RICE HUSK ASH – POZZOLANIC MATERIAL FOR SUSTAINABILITY

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Abstract

Finding a replacement for cement to assure sustainability is crucial as the raw materials (limestone, sand, shale, clay, iron ore) used in making cements which are naturally occurring are depleting. The raw materials are directly or indirectly mined each year for cement manufacturing and it is time to look into the use of agriculture waste by-products in replacing cement. Rice husk ash (RHA) which has the pozzolanic properties is a way forward. An intensive study on RHA was conducted to determine its suitability. From the various grade of concrete (Grade 30, 40, 50) studied, it shows that up to 30% replacement of OPC with RHA has the potential to be used as partial cement replacement (PCR), having good compressive strength performance and durability, thus have the potential of using RHA as PCR material and this can contribute to sustainable construction.

Keywords: Rice Husk Ash, Pozzolan, Compressive Strength, Permeability, Durability

1. Introduction

In this century, the utilization of rice husk ash (RHA) as cement replacement is a new trend in concrete technology. Besides, as far as the sustainability is concerned, it will also help to solve problems otherwise encountered in disposing of the wastes [Chandra, 1997]. Disposal of the husks is a big problem and open heap burning is not acceptable on environmental grounds, and so the majority of husk is currently going into landfill. The disposal of rice husks create environmental problem that leads to the idea of substituting RHA for silica in cement manufactured. The content of silica in the ash is about 92-97%.

Research had shown that small amounts of inert filler have always been acceptable as cement replacements, what more if the fillers have the pozzolanic properties, in which it will not only impart technical advantages to the resulting concrete but also enable larger quantities of cement replacement to be achieved. There are many advantages in using pozzolans in concrete, and they are; improved workability at low replacement levels and with pozzolans of low carbon content, reduced bleeding and segregation, low heat of hydration, lower creep and shrinkage, high resistance to chemical attack at later ages (due to lower permeability and less calcium hydroxide available for reaction), and low diffusion rate of chloride ions resulting in a higher resistance to corrosion of steel in concrete [Krishna, 2008]. Studies by Kartini [2010, 2009]; Gambhir [2006]; Hwang and Chandra [1997]; Mehta [1992] had showed the outstanding technical benefit of incorporating cement replacement materials (RHA) in which it significantly improves the durability properties of concrete. These properties are difficult to achieve by the use of pure Portland cement alone.

Extensive studies have been carried out and have indicated that the RHA can be beneficially utilized; however, in Malaysia the utilization of this ash is not routinely practiced or mandated. In order to have the confidence in the use of this ash, comprehensive studies have to be carried out based on Malaysia environment. This paper highlighted the study conducted on RHA in determining its suitability as cement replacement material. The workability, compressive strength, and durability performance of Grade 30, Grade 40 and Grade 50 N/mm^2 concrete with partial cement replacement of RHA are reported.

2. EXPERIMENTAL PROGRAMME

2.1 Material Preparation

The rice husk was obtained from Seri Tiram Jaya Mill in Kuala Selangor, Malaysia and was burnt in a ferrocement furnace to produce RHA. After burning and allow cooling inside the furnace for another 24 hours, the burnt ashes were taken out for grinding using a Los Angeles (LA) machine. Figure 1 shows the products obtained after the operation, i.e. rice husk ash (RHA).

Rice husk

After burning in ferrocement kiln

After grinding in Los Angeles machine (RHA)

Figure 1: Product produced after each process

In determining the element content of RHA, the Energy Dispersing X-ray Spectroscopy (EDAX) and X-ray Diffraction (XRD) were conducted. The XRD of RHA shown in Figure 2 indicates that the structure of silica present in RHA is of amorphous material having a diffused peak of 140 counts at about $\theta = 22^{o}$.

