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Research Article

Utilization of Rice Husk Ash for Sustainable Construction: A Review

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Abstract: Applications of Supplementary Cementitious Materials (SCM) in construction industry are getting priority due to environmental friendly behavior as well as enhanced mechanical and durability properties. Considering the characteristics of SCM, properly burnt and ground Rice Husk Ash (RHA) has significant potential on account of rich reactive silica (SiO_2) compound. When RHA is applied in cementitious system it improves the systems properties by two fold of effects; chemical or pozzlanic effect and physical or filler effect. The reactive silica compound present in RHA reacts with cement hydration products calcium hydroxide ($Ca\ (OH)_2$) and formed secondary C-S-H gel, which is counted as chemical or pozzolanic activity of RHA. The physical or filler effect of RHA is denoted as the proper distribution of finer RHA particles into the cementitious system. This study reviews the advantageous use of RHA for sustainable construction. The aim of this study is to promote the idea of using RHA by elaborating upon their various production processes, different properties, pozzolanic activity and its contribution to the cementitious system.

Keywords: Contribution of RHA, fineness, reactive silica, secondary C-S-H gel, supplementary cementitious materials

INTRODUCTION

Utilization of cement in the production of concrete is popular all over the world. However, production of cement is not only high energy intensive but also emits greenhouse gases (Mehta, 1999). As a result, construction industry is reaching its limiting value in terms of sustainability. Researchers are exploring alternative sources of cementitious materials for future construction considering sustainability. Some industrial by products (fly ash, slag, silica fume) and agricultural wastes (rice husk ash, palm oil fuel ash, sugarcane baggase ash) are produced every day. These materials are associated with cementitious properties. These cementitious materials are named as pozzolans. Rice Husk Ash (RHA) is one of the popular pozzolan. Generally, rice milling industry generates huge amount of rice husk during milling of paddy every year. However, popular use of this husk either used as fuel in the rice mills to produce steam during parboiling process or land filling which causes pollution (Mehta, 1977). On the other hand, RHA contains high amount of silica compound and it is almost 80-85% (Siddique, 2008). Usually, silica presents in RHA in two particular forms: amorphous silica which is chemically active, crystalline silica which is chemically inactive (Della *et al*., 2002). The amorphous form of the silica is the key of pozzolanic activity of RHA. The formation of amorphous silica depends on temperature and duration of burning (Chindaprasirt *et al*., 2007; Zain *et al*., 2011). Only properly burnt and ground RHA is favorable for use as a pozzolanic material because it contains high amount of amorphous silica (Chindaprasirt and Rukzon, 2008). Its fineness and reactivity is significantly improved after proper grinding (Zain *et al*., 2011). Higher fineness and specific surface area important property of RHA to increase pozzolanic and filler activity (Karim *et al*., 2014; Shukla *et al*., 2011; Raman *et al*., 2011; Muthadhi and Kothandaraman, 2010; El-Dakroury and Gasser, 2008; Giaccio *et al*., 2007). Thus, utilization of RHA (an agricultural waste material) in concrete production is very much helpful to reach the goal of the sustainable construction (Serniabat *et al*., 2014). Extensive research has been carried out by the past researchers using RHA as partial replacement of cement. This study illustrates a brief description on various production processes of RHA, favorable conditions for producing reactive RHA, properties of

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RHA, pozzolanic activity of RHA and its contribution in concrete and mortar.

PRODUCTION OF RHA

Various incineration processes were followed by the past researchers for the incineration of raw rice husk to produce RHA and reported in various literatures. Incineration processes of RHA are briefly discussed in the following sections.

Earlier, Loo *et al*. (1984) designed a ferrocement furnace in order to produce RHA. The authors reported that, at first raw rice husk was kept in the incineration furnace for burning and after incineration then it was allowed to cool for 24 h. Finally, they improved the fineness of cool incinerated ash using Los Angeles grinding machine. Because, grinding performance of Los Angeles machine incorporated with 40 mild steel rods of 10 mm diameter and 500 mm in length placed in the rotating drum is better than the conventional ball mills (Zain *et al*., 2011; Raman *et al*., 2011).

Nehdi *et al*. (2003) introduced another technology for the combustion of rice husk using fluidized beds which based on a different technique Torbed reactor as presented in Fig. 1. The Torbed reactor can operatewith gas velocities of 3-12 m/sec. The advantages of this RHA production technology are able to produce smaller RHA particles, more economic and easy to maintain temperature. Torbed reactor initially produced coarser RHA particles, ranges 44-46 μm. After that, this particle size can be reduced to 7 μm using a vibratory ring pulverizer. The authors reported that pozzolanic RHA has very low carbon content and can be obtained at combustion temperatures between 750 and 850°C using this technology.

Habeeb and Mahmud (2010) designed a rice husk incineration furnace having a capacity of 60 kg of raw rice husks as presented in Fig. 2. It has three small openings for ventilation. The design concept of this furnace is almost similar to Loo *et al*. (1984). The authors reported that to produce reactive RHA using this furnace, the burning temperature of rice husk should not exceed 690°C and particle sizes of RHA should less than 11.5 μm for a grinding time 360 min.

