increase in the hydration heat of cement blended with rice husk ash is due to (1) the acceleration of the early hydration of C3S ascribed to the high specific surface area of the rice husk ash (Feng et al., 2004) and (2) pozzolanic reaction. The comparison between the hydration heats of control sample (plain cement) with samples by partial pozzolanic materials replacement of cement is shown in Figure 1. Figure 1 demonstrates the cement added with RHA has larger enthalpy compared to the base cement (within 36 h). These effects can be summarized as the pozzolanic activity and the dilution effect. The pozzolanic effect is expected to increase the heat output due to the reaction of pozzolans with calcium hydroxide. The dilution effect is expected to decrease the heat output due to the dilution in the main cement compounds (C3S) (Mostafa et al., 2005).

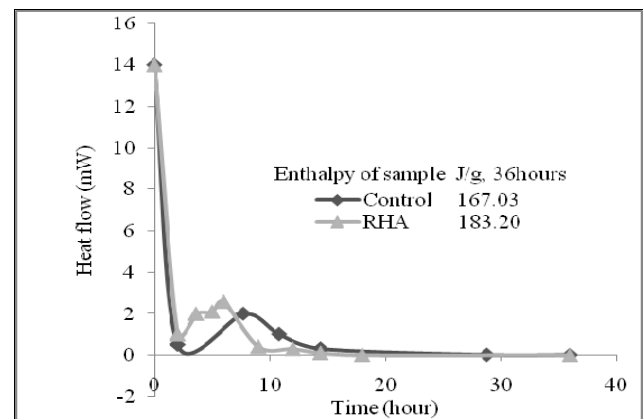


Figure 1. Calorimetric curves from the hydration of cement with 30% by weight of additive (Feng et al., 2004)

## 3. Fresh properties of mortar/concrete

### 3.1. Workability

Usually typical concrete mixtures contain too much mixing water because of two reasons: Firstly, the water demand and workability are significantly influenced by particle size distribution, particle packing effect, and voids present in the solid system. Typical concrete mixtures do not have an optimum particle size distribution, and this accounts for the undesirably high water requirement to achieve certain workability. Secondly, to plasticize a cement paste for achieving an acceptable consistency, much larger amounts of water than necessary for the hydration of cement have to be used because Portland cement particles, due to the presence of electric charge on the surface, tend to form flocs that trap volumes of the mixing water (Mehta 1997, 1999).

Studies by Owen (1979) and Jiang et al. (2000) have indicated that with high volume fly ash concrete mixtures, up to 20% reduction in water requirements can be achieved. However, there is the possibility of water reduction higher than 20% in the presence of RHA. This is because fine particles of rice husk ash get absorbed on the oppositely charged surfaces of cement particles and

prevent them from flocculation. The cement particles are thus effectively dispersed and will trap large amounts of water meaning that the system will have a reduced water requirement to achieve a given consistency. The particle packing effect is also responsible for the reduced water demand in plasticizing the system (Mehta 2004). Laskar et al. (2007) examined the effects of RHA on the rheological behavior of high performance concrete. In their study RHA was used to replace cement on mass basis at rates of 5%, 10%, 15% and 20%. Based on their test results, plastic viscosity increases tremendously with the increase in replacement level of RHA. RHA particles have the highest surface area and fineness and lower reaction ability than cement (Shetty 2004). RHA particles fill into the spaces made by larger cement particle, decrease frictional forces of RHA-ordinary Portland cement (OPC) system and improve packing ability thereby reducing yield stress. The steep increase in plastic viscosity with the replacement levels suggests that fineness and shape of RHA play critical role. The more the fineness the more is the number of contacts among the particles and hence the more is the resistance to flow. In addition, any deviation from a spherical shape implies an increase in plastic viscosity for the same phase volume (Nedhi et al., 1998).

### 3.2. Setting time

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 et al. (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. Dakroury et al. (2008) contended that this may be due to the slower pace of heat induced evaporation of water from the cement-RHA (Figure 2).

