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Effect of Rice Husk Ash on Strength and Durability of High Strength High Performance Concrete

H. B. Mahmud, Syamsul Bahri, Y. W. Yee, Y. T. Yeap

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***Abstract*—**This paper reports the strength and durability properties of high strength high performance concrete incorporating rice husk ash (RHA) having high silica, low carbon content and appropriate fineness. In this study concrete containing 10%, 15% and 20% RHA as cement replacement and water to binder ratio of 0.25 were investigated. The results show that increasing amount of RHA increases the dosage of superplasticizer to maintain similar workability. Partial replacement of cement with RHA did not increase the early age compressive strength of concrete. However, concrete containing RHA showed higher compressive strength at later ages. The results showed that compressive strength of concrete in the 90-115 MPa range can be obtained at 28 curing days and the durability properties of RHA concrete performed better than that of control concrete. The water absorption of concrete incorporating 15% RHA exhibited the lowest value. The porosity of concrete is consistent with water absorption whereby higher replacement of RHA decreased the porosity of concrete. There is a positive correlation between reducing porosity and increasing compressive strength of high strength high performance concrete. The results also indicate that up to 20% of RHA incorporation could be advantageously blended with cement without adversely affecting the strength and durability properties of concrete.

***Keywords*—**Compressive strength, durability, high performance concrete, rice husk ash.

I. INTRODUCTION

THE trend of utilizing concrete nowadays is in high performance concrete (HPC) because it offers high strength, good workability and better durability. The common strategy to increase the strength of concrete is by lowering w/b ratio and higher cement content than normal concrete. As cement is a major ingredient in concrete, this will increase the material cost. The consequences of producing cement cause increasing CO_2 emission which creates environmental issues. As one of the world's most significant manufactured materials, on average, approximately one ton of concrete is produced each year for every human being in the world [1]. Cement industries contribute approximately 5% of global CO_2 emissions [2]. In the past 10 years' cement industry has been pushed to effectively reduce and control CO_2 emissions [3]. Emission as an environmental impact of cement industries can be lowered through reducing the rate of cement consumption. Reference [4] suggested cement should be replaced partially with pozzolanic material from waste. The value of the CO_2 intensity can be decreased sharply if the substitution level of the pozzolanic material used is approximately 15-20%, but the rate of decrease gradually slowed if the replacement is lower than that range [3]. One of the industrial wastes commonly used in concrete as a pozzolan is silica fume, which is a residue from silicon industries. Incorporating silica fume in concrete improved the mechanical and durability of concrete due to the high content of reactive silicon dioxide (SiO_2) and very small spherical particles which can function as pozzolanic and filler materials [5]. However, silica fume is expensive than cement and it is mainly used in high strength concrete. As an alternative for substituting silica fume, rice husk ash (RHA) can be used due to its availability in Malaysia and Asia, where rice is the staple food.

Rice husk constitutes about 20% of 745 million metric tons of rice paddy production annually worldwide [6] and RHA is produced from 15% of burning rice husk [7]. Properly burned rice husk and ground RHA can be used as mineral admixture in cement production [8]. Reference [9] determined that the optimum combustion temperature of rice husk to achieve pozzolanic activity is around 650ºC within 60 min of burning time. The SEM of ground rice husk ash particles consisted of irregular-shaped and porous cellular surface [10].

As a porous material, concrete has air or water permeable properties which has a great influence on strength and durability characteristics [11], [12]. Many deterioration processes in concrete are related to water permeable properties which accommodated water under saturated condition. In countries having winter season, water that freezes below freezing temperature can expand and cause hydraulic pressure creating cracks in concrete [13], [14]. The ingress of moisture into the concrete can trigger sulfate attack and alkali aggregate reactivity. The permeable porosity of concrete has a major effect on its compressive strength and other mechanical properties [15]. Therefore, the porosity of concrete should be reduced in order to increase the durability and serviceability of concrete structures. Pozzolanic material can be used as partial cement replacement due to its capability in forming calcium silicate hydrate (CSH) as secondary reaction between calcium hydroxide from cement hydration and the silicon dioxide from the pozzolanic material.