Ramezanianpour *et al*. (2009) commenced another type of furnace in order to produce RHA. The detail of furnace reported by the author is shown in Fig. 3. This furnace is capable to produce good quality of rice husk ashes with various un-burnt carbon contents. Because, temperature and rate of burning easily measurable in this furnace. Burning temperature can be measured in this furnace using thermocouples at the fire zone of air inlet and outlet. The authors produced RHA at various temperatures rate such as 550, 600, 650, 700 and 750°C with duration of burning time 30, 60 and 90 min, respectively. Finally, they suggested that RHA produced at 650°C for 60 min can be considered to be non-crystalline RHA and also save the RHA production time.

Zain *et al*. (2011) developed a simple ferrocement furnace located at Structural and Concrete Lab in National University of Malaysia (UKM), Malaysia as shown in Fig. 4. It has two parts: one is ferrocement cylinder and another one is steel cylinder. The dimensions of the ferrocement cylinder are 1030 mm diameter, 1510 mm height and wall thickness is 60 mm. The produced heat during combustion is trapped by the ferrocement cylinder as well as preventing it from spreading into the air. The steel cylinder has dimensions of 760 mm diameter, 1090 mm height and thickness is 5 mm which acts as a container for burning of rice husk. In order to supply sufficient air during combustion air ducts also designed, whose dimensions are 100 mm diameter, 200 mm height and 100 mm thickness. The combustion temperature can be controlled by providing air through air ducts using electric fans. The surfaces of the steel cylinder and air ducts are porous with small holes of 5 mm diameter. The authors suggested that furnace of UKM is able to produce amorphous silica with the constant furnace combustion temperature at 500-700°C for 2 h. Although grinding for 30 min produced good result, grinding for 60 min or more is recommended by the authors for achieving standard fineness of RHA.

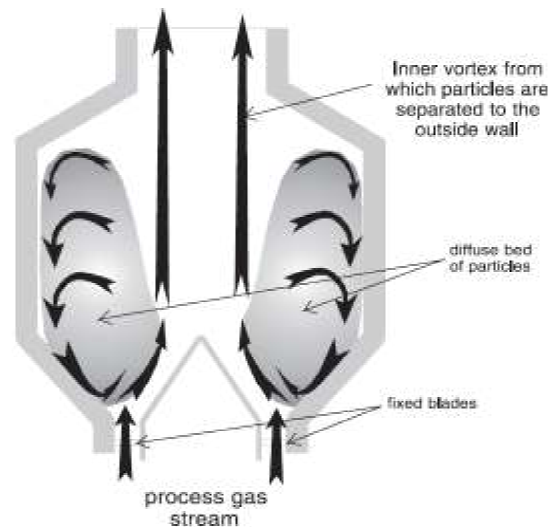

Fig. 1: Illustration of the cyclonic motion of rice husk particles in a torbed reactor (Nehdi *et al*., 2003)

Fig. 2: The ferrocement furnace (Habeeb and Mahmud, 2010)

Van *et al*. (2013) furnished a modified incinerator for the incineration of rice husk. The details of incinerator as presented in Fig. 5. This incinerator can produce about 20-25 kg of RHA within a burning period of two days in a single batch. This incineration process also able to produce RHA consists of high

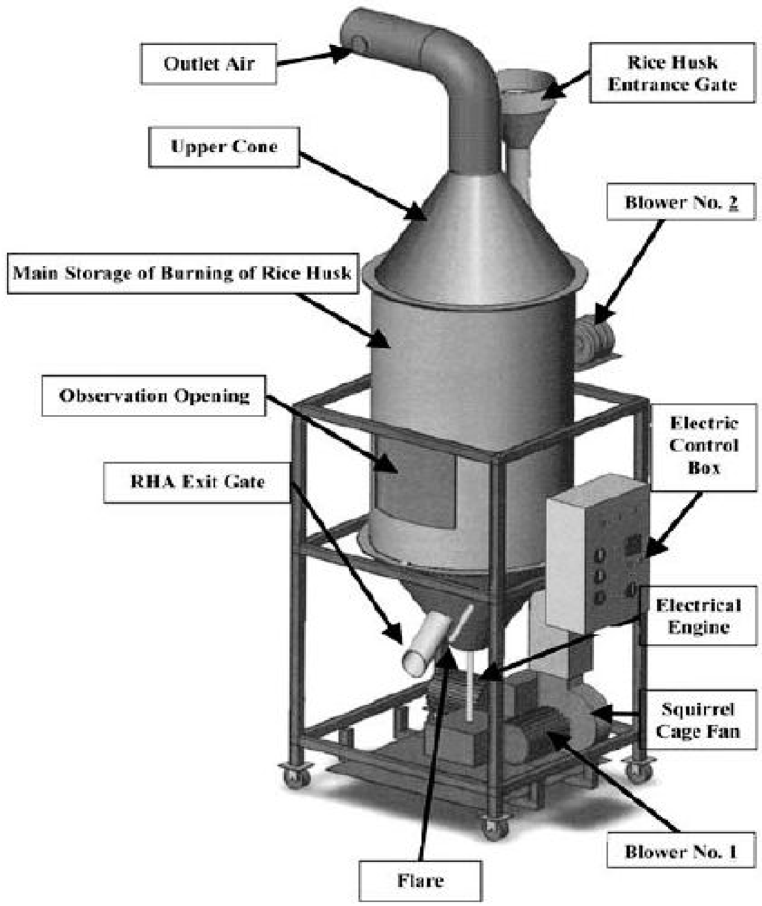

Fig. 3: Schematic shape of rice husk ash furnace (Ramezanianpour *et al*., 2009)