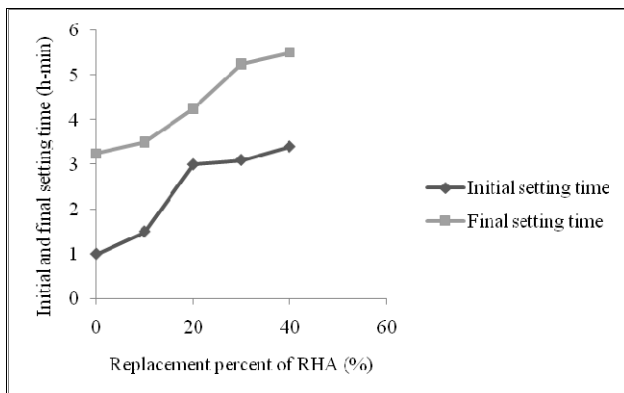


Figure 2. Initial and final setting times of RHA with different replacement percentages (Dakroury et al., 2008)

## 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 3 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.

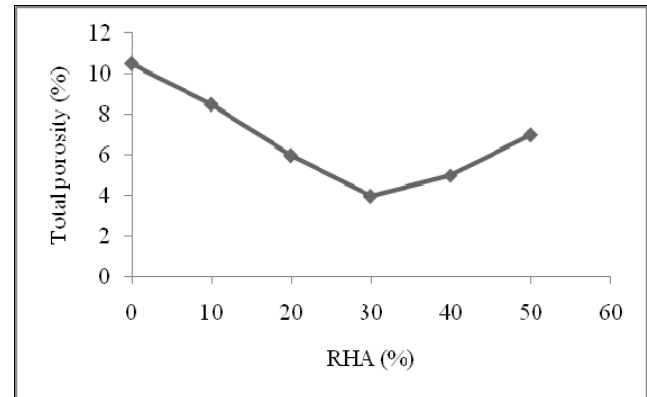


Figure 3. Total porosity of RHA hardened cement paste (Dakroury et al., 2008)

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).

### 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 content and reduced width of the interfacial zone between the paste and the aggregate. The development of more C-S-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.

#### 4.4. Tensile and Flexural Strength

Habeeb et al. (2009) investigated the effects of concrete incorporating 20% RHA as partial replacement of cement at three different particle sizes. In their study the tensile strength of concrete increased systematically with increasing RHA replacement. The results of tensile and flexural strength are shown in Table 2.

Table 2. Mechanical properties of concrete (Habeeb et al., 2009)

Mix	Flexural Strength (MPa)			Tensile Splitting (MPa)		
	Age (days)			Age (days)		
	28	90	180	28	90	180
CM <sup>a</sup>	4.5	4.9	5.1	2.6	2.8	2.9
20F1 <sup>b</sup>	4.9	5.4	5.5	2.9	3.0	3.2
20F2 <sup>c</sup>	5.0	5.4	5.7	3.2	3.3	3.5
20F3 <sup>d</sup>	5.2	5.7	6.1	3.2	3.5	3.9

<sup>a</sup> Control mix

<sup>b</sup> RHA with average particle size of 31.3

<sup>c</sup> RHA with average particle size of 18.3

<sup>d</sup> RHA with average particle size of 11.5

The use of RHA also resulted in significant improvement in flexural strength (De Sensale 2006, Sakr 2006). Habeeb et al. (2009) reported that the coarser RHA particle mixture showed the least improvement in tensile and flexural strength. Zhang et al. (1996) concluded that the addition of RHA to concrete exhibited an increase in the flexural strength and the higher strength was for the finer RHA mixture due to the increased pozzolanic reaction and the packing ability of the RHA fine particles.

## 5. Durability properties of concrete containing RHA

### 5.1. Alkali-silica reaction

Pozzolanic materials are used to prevent or minimize cracking in concrete due to the expansive gel formed by the alkali—silica reaction. Silica fume and RHA have been classified as highly active pozzolans. Hasparyk et al. (2000) studied the expansion of mortar bars made with different levels of cement replacement with rice husk ash (RHA). They reported that incorporation of high reactivity RHA as a partial cement replacement between 12% and 15% may be sufficient to control deleterious expansion due to alkali-silica reaction in concrete, depending on the nature of the aggregate. The mechanism by which RHA may suppress expansion due to alkali-silica reaction appeared to be entrapment of alkalis by the supplementary hydrates and a consequent decrease in the pH of pore solutions because the expansion of the mortar bar is sensitive to the pH level of the solution (Cao et al., 1997).