RHA is successfully used as partially cement replacement in normal concrete to improve the permeable porosity. Reference [16] reported that the durability performance conducted on normal strength concrete of 30 MPa containing 20% or 30% RHA by mass of cement reduced initial surface absorption and the absorption characteristics and increased the

H. B Mahmud is a Professor at the Dept. of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia (e-mail: hilmi@um.edu.my).

Syamsul Bahri is a Ph.D. candidate at the Dept. of Civil Engineering, University of Malaya and on study leave from the Lhokseumawe State Polytechnic, Lhokseumawe, Indonesia (e-mail: syamsul_b62@yahoo.com).

Y. W. Tee and Y. T Yeap are under-graduate students at the Dept. of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia.

resistance of concrete to chloride ion penetration in comparison with the OPC control concrete. Reference [17] mentioned that the fineness and amorphous silica influence and improved the microstructure of concrete. Reference [8] examined the influence of RHA on the chloride permeability of concrete utilizing RHA with LOI of 2.1% and found that RHA significantly reduced the electrical charge passed. Reference [18] mentioned that by grinding RHA to fine particles can minimize the effect of the residual carbon and the presence of crystalline compounds in RHA. From the previous researches, it is evident that RHA can be used as pozzolanic material for improving the mechanical and durability properties depending on the percentages of cement replacement, SiO_2 content, LOI and the particle size.

Information on the effect of RHA on durability properties of high strength high performance concrete is limited. It seems important to verify whether incorporating different amounts of RHA in HSHPC could improve durability properties. This research focuses on investigating the influence of RHA from a rice mill in Selangor, Malaysia, on the durability of high performance concrete of 100 MPa. Ordinary Portland cement Type I was partially replaced with 10, 15 and 20% of RHA (by mass of binder) in concretes containing w/b ratios of 0.25. The studies include the chemical and physical properties of RHA, compressive strength, water absorption, porosity and UPV. The results of the study would be beneficial for future applications of the RHA in high strength high performance concrete.

II. Material and Methodology

A. Materials

RHA was produced with uncontrolled combustion in a ferrocement furnace with peak temperature below 700°C and prepared as partial cement replacement (Fig. 1 (a)). RHA was ground using a Los Angeles (LA) machine with 40 steel bars of 10.5 kg weight. 36000 cycles were adopted to grind the RHA in the drum of LA machine. The average particle size of received RHA was around 85 µm and after grinding, the average particle size of RHA was 13 mµ (Fig. 1 (b)). Ordinary Portland cement used was Type I conforming to ASTM standard (CEM 42.5) and the average particle size of OPC was 20 µm.

The chemical characteristic of RHA and OPC was performed by XRF and LOI analysis. Chemical compositions of cement and rice husk ash are presented in Table I. It shows that SiO_2 content and LOI of RHA are 85.76% and 4.05% respectively, complying with ASTM C618 requirements.

XRD of RHA shows that RHA contain mainly amorphous silica (Fig. 2). Appearance of cristobalite could be due to the ash not being incinerated in proper manner and a possibility that the temperature of combustion may be just over 700°C for a short period.

Table II presents particle size distribution data of the OPC and RHA. The latter showed higher percentage of finer particles and close to that of OPC. RHA showed higher percentage of coarse particles with d (0.9) = 931 µm, i.e. 90% of particles are smaller than 931 µm. The highest concentration of smaller particles of cementitious materials will result in higher reactivity.