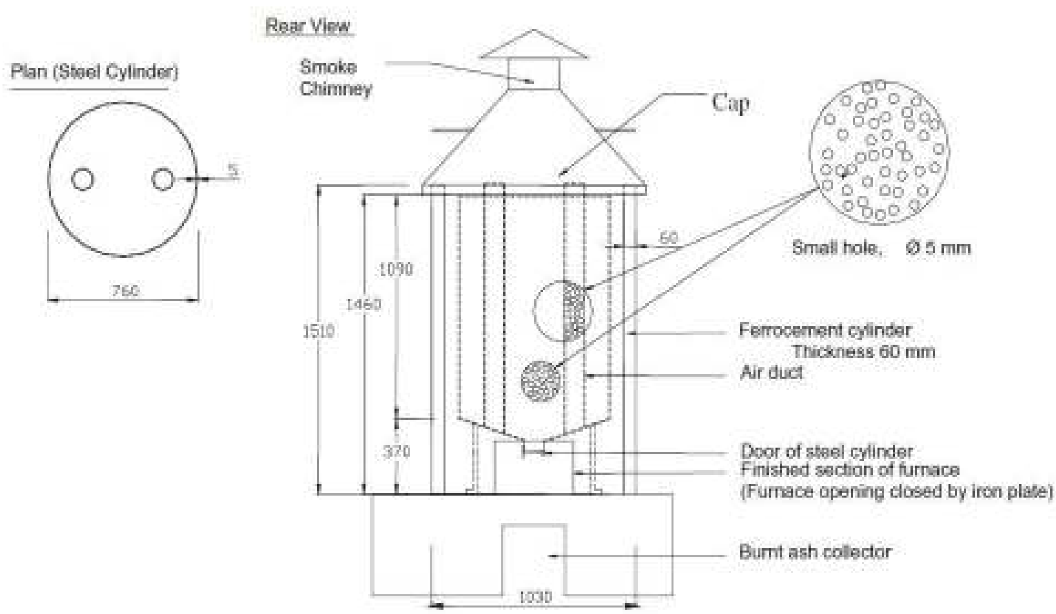

Fig. 4: Furnace at UKM for burning rice husk (Zain *et al*., 2011)

amount amorphous silica content about 97.4%. In order to produce active RHA, the authors ground RHA in a batch ball mill with diameter of 270 mm, length of 400 mm and rotation speed of 67 rpm for different grinding

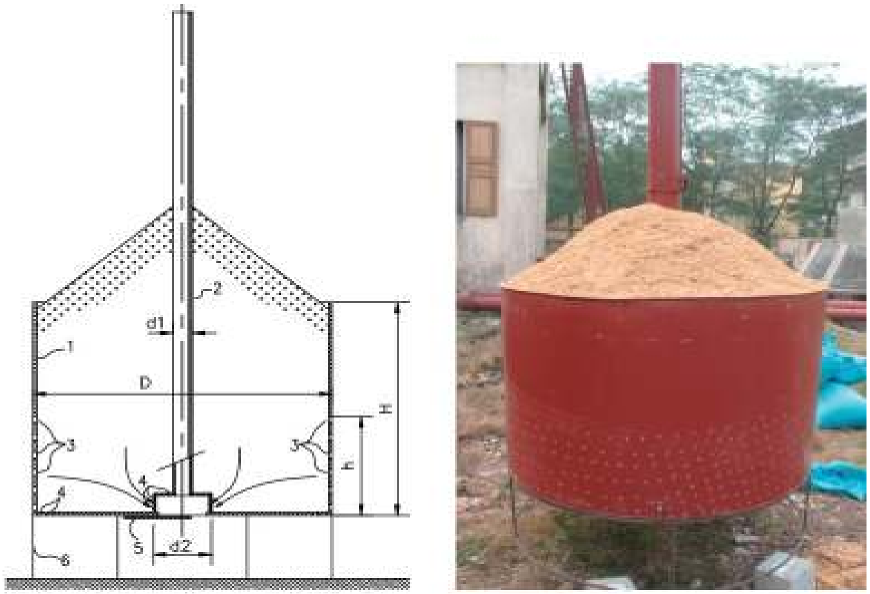

Fig. 5: Modified incinerator developed from the Sugita's batch method
1: Drum; 2: Chimney; 3 and 4: Holes; 5: Adjusting door; 6: Steel frame (Van *et al*., 2013)