### 5.2. Chloride-ion diffusion

It is approved that the long term deterioration of concrete and corrosion of reinforcing steel commonly occurs by entrancing the chloride ions into body of concrete structures. It is also well known that the rate of chloride ion diffusion into concrete is related to the permeability and pore size distribution. Concretes made with blended cements generally have lower permeability and more discontinuous pore structure than plain Portland cement concrete. Therefore, the diffusivity of chloride ions in blended cement concretes tends to be lower (Cook 1989). The ability of RHA mixtures to reduce the potential detrimental effects of chloride intrusion into concrete was reported by Anwar et al. (2001). They demonstrated that RHA outperform the specimen containing OPC alone and the levels of total and soluble chloride ions had large reductions as the depth of concrete zones surveyed increased. They also determined that for concretes studied, the first 10 mm of concrete cover provides little barrier to chloride ion penetration and underscores the importance of concrete cover to the reinforcement. On the other hand, all the results of zone 20-30 mm show lower values of total chloride ions content than the limits of reinforcement corrosion threshold. Therefore it can be concluded that there are significant reductions in chloride ions permeability due to replacing the OPC with RHA. As the replacement level of the RHA increases from 10% to 20% by weight the results are affected and low chloride ions contents are obtained. Consequently, they concluded that concrete containing RHA may require less depth of cover to protect the reinforcing steel than those concretes using OPC alone. Moreover, Anwar et al. (2001) contended that the soluble chloride ions contents of zone (20, 30 mm) for RHA concretes are smaller than the limits of threshold for corrosion of steel.

Gaynor (1987) reported that one half or three fourths of penetrated chlorides ions in hardened concrete are soluble in water and free to contribute to corrosion, but some studies demonstrated that the RHA concrete mixes show lower percent than the one reported by Gaynor. For instance, Anwar et al. (2001) have reported that the presence of RHA in concrete shows lower ratio of soluble/total chloride ions content than those of OPC concretes. It is shown that proportions of no ground RHA did not significantly change rapid chloride penetrability classification of concrete. However, using finely ground RHA reduced the rapid chloride penetrability of concrete from a moderate rating to low or very low ratings depending on the type and addition level of RHA (Nehdi et al., 2003). Salas et al. (2009) reported that the reduction in the average pore diameter of cement paste caused by the incorporation of rice husk ash in the mix will effectively reduce the pore sizes, permeability, and diffusivity of chloride ions in concrete.

### 5.3. Sulfate resistance

The role of RHA on the sulfate resistance of heavyweight concrete has been investigated by some researchers. Sakr (2006) immersed the 100mm cubes in a 5% MgSO<sub>4</sub> solution at specific times (1, 3, and 6 months) and found out that the failure occurs in compressive strength of concrete cubes as a result of sulfate attack. The results of this study revealed that concrete mixed with RHA had good resistance to sulfate attack. He concluded that reductions in compressive strength of concrete incorporating 15% of RHA when immersed in a sulfate solution for 28 days was much lower than concrete without RHA and compressive strength was generally increased as the immersion time in the sulfate solution increased. From his reported results it can be concluded that the incorporation of fly ash and ground rice husk ash with Portland cement resulted in a significant improvement in the resistance to attack by 5% sodium sulfate solution. Similar results have been reported by Chindaprasirt et al. (2007). They reported that better dimension stability is obtained with blended cements containing fly ash and RHA. From literature study it can be concluded that despite having higher water demand characteristics, RHA at a dosage of up to 40% cement replacement is very effective in providing sulfate resistance. Also Chindaprasirt et al. (2007) found that fly ash and rice husk ash mortar are of lower pH levels and thus less susceptible to sulfate attack and up to 40% of Portland cement could be replaced with fly ash and RHA to make blended cement mortar with reasonable strength development and good sulfate resistance.