Fig. 1 (a) RHA before grinding (b) RHA after grinding

TABLE I
CHEMICAL PROPERTIES OF OPC AND RHA

Chemical Composition (%)	OPC	RHA
Magnesium oxide (MgO)	2.06	0.81
Aluminum oxide (Al_2O_3)	5.6	0.25
Silicon dioxide (SiO_2)	21.28	85.76
Sulfate (SO_3)	2.14	0.31
Calcium oxide (CaO)	64.64	0.74
Iron oxide (Fe_2O_3)	3.38	1.15
Loss of Ignition (LOI)	0.6	4.05

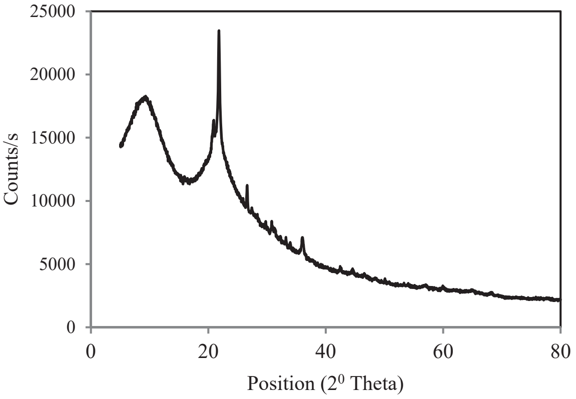

Fig. 2 The XRD of RHA

The fine and coarse aggregate used were mining sand and crushed granite with maximum sizes of 4.75 mm and 19 mm respectively. The specific gravity of mining sand and crushed granite was 2.84 and 2.66 respectively. The type of superplasticizer used was polycarboxylate ether polymer with 40% of solid content by mass.

TABLE II
PHYSICAL PROPERTIES OF OPC AND RHA

Properties	OPC	RHA
Specific gravity	3.15	2.06
Particle size		
d (0.5) (µm)	20.085	23.960
d (0.1) (µm)	3.424	4.146
d (0.9) (µm)	58.665	81.308
BET specific surface area (m^2/g)	1.060	40.888
Pore volume (cm^3/g)	0.004	0.058

B. Experimental Procedures

The workability of fresh concretes was measured with slump test based on BS 1881–102. After placement, concrete was covered with polyethylene sheet to avoid water evaporation. Mold of concrete was dismantled after 24 hours and specimens were placed in water curing tank. The specimens for compressive strength used were 100 x100 x 100 mm cubes based on BS 1881–116. Water absorption test and porosity were carried out according to ASTM C642-97. Ultrasonic pulse velocity (UPV) measurements were conducted according to ASTM C597 – 02. The compressive strength of concrete was determined at 1, 3, 7, 28 and 56 days and the average of three samples were reported.

C. Mix Proportions of Concretes

Table III shows the mix proportions of concrete incorporating RHA. Workability of all mixes was between 210-230 mm. A total of 4 concrete mixtures were prepared with a constant water/binder (w/b) ratio of 0.25 and a total binder content of 550 kg/m^3, partially replaced by cement by 0, 10, 15, 20% RHA (by mass).

TABLE III
MIX PROPORTIONS OF HSHPC CONCRETE

Ingredient	Mix Id			
	OPC	RHA10	RHA15	RHA20
Water	177	177	177	177
Cement (kg/m^3)	550	495	468	440
RHA (kg/m^3)	0	55	82	110
Coarse Agg. (kg/m^3)	1050	1050	1050	1050
Fine Agg. (kg/m^3)	702	690	685	681
SP (l/m3)	3.1	3.4	3.5	4

III. RESULTS AND DISCUSSION

A. Workability of HSHPC

Table IV shows that inclusion of RHA affects the fresh properties of HSHPC as RHA replacement increases the superplasticizer dosage in order to maintain similar workability in the range of 210–230 mm. This is related to the high specific surface of RHA. Therefore, the SP contents of RHA concrete mixtures were higher than that of the control OPC mixture. The SP content increases with increasing RHA percentage. The dosage of superplasticizer in fresh RHA concrete can be reduced through reducing the fineness of RHA [19].