Table 1: Typical physical properties of RHA

Parameters	Karim *et al.* (2014)	Shukla *et al.* (2011)	Raman *et al.* (2011)	Muthadhi and Kothandaraman (2010)	El Dakroury and Gasser (2008)	Giaccio *et al.* (2007)
Specific gravity	2.05	2.06	2.030	2.19	2.06	2.06
Fineness passing through 45-µm sieve (%)	96.70%	96%	-	99.50%	99%	-
Specific surface area (N_2 absorption) (m^2/kg)	-	-	23.455	-	38.90	28.80

Table 2: Typical chemical properties of RHA

Compounds	Van *et al*. (2013)	Memon *et al.* (2011)	Cordeiro *et al.* (2011)	Zerbino *et al.* (2011)	Gastaldini *et al.* (2010)
Silicon dioxide (SiO_2)	87.40	77.190	82.6	94.84	90
Aluminium oxide (Al_2O_3)	0.40	6.190	0.4	0.39	0.28
Ferric oxide (Fe_2O_3)	0.30	3.650	0.5	0.54	0.14
Calcium oxide (CaO)	0.90	2.880	0.8	1.32	0.45
Magnesium oxide (MgO)	0.60	1.455	0.7	0.40	0.28
Sodium oxide (Na_2O)	0.04	-	0.1	0.11	0.08
Potassium oxide (K_2O)	3.39	1.815	1.8	1.45	1.55
Manganese oxide (MnO)	-	0.135	0.3	-	-
Sulfur trioxide (SO_3)	0.40	-	-	0.01	0.02
Loss on ignition (LOI)	4.60	5.429	11.9	0.25	5

periods. In each batch, the internal volume was partially filled with 21 kg steel balls (7 kg of 12.5 mm, 8.4 kg of 22 mm and 5.6 kg of 28 mm diameter) and 1 kg RHA.

Form discussions related to production process of RHA, it is noticed that temperature control and grinding after burning process are the most significant to produce highly reactive RHA. Only properly burnt and ground RHA is suitable for the reactive amorphous silica content. Higher burning temperature may produce some crystalline formation of silica (Ismail and Waliuddin, 1996). If RHA is produced with some crystalline silica due to higher burning temperature, then reactive RHA could be obtained by fine grinding (Rodrigues *et al*., 2006). Most of the researchers suggested to maintain temperature below 700°C during incineration of rice husk. Madandoust *et al*. (2011) also reported that silica content of the ash transforms into non-crystalline or amorphous silica while rice husk is burning between 550 and 700°C temperature for 1 h. Therefore, it is clear that temperature ranges form 550-650°C and using proper grinding media after incineration of raw rice husk can produce higher fineness and reactive silica content RHA.

PROPERTIES OF RHA

Typical physical and chemical properties of RHA obtained from various literatures are presented in Table 1 and 2. Generally, mean particle size of properly ground RHA is less than cement particles. Particles size of RHA normally ranges 5 to 10 µm. The ground RHA particles indicate higher fineness, more than 95% passing through 45 µ sieve. When RHA is applied in cementitious system, it contributes to the hardened properties of concrete or mortar by filling or densification of microstructure due to higher fineness (Khan *et al*., 2014a; Shukla *et al*., 2011; Raman *et al*., 2011; El-Dakroury and Gasser, 2008). Higher specific surface is another important property of RHA which contributes in both pozzolanic and filler action (El-Dakroury and Gasser, 2008; Giaccio *et al*., 2007). Pozzolanic effect is governed by the pozzolanic reaction of RHA. Pozzolanic reaction of RHA depends on reactive amorphous silica compound that present in properly burnt and ground RHA. When this amorphous silica gets contact with hydration product of cement then it produces secondary binder (Yu *et al*., 1999; Feng *et al*., 2004; Jamil *et al*., 2013; Khan *et al*., 2014b). Table 2 indicates that RHA contains high silica compound and it varies 75-97%. The amount of active silica present in RHA depends on proper burning and grinding. Total percentage of major oxide ($SiO_2 + AlO_2 + Fe_2O_3$) is over 70% which satisfies ASTM C618 standard for class F pozzolan. The lower loss on ignition values of RHA indicates less amount of carbon content, not more than 10%. Sometimes uncontrolled burning produced crystalline silica which unable to produce pozzolanic reaction, however this inactive silica can take part in filler action. Therefore, mainly reactive silica compound, large specific surface area and higher fineness of RHA makes it suitable to use as partial replacement of cement.

POZZOLANIC ACTIVITY OF RHA

RHA is a highly reactive pozzolanic material; it contains non-crystalline silica and high specific surface area that are accountable for its high pozzolanic reactivity. The reactive non-crystalline or amorphous silica present in RHA react with hydration product of cement and produces an additional C-S-H gel (Yu *et al*., 1999; Feng *et al*., 2004). As a result the quality of RHA mixed concrete or mortar is improved significantly. Usually, pozzolanic activity of RHA depends on:

- Presence of amorphous silica
- Fineness of RHA particles
- Its specific surface area (Zain *et al*., 2011; Shukla *et al*., 2011; Raman *et al*., 2011)

The pozzolanic reaction can be satisfactorily described by the Jander diffusion equation that is based on Fick's parabolic law of diffusion (Cabrera and Rojas, 2001). 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.