### 5.4. Corrosion resistance and drying shrinkage

Saraswathy et al. (2007) investigated the corrosion performance of concrete made with 0, 5, 10, 15, 20, 25, and 30% RHA as partial replacement of cement. They have monitored the open circuit potential measurements with reference to saturated calomel electrode (SCE) periodically with time as per ASTM C876. From their study it can be observed that the time of cracking were 42, 72, and 74 hours for concretes made with 0, 5, and 10% RHA. However, no cracking was observed for concretes with 15, 20, 25, and 30% RHA ever after 144 hours of exposure. These findings indicate that there was no crack in concretes made with 15, 20, 25 and 30% rice husk even after 144 h of exposure. In contrast, ordinary Portland cement concrete, the specimen was cracked after only 42 h of exposure in 5% NaCl solution. Saraswathy et al.'s (2007) study indicated that the concrete specimens containing 5 and 10% rice husk ash also failed within 72 and 74 hours of exposure. It can be concluded from their study that the replacement of rice husk ash refined the pores and thereby reducing the permeability. Moreover, the study by Saraswathy and her colleagues (2007) suggests that the incorporation of RHA up to 30% replacement level reduces the chloride penetration, decreases permeability, and improves strength and

corrosion resistance properties. Finally, they have recommended the replacement level of up to 25%. In the same vein, Chindapasirt et al. (2008) studied the effect of RHA and fly ash on corrosion resistance of Portland cement concrete and concluded that both fly ash and RHA are very effective in improving the corrosion resistance of mortars indicating better contribution of RHA to corrosion resistance in comparison to that of fly ash.

Similarly, Habeeb et al. (2009) studied the effect of RHA on shrinkage of concrete mixtures containing 20% of RHA at three different average particle sizes. They concluded that the drying shrinkage was significantly affected by RHA fineness. The addition of micro fine particles of RHA to concrete would increase the drying shrinkage. While coarser particles of RHA exhibited lower values than the plain cement based concrete. These contributions can be justified by the pozzolanic and the filler effects.

### Conclusions

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.

RHA blended concrete can decrease the temperature effect that occurs during the cement hydration. RHA blended concrete can improve the workability of concrete compared to OPC. It can also increase the initial and also final setting time of cement pastes. 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 as well as the tensile and flexural strength of concrete. 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. RHA replacement of cement is effective for improving the resistance of concrete to sulfate attack. The sulfate resistance of RHA concrete increases with increasing the RHA replacement level up to 40%. Substitution of RHA has shown to increase the chemical resistance of such mortars over those made with plain Portland cement. Incorporation of RHA as a partial cement replacement between 12% and 15% may be sufficient to control deleterious expansion due to alkali-silica reaction in concrete, depending on the nature of the aggregate. It can be concluded that the use of rice husk ash leads to enhanced resistance to segregation of fresh concrete

compared to a control mixture with Portland cement alone. Also RHA can significantly reduce the mortar-bar expansion. Finally, this literature search showed that the mechanical properties of concrete are enhanced when the substitution of Portland cement was done by RHA.

### Acknowledgements:

Authors wish to thank Mr. Ali Ziyaemehr, faculty of Modern Languages and Communication, Universiti Putra Malaysia for proof reading this paper and providing language assistance.

### Corresponding Author:

Alireza Naji Givi  
Institute of Advanced Technology  
Universiti Putra Malaysia, Malaysia  
E-mail: [najigivi@yahoo.com](mailto:najigivi@yahoo.com)

### References

1. Anwar, M., Miyagawa, T., and Gaweesh, M. 2001. Using rice husk ash as a cement replacement material in concrete. In the Proceedings of the 2001 first international Ecological Building Structure Conference. pp. 671- 684.
2. Aziz, M.A.E., Aleem, S.A.E., Heikal, M. 2005. Didamony H.E. Hydration and durability of sulphate-resisting and slag cement blends in Caron's Lake water. *Cement and Concrete Research*. 35(8): 1592– 1600.
3. Berry, E. Hemmings, R.T., Zhang, M., Cornelius, B.J., and Golden, D.M. 1994. Hydration in High-Volume Fly Ash Concrete Binders. *ACI Mater Journal*. 91(4): 382-389.
4. Bhanumathidas, and N., Mehta, P.K. Concrete mixtures made with ternary blended cements containing fly ash and rice husk ash. In: Malhotra VM, editor. In the Proceedings of the 2004 seventh CANMET International Conference. pp. 379–91.
5. Bui, D.D., Hu, J., and Stroeven, P. 2005. Particle size effect on the strength of rice husk ash blended gap-graded Portland cement concrete. *Cement and Concrete Composites*. 27(3): 357–366.
6. Cabrera, J., and Rojas, M.F. 2001. Mechanism of hydration of the metakaolin-lime-water system. *Cement and Concrete Research*. 31(2): 177–182.
7. Cao, H.T., Bucea, L., Ray, A., and Yozghatlian, S. 1997. The effect of cement composition and pH of environment on sulfate resistance of Portland cements and blended cements. *Cement Concrete Composites*. 19(2): 161–171.
8. Chindapasirt, P., Jaturapitakkul, C., and Sinsiri, T. 2005. Effect of fly ash fineness on compressive strength and pore size of blended cement paste. *Cement and Concrete Composites*. 27(4): 425–428.
9. Chindapasirt, P., and Rukzon, S. 2008. Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. *Construction and Building Materials*. 22(8): 1601–1606.
10. Chindapasirta, P., Kanchandaa, P., Sathonsaowaphaka, A., and Caob, H.T. 2007. Sulfate resistance of blended