TABLE IV
FRESH CONCRETE PROPERTIES OF DIFFERENT MIXTURES

Mixtures	Slump (mm)	Slump Flow (mm)	Superplasticizer (l /m^3)	Fresh Density (kg/m^3)
OPC	220	410	3.1	2594
RHA 10	230	420	3.4	2574
RHA 15	220	430	3.5	2542
RHA 20	210	410	4.0	2534

B. Effect of RHA on Compressive Strength of HSHPC

Fig. 3 shows that RHA improve the compressive strength after 3 days especially strengths for 15% RHA replacement. At early age, RHA concretes showed lower strength than that of OPC concrete. In the early age, incorporating 10–20% RHA in concrete reduces similar percentages of cement and this increases the volume of capillary pores and accumulates CaOH on the interface making the structure of mixtures less dense [20]. The effects of this process cause the strength of RHA concrete to be lower than that of OPC concrete. At later ages, starting at 7 days, pozzolanic reaction starts to proceed and decrease the amount of CaOH and improved the densification [21]. At 28 days, all compressive strengths of RHA concretes are 18% higher than that of OPC. RHA improved the microstructure of concrete through increased CSH compound, reduced pores and resulting in dense concrete [22]. Reference [23] reported that, at all the ages, cement replaced partially with RHA significantly increased the compressive strength of concretes. In self compacted concrete (SCC), the compressive strength of SCC blended with 15% RHA was higher than that of normal [24]. However, some researchers reported that improvement on compressive strength of concrete also depends on type of silica in RHA [25], level of replacement [26], LOI content and also fineness of RHA [27]. Comparing with silica fume, [28] reported that 10% RHA concrete showed comparable compressive strength with the 10% SF concrete. It means that the use of RHA in HSHPC is not jeopardizing the strength of concrete. The compressive strength is enhanced in the later phase. Comparison of the data at 28 and 56 days show that the compressive strengths of concretes up to 20% RHA are similar and 20% higher than that of OPC concrete. With w/b ratio of 0.25, compressive strength of RHA concrete in the 100-115 MPa range at 28 days is achievable in this investigation.

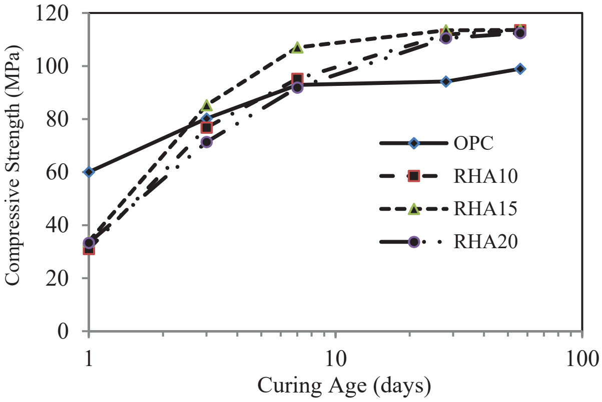

Fig. 3 Compressive Strength of HSHPC

C. Effect of RHA on Water Absorption

Fig. 4 shows the experimental results of water absorption. It shows that the water absorption value among RHA concrete is almost similar, in the range of 1-2% and lower than that of OPC concrete. OPC concrete exhibited higher water absorption due to the water space not fully occupied with hydration cement product. Reference [29] mentioned that the space left after cement hydration is around 20%. At early age, the water absorption of the RHA concrete is 25-75% lower than that of OPC concrete. These results confirm the importance of water absorption being evaluated at early age as at later age the rate of water absorption of RHA concrete does not much change that much.

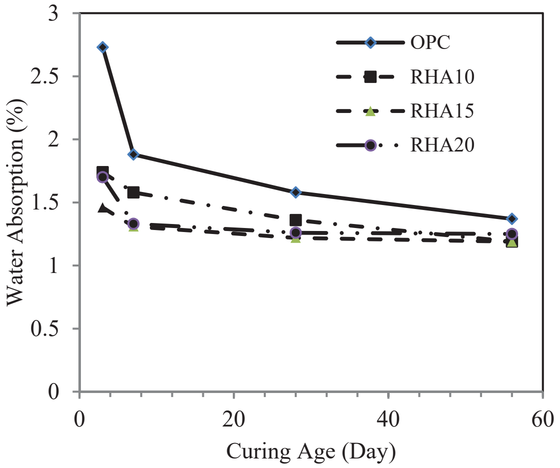

Fig. 4 Water Absorption of HSHPC

D. Effect of RHA on Porosity

The porosity results are shown in Fig. 5. The OPC concrete exhibited 50% higher porosity than that of RHA concrete due to the water space not fully occupied with hydration cement product. Similar results were reported by [30]. Incorporating RHA in concrete has significant effect on the porosity of the RHA concrete. All the RHA concrete showed porosity value of less than 2.5%.