Presently, Jamil *et al*. (2013) reported a theoretical estimation for the maximum percentages replacement of RHA based on pozzolanic reaction between RHA and cement hydration product calcium hydroxide ($Ca(OH)_2$). The author mentioned that, anhydrous calcium silicates (C_3S and C_2S) present in cement only involves to produce $Ca(OH)_2$.

The hydration of cement (C_3S and C_2S) follows the equations (Metha and Monteiro, 2006):

$$2\ (3CaO.SiO_2) + 6\ H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca\ (OH)_2$$

$$2\ (CaO.SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca\ (OH)_2$$

It is observed that hydration of cement (C_3S and C_2S) produces calcium hydroxide ($Ca(OH)_2$).

Based on chemical equilibrium, pozzolanic reaction between silica and $Ca(OH)_2$ in the presence of water is as follows (Jamil *et al*., 2013; Yu *et al*., 1999):

$$2SiO_2 + 3Ca\ (OH)_2 + H_2O \rightarrow 2Ca_{1.5}\ SiO_{3.5}\ 2H_2O$$

CONTRIBUTION OF RHA IN CEMENTITIOUS SYSTEM

Concrete or mortar incorporating with RHA shows higher strength and durability than concrete without RHA. Strength of RHA blended concrete depends on several factors such as curing period, water to cement ratio, cement replacement level and quality of ash. Early ages strength development of RHA blended concrete is not significant while compared to the longer ages curing. This may due to the formation of secondary C-S-H gel at later ages that provides a homogeneous and compacted microstructure. Water to cement ratio also plays important role in the strength development of RHA blended concrete. Gastaldini *et al*. (2010) found the highest compressive strength for 20% RHA mixed concrete at water to cement ratio 0.35 while compared strengths for other water to cement ratios. De Sensale (2006) reported that performance of controlled incinerated RHA blended concrete much better than residual RHA mixed concrete. According to Habeeb and Mahmud (2010) study, strength of RHA blended concrete increases with the increment of RHA percentages. The author reported that available silica from the addition of RHA reacted with that portion of C-H released from the hydration process and thus, the C-S-H released from the pozzolanic reaction. As a result, greater portion of RHA may produce greater amount of C-S-H. Saraswathy and Song (2007) reported that up to 30% replacement level of RHA, there is no decrease in compressive strength observed when compared to control concrete after 7 to 28 days of curing. According to Isaia *et al*. (2003) study, 20%

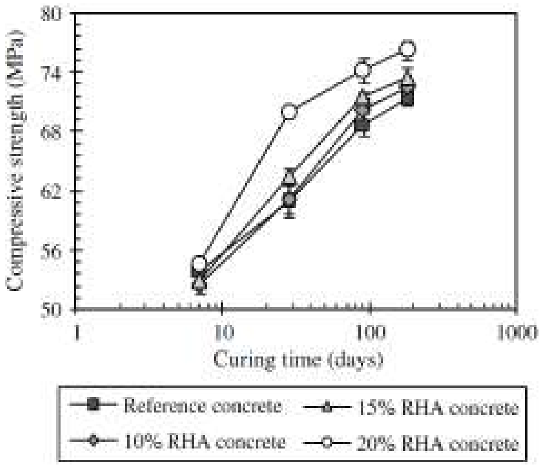

Fig. 6: Evolution of compressive strength of concretes against curing time (Cordeiro *et al*., 2009)

RHA mixed concrete showed higher strength than control concrete at both 28 and 90 days curing period. Figure 6 shows the compressive strength development concrete containing various percentages of RHA which is a finding of Cordeiro *et al*. (2009). It is seen that 20% RHA concrete shows significant strength at all ages. From above discussions, it is clear that strength of RHA associated concrete increases up to 30% replacement of cement. Mortar incorporating with RHA also shows similar manner. Chindaprasirt *et al*. (2008) reported that strength 40% RHA mixed concrete is higher than control mortar after 90 days of curing. Ganesan *et al*. (2008) concluded that, cement can be replaced up to 30% by RHA without any adverse effect on strength and durability properties of mortar. Tensile strength of RHA mixed concrete and mortar is also better than control concrete as shown in Fig. 7 which is obtained from Madandoust *et al*. (2011). However, early tensile strength of RHA mixed concrete is not good enough when it is compared to control concrete.

Therefore, cement can be replaced up to 30% by RHA without effecting strength of concrete and mortar. The difference of strength between RHA mixed mortar and control mortar is much significant at long term ages.