- cements containing fly ash and rice husk ash. *Construction and Building Materials*. 21(6): 1356-1361.
11. Cook, D.J., Hinczak, I., Jedy, M., Cao, H.T. The behavior of Slag Cement Concretes in Marine Environment-Chloride Ion Penetration. In the Proceedings of the 1989 Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete 3rd International Conference pp. 1467- 1483.
  12. Cook, D.J., Cao, and H.T. 1987. An Investigation of the Pore Structure in Fly Ash/OPC Blends. In the Proceedings of the 1987 1st International RILEM Congress on From Materials Science to Construction Materials Engineering, Pore Structure and Materials Properties. pp. 69-76.
  13. Cook, J.D. Rice husk ash. 1986. In: Swamy, R.N., editor. *Concrete technology and design. Cement replacement materials*, vol. 3. London: Surrey University Press. pp. 171–95.
  14. Coutinho, J.S. 2002. The combined benefits of CPF and RHA in improving the durability of concrete structures. *Cement and Concrete Composites*. 25(1): 51-59.
  15. Dakroury, A.E., and Gasser, M.S. 2008. Rice husk ash (RHA) as cement admixture for immobilization of liquid radioactive waste at different temperatures. *Journal of Nuclear Materials*. 381(3): 271–277.
  16. De Sensale, G.R. 2006. Strength development of concrete with rice-husk ash. *Cement and Concrete Composites*. 28(2): 158–160.
  17. Della, V.P., Kuhn, I., Hotza, D. 2002. Rice husk ash as an alternate source for active silica production. *Materials Letters*. 57(4): 818–821.
  18. Englehardt, J. D., and Peng, C. 1995. Pozzolanic filtration/solidification of radionuclides in nuclear reactor cooling water. *Waste Management*. 15 (8): 585-592.
  19. Feng, Q., Yamamichi, H., Shoya, M., and Sugita, S. 2004. Study on the pozzolanic properties of rice husk ash by hydrochloric acid pretreatment. *Cement and Concrete Research*. 34(3): 521–526.
  20. Ganesan, K., Rajagopal, K., and Thangavel, K. 2008. Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete. *Construction and Building Materials*. 22(8): 1675–1683.
  21. Gu neyisia, E., O zturanb, T., Gesog lu, M. 2007. Effect of initial curing on chloride ingress and corrosion resistance characteristics of concretes made with plain and blended cements. *Building and Environment*. 42(7): 2676–2685.
  22. Habeeb, G.A., and Fayyadh, M.M. 2009. Rice Husk Ash Concrete: the Effect of RHA Average Particle Size on Mechanical Properties and Drying Shrinkage. *Australian Journal of Basic and Applied Sciences*. 3(3): 1616-1622.
  23. Hewlett, P.C. 1998. *Chemistry of Cement and Concrete*, Wiley, New York. pp. 471–601.
  24. Isaia, G.C., Gastaldini, A.L.G., Moraes, R. 2003. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. *Cement and Concrete Composites*. 25(1): 69–76.