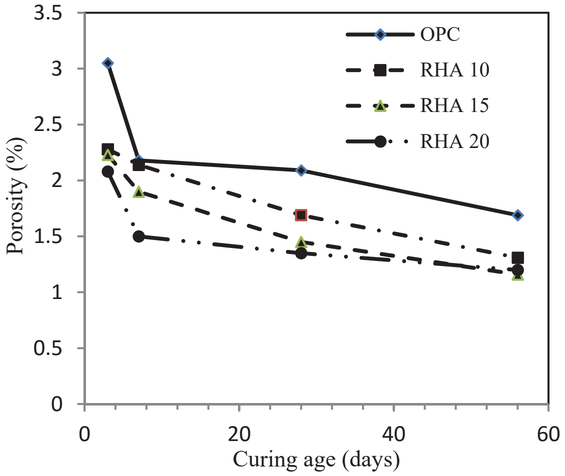

Fig. 5 Permeable Porosity of HSHPC

E. Relation between Porosity and Compressive Strength

The porosity of concrete has been used extensively for the prediction of the properties of concrete. RHA has been in use in concrete as a cementitious component since 1970 and has been shown to reduce and refine the pore structure [7]. Fig. 6 shows the relationships for RHA and OPC concrete. Incorporating RHA in concrete reduces the permeable porosity and increases the compressive strength. This relationship gave very strong R^2 value of higher than 0.95 (1)–(4). It is interesting to note that the relationship for RHA concrete is in polynomial form but that of OPC concrete is linear. The relationship of the 10% and 15% RHA concrete shows similar concave shape behaviour. The change of permeable porosity in the range of 1.2-1.7 did not change the compressive strength of concrete. As previously explained, the 10% and 15% RHA concretes are more reactive from 7 days up to 28 days than the 20% RHA.

$$Y_{OPC} = -13.949\,x + 123 \;\; ; R^2 = 0.9978 \tag{1}$$

$$Y_{RHA10} = -63.044\,x^2 + 191.66\,x - 29.96\,;\; R^2 = 0.9726 \tag{2}$$

$$Y_{RHA15} = -44.638\,x^2 + 126.42x - 26.1 \;;\; R^2 = 0.9827 \tag{3}$$

$$Y_{RHA20} = 25.046\,x^2 - 131.85\,x + 237\,;\; R^2 = 0.9514 \tag{4}$$

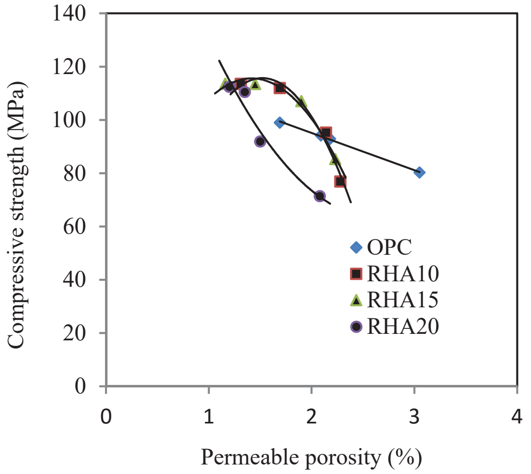

Fig. 6 Relation between Porosity and Compressive Strength of HSHPC

F. Effect of RHA on UPV of HSHPC

The uniformity and relative quality of concrete can be identified through the presence of voids and cracks and this can be assessed using ultra-pulse velocity methods. Generally, high pulse velocity value indicates dense concrete which means good quality concrete. According to [31] concrete with UPV value in the range of 3660–4575 m/s has good durability. It can be seen in Fig. 7 that at early ages, the UPV values of OPC concrete are higher than that of RHA concrete but at later ages, the reverse is true. At early age, RHA concrete which contains lower cement content than OPC concrete is less dense due to lower hydration reaction, as clearly shown in Fig. 7. However, after 7 days, the pozzolanic reaction of the RHA concrete commenced and this create more CSH and hence make the RHA concrete denser. Hence the UVP value of RHA concrete is consistently higher than OPC concrete from 7 days onwards. However, at 28 days, UPV of all the specimens is higher than 3660 m/s, indicating that all the HSHP concretes are highly durable [31].