The application of RHA in concrete brings the following advantages:

- Increases compressive strength (Saraswathy and Song, 2007; Habeeb and Mahmud, 2010; Gastaldini *et al*., 2010; Isaia *et al*., 2003), flexural strength (Ismail and Waliuddin, 1996; Coutinho, 2003; Karim *et al*., 2013), split tensile strength of concrete (Madandoust *et al*., 2011; De Sensale, 2006; Habeeb and Fayyadh, 2009)
- Reduces cost (Memon *et al*., 2011)
- Increases workability ((Habeeb and Fayyadh, 2009; Coutinho, 2003; Mahmud *et al*., 2004; Givi *et al*., 2010)
- Increases resistance to chemical attack (Chindaprasirt *et al*., 2007; Chindaprasirt *et al*., 2008)
- Reduces effect of alkali-silica reactivity (Nicole *et al*., 2000)
- Reduces shrinkage packing or densification of particles in concrete (Habeeb and Fayyadh, 2009)
- Reduces heat gain through the walls of buildings (Lertsatitthanakorn *et al*., 2009)
- Reduces amount of super plasticizer (Sata *et al*., 2007)
- Reduces potential for efflorescence due to reduced calcium hydroxide (Chindaprasirt *et al*., 2007)
- Reduces permeability (Ganesan *et al*., 2008; Zhang and Mohan, 1996; Jaya *et al*., 2011)
- Improves consistency of OPC-RHA blended paste environmental management as well as sustainable with increasing amount of RHA percentage (Karim *et al*., 2013; Singh *et al*., 2002)
- Reduces material cost and emission of CO_2 due to less cement utilization (Chindaprasirt *et al*., 2007; Memon *et al*., 2011)
- Increases compressive strength and decreases leach ability (El-Dakroury and Gasser, 2008)

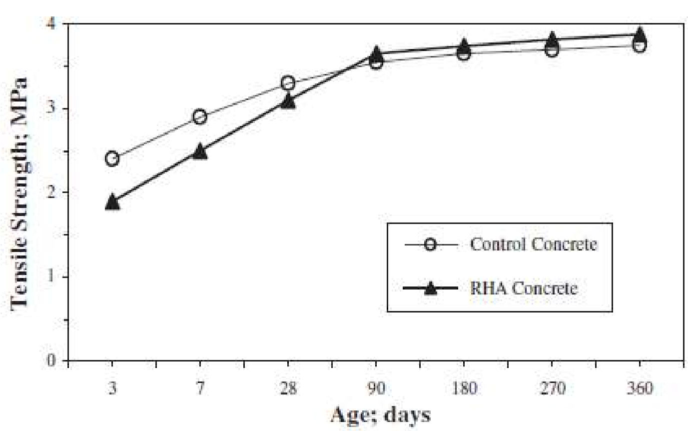

Fig. 7: Development of tensile strength with age (Madandoust *et al*., 2011)

- Reduces the plasticity of soil (Basha *et al*., 2005)
- RHA reduces porosity of concrete (Chindaprasirt and Rukzon, 2008, 2009; Zhang *et al*., 1996)
- Electrical resistivity (Gastaldini *et al*., 2009) and ultrasonic pulse velocity of concrete increased (Safiuddin *et al*., 2010) and reduced corrosion (Saraswathy and Song, 2007; Tuan *et al*., 2011)
- Decreased air permeability (De Sensale, 2006)
- RHA mixed concrete showed better bond strength as compared to normal concrete (Saraswathy and Song, 2007; Sakr, 2006)
- Produced self-compacting concrete and ultra-high performance concrete (Memon *et al*., 2011; Tuan *et al*., 2011)

CONCLUSION AND RECOMMENDATIONS

This literature review deals with the production procedure of RHA as well as its effect on concrete and mortar properties. It is noticed that in order to get desired properties RHA, controlled burning and well grinding are essential. It is difficult to get all ash in reactive form of amorphous silica since some of ash converted to crystalline form. Incorporating incinerated rice husk ash has a significant effect on the properties of concrete or mortar. Compressive strength of mortar and concrete increased when cement is partially replaced by RHA. This is due to reactive amorphous silica content that contains in RHA. This active silica reacts with hydration product of cement and produced secondary C-S-H gel, which brings a significant change in microstructure. Finer RHA fills pore or voids into the microstructure of concrete and mortar. Finally, this literature has been reported some recommendations for future research in this area. These include the following:

- Need to develop higher capacity of RHA burning furnace for commercial or industrial purpose.
- Need to elaborate cost analysis between concrete with or without RHA.
- Need to test strength of concrete that contains higher percentages of RHA.

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REFERENCES

Basha, E.A., R. Hashim, H.B. Mahmud and A.S. Muntohar, 2005. Stabilization of residual soil with rice husk ash and cement. Constr. Build. Mater., 19(6): 448-453.

Cabrera, J. and M.F. Rojas, 2001.Mechanism of hydration of the metakaolin-lime-water system. Cement Concrete Res., 31(2): 177-182.

Chindaprasirt, P. and S. Rukzon, 2008. Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. Constr. Build. Mater., 22(8): 1601-1606.

Chindaprasirt, P. and S. Rukzon, 2009. Pore structure changes of blended cement pastes containing fly ash, rice husk ash and palm oil fuel ash caused by carbonation. J. Mater. Civil Eng., 21(11): 666-671.

Chindaprasirt, P., S. Rukzon and V. Sirivivatnanon, 2008. Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice hush ash and fly ash. Constr. Build. Mater., 22(5): 932-938.

Chindaprasirt, P., P. Kanchanda, A. Sathonsaowaphak and H.T. Cao, 2007. Sulfate resistance of blended cements containing fly ash and rice husk ash. Constr. Build. Mater., 21: 1356-1361.