  25. Ismaila, M.S., and Waliuddin, A. M. 1996. Effect of rice husk ash on high strength concrete. *Construction and Building Materials*. 10(7): 521-526.
  26. Ithuralde, G. 1992. Permeability: The Owner’s Viewpoint. In: Mailer Y. ed. *High Performance Concrete From Material to Structure*. London: 276-294.
  27. Jiang, L.H., and Malhotra, V.M. 2000. Reduction in Water Demand of Non Air-Entrained Concrete Incorporating Large Volume of Fly Ash. *Cement and Concrete Research* . 30(11): 1785-1789.
  28. Kassim, K.A., and Chern, K.K. 2004. Lime stabilized Malaysian cohesive soils. *Civil engineering National Journal*. 16(1): 13-23.
  29. Khatri, R.P, Sirivivatnanon, V., and Yang, J.L. 1997. Role of permeability in sulfate attack. *Cement Concrete Research*. 27(8): 1179–89.
  30. Lertsatitthanakorn, C., Atthajariyakul, S., and Soponronnarit, S. 2009. Techno-economical evaluation of a rice husk ash (RHA) based sand–cement block for reducing solar conduction heat gain to a building. *Construction and Building Materials*. 23(1): 364–369.
  31. Lin, R.B., Shih, S.M., and Liu, C.F. 2003. Characteristics and relativities of Ca(OH)<sub>2</sub>/silica fume sorbents for low-temperature flue gas desulfurization. *Chemical Engineering Science*. 58 (16): 3659-3668.
  32. Mahmud, H.B., Majuar, E., Zain, M.F.M., and Hamid, N.B.A.A. 2009. Mechanical Properties and Durability of High Strength Concrete Containing Rice Husk Ash. *Journal of advanced concrete technology*. 79(1): 21-30.
  33. Mahmud, H.B, Hamid, N.B.A.A., and Chia, B.S.1996. High Strength Rice Husk Ash – A preliminary Investigation. In the Proceedings of the 1996 3rd Asia Pacific Conferences on Structural Engineering and Construction. pp. 383-389.
  34. Mehta, P.K. 1992. Rice Husk Ash - A unique supplementary cementing material *Proceeding International Symposium on Advances in Concrete Technology*. Editor. Malhotra,V.M. Athens, Greece, 407-430.
  35. Mehta, P.K. 1987. Studies on the Mechanisms By Which Condensed Silica Fume Improves the Properties of Concrete: Durability Aspect. In: *International Workshop on Condensed Silica Fume in Concrete*, Ottawa, Proceedings. 1-17.
  36. Mehta, P.K. 1990. Aitcin P.C.C. Principles Underlying Production of High-Performance Concrete. *Journal of Cement, Concrete and Aggregates*. 12(2): 70-78.
  37. Mehta, P.K. 2004. High performance, high volume fly ash concrete for sustainable development. In: *Proceedings of the International Workshop on Sustainable Development and Concrete Technology*, University of California, Berkeley, USA.
  38. Mehta, P.K. 1999. Concrete Technology for Sustainable Development. *Concrete International*. 21(11): 47-52.
  39. Mehta, P.K. 1997. Durability: Critical Issues for the Future. *Concrete International*. 19(7): 69–76.