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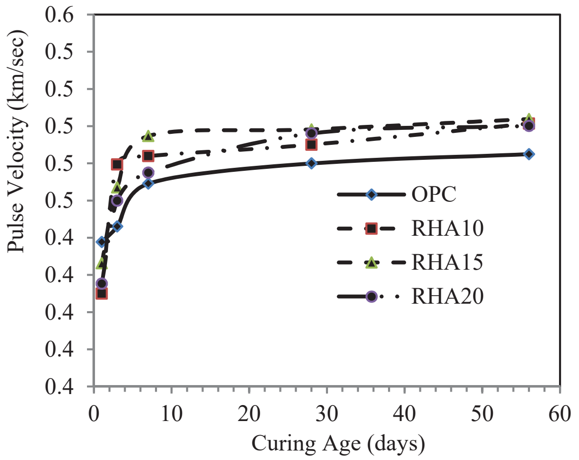

Fig. 7 Ultrasonic Pulse Velocity of HSHPC

IV. CONCLUSION

Based on the investigations on the fresh, strength and durability properties of concrete containing RHA, the following can be concluded:

1. Increasing the amount of RHA increase the SP content for similar workability.
2. RHA can be used as cement replacement up to 20% and its compressive strength is 20% higher than that of OPC concrete.
3. Generally, the compressive strength and durability properties of RHA concrete are better than that of OPC concrete.
4. The use of RHA brings technical benefits including savings in production cost of concrete and reduces the CO_2 emissions due to reduced consumption of cement.

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REFERENCES

[1] B.C. Lippiatt and S. Ahmad. Measuring the life-cycle environmental and economic performance of concrete: the BEES approach. in Proceedings of the International workshop on sustainable development and concrete technology. Beijing, 2004, 213-230.

[2] D.N. Huntzinger and T.D. Eatmon, A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. Journal of Cleaner Production, 2009. 17(7): p. 668-675.

[3] K.-H. Yang, Y.-B. Jung, M.-S. Cho, and S.-H. Tae, Effect of supplementary cementitious materials on reduction of CO2 emissions from concrete. Journal of Cleaner Production, 2014.

[4] P.K. Mehta, Greening of the Concrete Industry for Sustainable Development. Concrete international, 2002. 23.

[5] R.J. Detwiler and P.K. Mehta, Chemical and physical effects of silica fume on the mechanical behavior of concrete. ACI Materials Journal, 1989. 86(6).

[6] FAO, Rice market monitor, vol XVIII. 2015, Issue 1.

[7] P.K. Mehta. Properties of blended cements made from rice husk ash. in ACI Journal Proceedings. 1977. ACI.

[8] K. Ganesan, K. Rajagopal, and K. Thangavel, Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete. Construction and Building Materials, 2008. 22(8): p. 1675-1683.

[9] A. Ramezanianpour, M. Mahdikhani, and G. Ahmadibeni, The effect of rice husk ash on mechanical properties and durability of sustainable concretes, International Journal of Civil Engineering, 2009.7(2): p.83-91

[10] P. Chindaprasirt, S. Rukzon, and V. Sirivivatnanon, Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. Construction and Building Materials, 2008. 22(5): p. 932-938.

[11] Y.-Y. Kim, K.-M. Lee, J.-W. Bang, and S.-J. Kwon, Effect of W/C ratio on durability and porosity in cement mortar with constant cement amount. Advances in Materials Science and Engineering, 2014. 2014.