Cordeiro, G.C., R.D.T. Filho and E.M.R. Fairbairn, 2009. Use of ultrafine rice husk ash with high-carbon content as pozzolan in high performance concrete. Mater. Struct., 42: 983-992.

Cordeiro, G.C., R.D.T. Filho, L.M. Tavares, E.M.R. Fairbairn and S. Hempel, 2011. Influence of particle size and specific surface area on the pozzolanic activity of residual rice husk ash. Cement Concrete Comp., 33(5): 529-534.

Coutinho, J., 2003. The combined benefits of CPF and RHA in improving the durability of concrete structures. Cement Concrete Comp., 25(1): 51-59.

De Sensale, G.R., 2006. Strength development of concrete with rice-husk ash. Cement Concrete Comp., 28(2): 158-160.

Della, V.P., L. Kuhn and D. Hotza, 2002. Rice husk ash as an alternative source for active silica production. Mater. Lett., 57: 818-821.

El-Dakroury, A. and M.S. Gasser, 2008. Rice Husk Ash (RHA) as cement admixture for immobilization of liquid radioactive waste at different temperatures. J. Nucl. Mater., 381(3): 271-277.

Feng, Q., H. Yamamichi, M. Shoya and S. Sugita, 2004. Study on the pozzolanic properties of rice husk ash by hydrochloric acid pretreatment. Cement Concrete Res., 34(3): 521-526.

Ganesan, K., K. Rajagopal and K. Thangavel, 2008. Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete. Constr. Build. Mater., 22(8): 1675-1683.

Gastaldini, A.L.G., G.C. Isaia, T.F. Hoppe, F. Missau and A.P. Saciloto, 2009. Influence of the use of rice husk ash on the electrical resistivity of concrete: A technical and economic feasibility study. Constr. Build. Mater., 22(11): 3411-3419.

Gastaldini, A.L.G., G.C. Isaia, A.P. Saciloto, F. Missau and T.F. Hoppe, 2010. Influence of curing time on the chloride penetration resistance of concrete containing rice husk ash: A technical and economical feasibility study. Cement Concrete Comp., 32(10): 783-793.

Giaccio, G., G.R. de Sensale and R. Zerbino, 2007. Failure mechanism of normal and high-strength concrete with rice-husk ash. Cement Concrete Comp., 29(7): 566-574.

Givi, A.N., Rashid, S.A., Aziz F.N.A. and Salleh, M.A.M. 2010. Assessment of the effects of rice husk ash particle size on strength, permeability and workability of binary blended concrete. Constr. Build. Mater., 24: 2145-2150.

Habeeb, G.A. and M.M. Fayyadh, 2009. Rice husk ash concrete: The effect of RHA average particle size on mechanical properties and drying shrinkage. Austr. J. Basic Appl. Sci., 3(3): 1616-1622.

Habeeb, G.A. and H.B. Mahmud, 2010. Study on properties of rice husk ash and its use as cement replacement material. Mater. Res., 13(2): 185-190.

Isaia, G.C., A.L.G. Gastaldini and R. Moraes, 2003. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cement Concrete Comp., 25(1): 69-76.

Ismail, M.S. and A.M. Waliuddin, 1996. Effect of rice husk ash on high strength concrete. Constr. Build. Mater., 10: 521-526.

Jamil, M., A.B.M.A. Kaish, S.N. Raman and M.F.M. Zain, 2013. Pozzolanic contribution of rice husk ash in cementitious system. Constr. Build. Mater., 47: 588-593.

Jaya, R.P., B.H.A. Bakar, M.A.M. Johari and M.H.W. Ibrahim, 2011. Strength and permeability properties of concrete containing rice husk ash with different grinding time. Cent. Eur. J. Eng., 1(1): 103-112.

Karim, M.R., M.F.M. Zain, M. Jamil and F.C. Lai, 2013. Fabrication of a non-cement composite binder by using slag, palm oil fuel ash and rice husk ash with sodium hydroxide as an activator. Constr. Build. Mater., 49: 894-902.

Karim, M.R., M.M. Hossain, M.N.N. Khan, M.F.M. Zain, M. Jamil and F.C. Lai, 2014. On the utilization of pozzolanic wastes as an alternative resource of cement. Materials, 7: 7809-7827.

Khan, M.N.N., M. Jamil, M.R. Karim and M.F.M. Zain, 2014a. Strength and durability of mortar and concrete containing rice husk ash: A review. World Appl. Sci. J., 32(5): 752-765.

Khan, M.N.N., M. Jamil, A.B.M.A. Kaish and M.F.M. Zain, 2014b. An overview on manufacturing of rice husk ash as supplementary cementitious material. Aust. J. Basic Appl. Sci., 8(19): 176-181.

Lertsatitthanakorn, C., S. Atthajariyakul and S. Soponronnarit, 2009. Techno-economical evaluation of a Rice Husk Ash (RHA) based sand-cement block for reducing solar conduction heat gain to a building. Constr. Build. Mater., 23(1): 364-369.

Loo, Y.C., P. Nimityongskul and P. Karasudhi, 1984. Economical rice husk-ash concrete. Build. Res. Pract., 12(4): 233-238.

