Review article:

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

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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, 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[a] (*Wt. %)*

Chemical properties

Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss on ignition
Mehta (1992)	87.2	0.15	016	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^3)	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	---

[a] 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) $_2$, 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_2 (Omotosoa et al., 1995). Hydration of C3S, C2S also C3A and C4AF (A and F symbolize Al_2O_3 and Fe_2O_3) respectively, is important. Upon wetting, the following reactions occur (Englehard et al., 1995):

$$2(3CaO\text{-}SiO_2) + 6H_20 \rightarrow 3CaO.2SiO_2.3H_20 + 3Ca\,(OH)_2 \qquad (1)$$

$$2(2CaO.SiO_2) + 4H_20 \rightarrow 3CaO.2SiO_2.3H_20 + Ca\,(OH)_2 \qquad (2)$$

$$3CaO.A1_20_3 + 31H_20 + 3CASO_4 \rightarrow 3CaO.\ A1_20_3.\ 3CaSO_4.\ 31\ H_20 \qquad (3)$$

$$4CaO.A1_20_3.Fe_20_3 + 10H_20 + 2Ca\,(OH)_2 \rightarrow 6CaO.\ AI_20_3.\ Fe_20_3.\ 12\ H_20 \qquad (4)$$

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 ($3CaO.3CaSO_4.31H_20$, 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^- and Ca^{2+} react with the SiO_2 or $AI_20_3\text{-}SiO_2$ framework to form calcium silicate hydrate (C-S-H), calcium aluminate hydrate (C-A-H), and calcium aluminate ferrite hydrate:

Tobermorite gel:

$$SiO_2 + Ca\,(OH)_2 + H20 \rightarrow CaO.SiO_2.H_20 \qquad (5)$$

Calcium aluminate hydrate:

$$Ca\,(OH)_2 + H_20 + Al_20_3 \rightarrow aO.A1_20_3.Ca(OH)_2.H_2O \qquad (6)$$

Calcium aluminate ferrite hydrate:

$$Ca\,(OH)_2 + Fe_20_3 + A1_20_3 + H_20 \rightarrow Ca(OH)_2.A1_20_3.Fe_20_3.H_20 \qquad (7)$$

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 (Dakroury 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 cites 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).

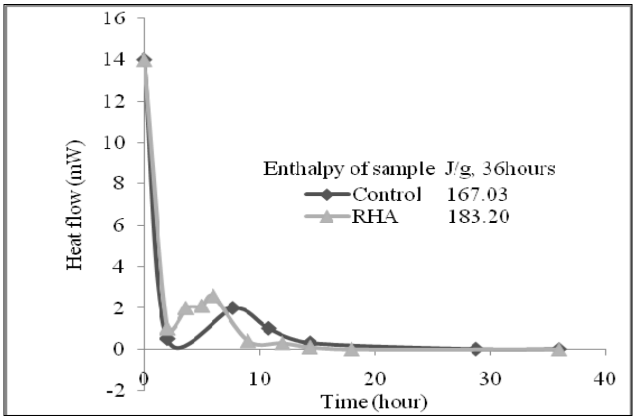

Figure 1. Calorimetric curves from the hydration of cement with 30% by weight of additive (Feng et al., 2004)

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).

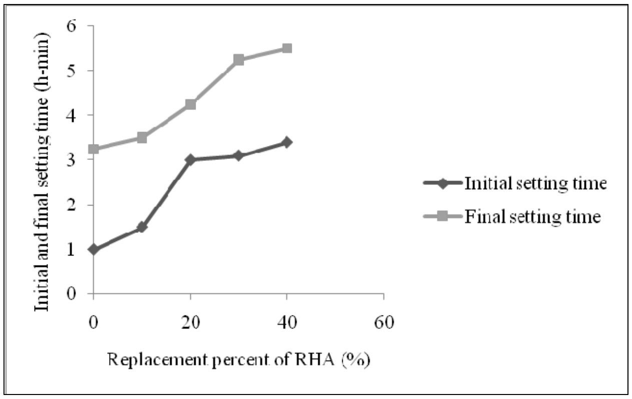

Figure 2. Initial and final setting times of RHA with different replacement percentages (Dakroury et al., 2008)

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.

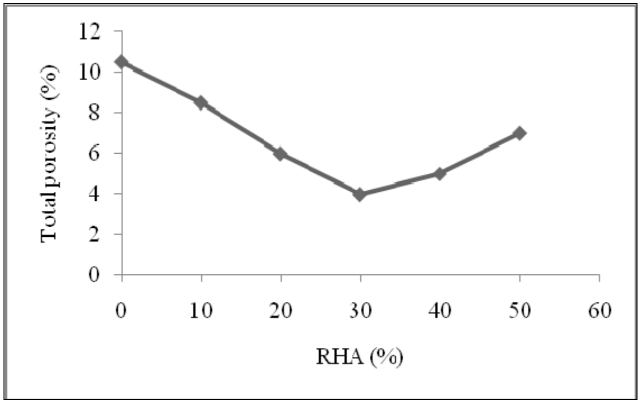

Figure 3. Total porosity of RHA hardened cement paste (Dakroury et al., 2008)

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)

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

[a] Control mix
[b] RHA with average particle size of 31.3
[c] RHA with average particle size of 18.3
[d] 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 clalorides 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% MgSO4 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, Chindaprasirt 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.

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