[12] M. Safiuddin and N. Hearn, Comparison of ASTM saturation techniques for measuring the permeable porosity of concrete. Cement and Concrete Research, 2005. 35(5): p. 1008-1013.

[13] A.M. Neville, Properties of concrete. 1995, Pitman, UK.

[14] M. Pigeon and R. Pleau, Durability of concrete in cold climates. 2010: CRC Press.

[15] M. Choinska, A. Khelidj, G. Chatzigeorgiou, and G. Pijaudier-Cabot, Effects and interactions of temperature and stress-level related damage on permeability of concrete. Cement and Concrete Research, 2007. 37(1): p. 79-88.

[16] K. Kamaruddin and H.B. Mahmud, Absorption and permeability performance of Selangor rice husk ash blended grade 30 concrete. Journal of engineering science and technology, 2010. 5(1): p. 1-16.

[17] R. Madandoust, M.M. Ranjbar, H.A. Moghadam, and S.Y. Mousavi, Mechanical properties and durability assessment of rice husk ash concrete. Biosystems engineering, 2011. 110(2): p. 144-152.

[18] G.C. Cordeiro, R.D. Toledo Filho, and E.d.M.R. Fairbairn, Use of ultrafine rice husk ash with high-carbon content as pozzolan in high performance concrete. Materials and Structures, 2009. 42(7): p. 983-992.

[19] G.A. Habeeb and H.B. Mahmud, Study on properties of rice husk ash and its use as cement replacement material. Materials Research, 2010. 13(2): p. 185-190.

[20] H. Chao-Lung, B. Le Anh-Tuan, and C. Chun-Tsun, Effect of rice husk ash on the strength and durability characteristics of concrete. Construction and Building Materials, 2011. 25(9): p. 3768-3772.

[21] W. Tangchirapat, C. Jaturapitakkul, and P. Chindaprasirt, Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete. Construction and Building Materials, 2009. 23(7): p. 2641-2646.

[22] N. Van Tuan, G. Ye, K. Van Breugel, and O. Copuroglu, Hydration and microstructure of ultra high performance concrete incorporating rice husk ash. Cement and Concrete Research, 2011. 41(11): p. 1104-1111.

[23] R. Sai, A. Juma, D. Prakash, S. Haider, and S.K. Rao, An Experimental Study on Synergic Effect of Sugar Cane Bagasse Ash with Rice Husk Ash on Self Compaction Concrete. Advances in Computer Science and its Applications, 2012. 1(2): p. 164-170.

[24] V. Kannan and K. Ganesan, Chloride and chemical resistance of self compacting concrete containing rice husk ash and metakaolin. Construction and Building Materials, 2014. 51: p. 225-234.

[25] G.R. Sensale, Strength development of concrete with rice-husk ash. Cement and Concrete Composites, 2006. 28(2): p. 158-160.

[26] S.N. Raman, T. Ngo, P. Mendis, and H.B. Mahmud, High-strength rice husk ash concrete incorporating quarry dust as a partial substitute for sand. Construction and Building Materials, 2011. 25(7): p. 3123-3130.

[27] S. Rukzon, P. Chindaprasirt, and R. Mahachai, Effect of grinding on chemical and physical properties of rice husk ash. International Journal of Minerals, Metallurgy and Materials, 2009. 16(2): p. 242-247.

[28] H.B. Mahmud, M.F.B.A. Malik, R.A. Kahar and S.N. Raman. Mechanical properties and durability of normal and water reduced high strength Grade 60 concrete containing rice husk ash. Journal of Advanced Concrete Technology, Japan Concrete Institute, 2009,7(1): p 21-30.

[29] E.J. Garboczi and D.P. Bentz, Computer simulation and percolation theory applied to concrete. Annual Review of Computational Physics, 1999. 7: p. 85-123.

[30] V. Saraswathy and H.-W. Song, Corrosion performance of rice husk ash blended concrete. Construction and Building Materials, 2007. 21(8): p. 1779-1784.

[31] V.M. Malhotra, Testing hardened concrete: nondestructive methods. 1976: Iowa State Press.

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