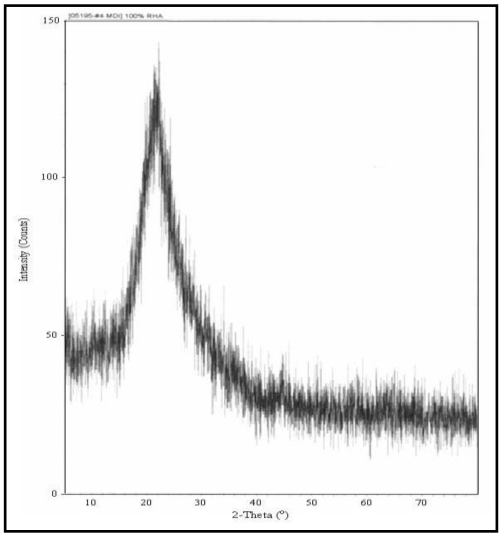

Figure 2: XRD of RHA Particles

A typical chemical composition of RHA obtained after burning and grinding is shown in Table 1. From Table 1, it can be seen that the SiO_2 for RHA is 96.7% with 0.91% of potassium (K_2O), and have some minor oxides such as alkalis, sulfate, and calcium oxide. The $SiO_2 + Al_2O_3 + Fe_2O_3$ of RHA were 97.8%. Based on the data presented in Table 1 and with ASTM C618:2003 definition, i.e. for a material to be classified as pozzolan, it should have SiO_2 minimum of 70%, while for loss of ignition (LOI) a maximum of 6%. Therefore from this study, the RHA used can be classified as Class N pozzolanic. The LOI for RHA is about 4.81%. It is to be stated here that the RHA used in this study was burnt in the incinerator under uncontrolled burning condition.

Table 1: Chemical composition of RHA and OPC

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	Na_2O	K_2O	P_2O_5	MnO	SO_3	LOI
OPC	15.05	2.56	4.00	0.12	1.27	72.17	0.08	0.41	0.06	0.06	2.90	1.33
RHA	96.7	1.01	0.05	0.16	0.19	0.49	0.26	0.91	-	-	-	4.81

From the fineness test conducted, it was found out that the fineness of RHA as that retained on 45µm sieve was about 21.87%, which conformed to grade A of dry pulverized–fuel ash (pfa) based on ASTM C430: 2008. The influence of fineness of RHA is important as it will influence the compressive strength [Chopra et al., 1981; Shimizu and Jorillo, 1990]. The Blaine surface area (BET) of RHA determined using nitrogen absorption method ranged between 10.857m^2/g to 17.463m^2/g with specific gravity of 2.1. The average particle size of RHA is 25.83µm.

Other materials used in the concrete mixture were Portland cement, granite (coarse aggregate) of 20 mm maximum size and mining sand (fine aggregate) of 5 mm maximum size. The fineness modulus for the coarse aggregate and fine aggregate were 2.43 and 4.61 respectively. The type of superplasticizer used in this research is sulphonated naphthalene formaldehyde condensed polymer based admixture, commercially known as 'Rheobuild 1000', which is a water-soluble. It satisfies the requirements of ASTM C494/ C494M: 2010 Type A and Type F, and BS EN 934: Part 2:2009.

2.2 Mix Proportion

The control OPC concrete was designed to achieve Grade 30, Grade 40 and Grade 50 N/mm^2 using the DOE method [DOE, 1988]. Based on this, the cement content of 325 kgm^{-3}, 375 kgm^{-3} and 445 kgm^{-3} were adopted for each of the grades. The water to binder ratio (w/b) of the Grade 30, Grade 40, and Grade 50 were 0.63, 0.50 and 0.43 respectively. Increased in the amount of RHA content resulted in dry mix concrete [Kartini et al., 2004], therefore Sp was used to enhance the fluidity of the mixes. The Sp dosage in subsequent mixtures was tailored to achieve slump in the range of 100 mm to 150 mm. Table 2 summarizes the mix proportions for control OPC and various RHA concrete mixes for Grade 30, Grade 40 and Grade 50.

Table 2: Mix proportions and workability for control and various RHA concrete mixes

Mixture Designation	Mass per Unit Volume of Materials (kg/m^3)					w/b*	Slump
	Cement	RHA	Water	Aggregate			
				Fine	Coarse		
GRADE 30							
OPC$_{30}$	325	-	205	900	940	0.63	40-50
RHA$_{30}$20	260	65	205	900	940	0.63	100-150
RHA$_{30}$30	228	97	205	900	940	0.63	100-150
OPC$_{30}$Sp	325	-	205	900	940	0.63	100-150
RHA$_{30}$20Sp	260	65	205	900	940	0.63	100-150
RHA$_{30}$30Sp	228	97	205	900	940	0.63	100-150
GRADE 40							
OPC$_{40}$Sp	375	-	190	580	1235	0.50	100-150
RHA$_{40}$10Sp	338	37	190	580	1235	0.50	100-150
RHA$_{40}$15Sp	319	56	190	580	1235	0.50	100-150
RHA$_{40}$20Sp	300	75	190	580	1235	0.50	100-150
RHA$_{40}$25Sp	281	94	190	580	1235	0.50	100-150
RHA$_{40}$30Sp	262	113	190	580	1235	0.50	100-150
GRADE 50							
OPC$_{50}$Sp	445	-	190	524	1225	0.43	100-150
RHA$_{50}$10Sp	401	44	190	524	1225	0.43	100-150
RHA$_{50}$15Sp	378	67	190	524	1225	0.43	100-150
RHA$_{50}$20Sp	356	89	190	524	1225	0.43	100-150
RHA$_{50}$25Sp	334	111	190	524	1225	0.43	100-150
RHA$_{50}$30Sp	312	133	190	524	1225	0.43	100-150