40. Molhotra, V.M. 1993. Fly Ash, Slag, Silica Fume, and Rice Husk Ash in Concrete: A review, *Concrete International*. 15(4): 2-28.
41. Mostafa, N.Y., and Brown, P.W. 2005. Heat of hydration of high reactive pozzolans in blended cements: Isothermal conduction calorimetry. *Thermochimica Acta*. 435(2): 162–167.
42. Nedhi, M., Mindess, S., and Aitcin, P.C. 1998. Rheology of high performance concrete: effect of ultra-fine particles. *Cement and Concrete Research*. 28(5): 687–97.
43. Nehdi, M., Duquette, J., and El Damatty, A. 2003. Performance of rice husk ash produced using a new technology as a mineral admixture in concrete. *Cement and Concrete Research*. 33(8): 1203–1210.
44. Nicole, P.H., Monteiro, P.J.M., and Carasek, H. 2000. Effect of Silica Fume and Rice Husk Ash on Alkali-Silica Reaction. *Materials Journal*. 97(4): 486-492.
45. Omotsoa, O.E., Ivey, D.G., Mikulab, R. 1995. Characterization of chromium doped tricalcium silicate using SEM/EDS, XRD and FTIR. *Journal of Hazardous Materials*. 42(1): 87-102.
46. Owen, P.L. 1979. Fly Ash and Its Usage in Concrete. *Journal of Concrete Society*. 13(7): 21-26.
47. Papadakis, V. G., and Tsimas S. 2002. Supplementary cementing materials in concrete: Part I: efficiency and design. *Cement and Concrete Research*. 32 (10): 1525-1532.
48. Poon, C.S., Wong, Y.L., and Lam, L. 1997. The influence of different curing conditions on the pore structure and related properties of fly ash cement pastes and mortars. *Construction and Building Materials*. 1(7-8): 383–93.
49. Rodrigues, C.S., Ghavami, K., and Stroeven, Piet. 2006. Porosity and water permeability of rice husk ash-blended cement composites reinforced with bamboo pulp. *Journal of Materials Science*. 41(21): 6925-6937.
50. Rodriguez, G.S. 2006. Strength development of concrete with rice-husk ash. *Cement and Concrete Composites*. 28(2): 158-160.
51. Rojas, M.I.S., Luxan, M.P., Frias, M., and Garcia, N. 1993. The influence of different additions on Portland cement hydration heat. *Cement and Concrete Research*. 23(1): 46-54.
52. Sakr, K. 2006. Effects of Silica Fume and Rice Husk Ash on the Properties of Heavy Weight Concrete. *Journal of materials in civil engineering*. 18 (3): 367-376.
53. Salas, A., Delvasto, S., Gutierrez, R.M., and Lange D. 2009. Comparison of two processes for treating rice husk ash for use in high performance concrete. *Cement and Concrete Research*. 39(9): 773–778.
54. Saraswathy, V., and Ha-Won, S. 2007. Corrosion performance of rice husk ash blended concrete. *Construction and Building Materials*. 21 (8): 1779–1784.
55. Sata, V., Jaturapitakkul, C., Kiattikomol, K. 2007. Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete. *Construction and Building Materials*. 21(7): 1589–1598.
56. Shetty, M.S. 2004. *Concrete technology*. New Delhi: S. Chand and Company.
57. Shi, C., Stegemann, J.A. 2000. Acid corrosion resistance of different cementing materials. *Cement and Concrete Research* 30(5): 803–808.
58. Siddique, F. 2008. *Waste materials and by-products in concrete: with 174 tables*. Springer Press.
59. Smith, R.G. and Kamwanja, G.A. 1986. The Use of Rice Husk for Making a Cementitious Material, *Proc. Joint Symposium on the Use of Vegetable Plants and their Fibers as Building Material*, Baghdad.
60. Sugita, S., Yu, Q., Shoya, M., Tsukinaga, Y., and Isojima, Y. 1997. In the Proceedings of the 1997 10th International Congress on the Chemistry of Cement, Gothenburg. pp.85-109.
61. Sugita S., Yu Q., Shoya M., Tsukinaga Y., Isojima Y., *The Concrete Way to Development*, FIP Symposium 1997, Johannesburg, South Africa, 2, 621, 1997.
62. Tashima, M.M., Silva, C.A.R., Akasaki, J.L., and Barbosa, M.B. 2004. The Possibility of Adding the Rice Husk Ash (RHA) to the Concrete. In the Proceedings of the 2004 International RILEM Conference on the Use of Recycled Materials in Building and Structures. pp. 778 – 786.
63. Toutanji, H., Delatte, N., Aggoun, S., Duval, R., and Danson, A. 2004. Effect of Supplementary Cementitious Materials on the Compressive Strength and Durability of Short-Term Cured Concrete. *Cement and Concrete Research*. 34(2): 311-319.
64. Villar-Cocin, E., Valencia-Morales, E., Gonzalez-Rodriguez, R., and Hernandez-Ruiz, J. 2003. Kinetics of the pozzolanic reaction between lime and sugar cane straw ash by electrical conductivity measurement: A kinetic-diffusive model. *Cement and Concrete Research*. 33(4): 517–524.
65. Yu, Q., Sawayama, K., Sugita, S., Shoya, M., and Isojima, Y. 1999. The reaction between rice husk ash and Ca(OH)<sub>2</sub> solution and the nature of its product. *Cement and Concrete Research*. 29(1): 37–43.
66. Zhang, M.H., Lastra, R., and Malhotra, V.M. 1996. Rice-husk ash paste and concrete: Some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste. *Cement and Concrete Research*. 26(6): 963-977.
67. Zhang, M.H. and Mohan, M.V. 1996. High-Performance Concrete Incorporating Rice Husk Ash as a Supplementary Cementing Material. *ACI Materials Journal*. 93(6): 629-636.

**Submission date:** 12/14/2009

**Submission Address:** Marsland Press, P.O. Box 21126, Lansing, Michigan 48909, The United States, 347-321-7172.