Madandoust, R., M.M. Ranjbar, H.A. Moghadam and S.Y. Mousavi, 2011. Mechanical properties and durability assessment of rice huskash concrete. Biosyst. Eng., 110: 144-152.

Mahmud, H.B., E. Majuar, M.F.M. Zain and N.B.A.A. Hamid, 2004. Mechanical properties and durability of high strength concrete containing rice husk ash. Am. Concrete Inst., 221: 751-766.

Mehta, P.K., 1977. Properties of blended cements made from rice husk ash. J. Am. Concr. Inst., 74(9): 440-442.

Mehta, P.K., 1999. Concrete technology for sustainable development. Concrete Int., 21(11): 47-53.

Memon, S.A., M.A. Shaikh and H. Akbar, 2011. Utilization of rice husk ash as viscosity modifying agent in self compacting concrete. Constr. Build. Mater., 25(2): 1044-1048.

Metha, P.K. and P.J.M. Monteiro, 2006. Concrete Microstructures Properties and Materials. 3rd Edn., McGraw Hill, New York.

Muthadhi, A. and S. Kothandaraman, 2010. Optimum production conditions for reactive rice husk ash. Mater. Struct., 43(9): 1303-1315.

Nehdi, M., J. Duquette and A. El Damatty, 2003. Performance of rice husk ashproduced using a new technology as amineral admixture in concrete. Cement Concrete Res., 33(8): 1203-1210.

Nicole, P.H., P.J.M. Monteiro and H. Carasek, 2000. Effect of silica fume and rice husk ash on alkali-silica reaction. Mater. J., 97(4): 486-492.

Raman, S.N., T. Ngo, P. Mendis and H.B. Mahmud, 2011. High-strength rice husk ash concrete incorporating quarry dust as a partial substitute for sand. Constr. Build. Mater., 25(7): 3123-3130.

Ramezanianpour, A.A., K.M. Mahdi and G. Ahmadibeni, 2009. The effect of rice husk ash on mechanical properties and durability of sustainable concretes. Int. J. Civil Eng., 7(2): 83-91.

Rodrigues, C.S., K. Ghavami and P. Stroeven, 2006. Porosity and water permeability of rice husk ash-blended cement composites reinforced with bamboo pulp. J. Mater. Sci., 41(21): 6925-6937.

Safiuddin, M., J. West and K.A. Soudki, 2010. Hardened properties of self-consolidating high performance concrete including rice husk ash. Cement Concrete Comp., 32(9): 708-717.

Sakr, K., 2006. Effects of silica fume and rice husk ash on the properties of heavy weight concrete. J. Mater. Civil Eng., 18(3): 367-376.

Saraswathy, V. and H. Song, 2007. Corrosion performance of rice husk ash blended concrete. Constr. Build. Mater., 21(8): 1779-1784.

Sata, V., C. Jaturapitakkul and K. Kiattikomol, 2007. Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete. Constr. Build. Mater., 21(7): 1589-1598.

Serniabat, T.S., M.N.N. Khan and M.F.M. Zain, 2014. Use of waste glass as coarse aggregate in concrete: A possibility towards sustainable building construction. World Acad. Sci. Eng. Technol., 8(10): 1007-1010.

Shukla, A., C.K. Singh and A.K. Sharma, 2011. Study of the properties of concrete by partial replacement of ordinary Portland cement by rice husk ash. Int. J. Earth Sci. Eng., 4(06): 965-968

Siddique, R., 2008. Waste Materials and By-products in Concrete. Springer Press, Berlin.

Singh, N.B., V.D. Singh, R. Sarita and C. Shivani, 2002. Effect of lignosulfonate, calcium chloride and their mixture on the hydration of RHA-blended Portland cement. Cement Concrete Res., 32(3): 387-392.

Tuan, N.V., G. Ye, K. Breugel, A.L.A. Fraaij and D.D. Bui, 2011. The study of using rice husk ash to produce ultra high performance concrete. Constr. Build. Mater., 25(4): 2030-2035.

Van, V.T.A., C. Robler, D.D. Bui and H.M. Ludwig, 2013. Mesoporous structure and pozzolanic reactivity of rice husk ash in cementitious system. Constr. Build. Mater., 43: 208-216.

Yu, Q., K. Sawayama, S. Sugita, M. Shoya and Y. Isojima, 1999. The reaction between rice husk ash and Ca (OH) 2 solution and the nature of its product. Cement Concrete Res., 29(1): 37-43.

Zain, M.F.M., M.N. Islam, F. Mahmud and M. Jamil, 2011. Production of rice husk ash for use in concrete as a supplementary cementitious material. Constr. Build. Mater., 25(2): 798-805.

Zerbino, R., G. Giaccio and G.C. Isaia, 2011. Concrete incorporating rice-husk ash without processing. Constr. Build. Mater., 25(1): 371-378.

Zhang, M.H. and M.V. Mohan, 1996. High-performance concrete incorporating rice husk ash as a supplementary cementing material. ACI Mater. J., 93(6): 629-636.

Zhang, M.H., R. Lastra and V.M. Malhotra, 1996. Rice husk ash paste and concrete: Some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste. Cement Concrete Res., 26(6): 963-977.