* Binder (OPC +RHA)

2.3 Testing

The compressive strength was computed using the formula given by BS EN 12390-3 :2000 and tested on 100 mm cubes at ages of 28, 60, 90 and 120 days, after curing in water. For the durability performance, the tests conducted were the water permeability, water absorption and Rapid Chloride Ion Penetration (RCPT) and the specimens size were 150 mm Ø cylinder with 150 mm thickness, 50 mm Ø cylinder with 100 mm thickness, and 100 mm Ø cylinder with 50 mm thickness respectively. In determining the water permeability of the mixes, BS EN 12390-8 :2000 was used, while for water absorption test, it was based on BS 1881-122 :1983, in which before testing, the concrete specimens were oven dried to constant mass at 105 ± 5 ^{o}C for 72 ± 2 hours and then stored in air-tight containers before subjected to testing. The concrete specimens are weighed before immersion and after immersion for 30 minutes. For RCPT, the test was done according to the standard procedure described in ASTM C1202:1997.

3. *RESULTS AND DISCUSSIONS*

3.1 Workability

When the amount of replacement of OPC with RHA increases, the workability of the concrete mixes decreases. The reasons being, concrete containing RHA requires more water for a given consistency due to its absorptive character of cellular RHA particles and of high fineness (this increases its specific surface area). Therefore, in order to enhance the fluidity and consistency of the mix, i.e. to maintain the workability of the mixes in term of slump of 100 mm to 150 mm, a proper dosage of Sp was added. The addition of Sp will absorbed onto the cement particles, and imparts a strong negative charge, which helps to lower the surface tension of the surrounding water considerably and thus, greatly enhances the fluidity of the mixes. Figure 3 shows some typical slumps for the various mixes of OPC and RHA concrete without and with Sp.

3.2 Compressive Strength

The results of the compressive strength for the various mixes at Grade 30, Grade 40 and Grade 50 are presented graphically in Figure 4, Figure 5 and Figure 6 respectively. For RHA concrete without Sp, it can be seen from the Figure 4 that all the RHA concrete are well above the target strength of 30 N/mm^2 at 28 days. However, the compressive strength of RHA concrete at 28 days are lower than the control concrete due to the higher water content in the mix in order to maintain similar workability. Increasing RHA more than 20% did not contribute further improvement in strength. Replacement of OPC up to 30% RHA can still produce the target strength of 30 N/mm^2.

Figure 3: The slump for the various mixes of fresh concrete with and without Sp

For RHA concrete with Sp of Grade 30, the compressive strength is higher at 20% and 30% replacement when compared to the control concrete (OPC). It can be seen that the combine effect to compressive strength is significant with inclusion of Sp while maintaining w/b ratio i.e. 37.1 N/mm^2 for RHA20Sp and 34.9 N/mm^2 for RHA30Sp concretes at age 28 days. Thus, suggesting that inclusion of Sp is important as it shows a marked improvement in terms of strength. This might be due to the fact that by adding Sp while keeping the w/b ratio constant, it enhanced the fluidity of the mix thus improved the workability and strength.

Generally, from Figure 5 and Figure 6 it can be seen that the compressive strength of all RHA concrete are well above the targeted strength of 40 N/mm^2 and 50 N/mm^2 respectively at 28 days, except that for 25% and 30% replacement of Grade 50. Increase of RHA in the mixes, will reduced the compressive strength, however still achieved the target strength of the specified grade. Therefore, the optimum amount of OPC that can be replaced with RHA is about 30% for Grade 30, while for Grade 50 concrete it was about 20% replacement. However, for Grade 40 concrete, it is expected that the optimum can go more than 30% replacement. Figure 4, Figure 5 and Figure 6 also showed that prolong curing of these concretes resulted in increased in strength.

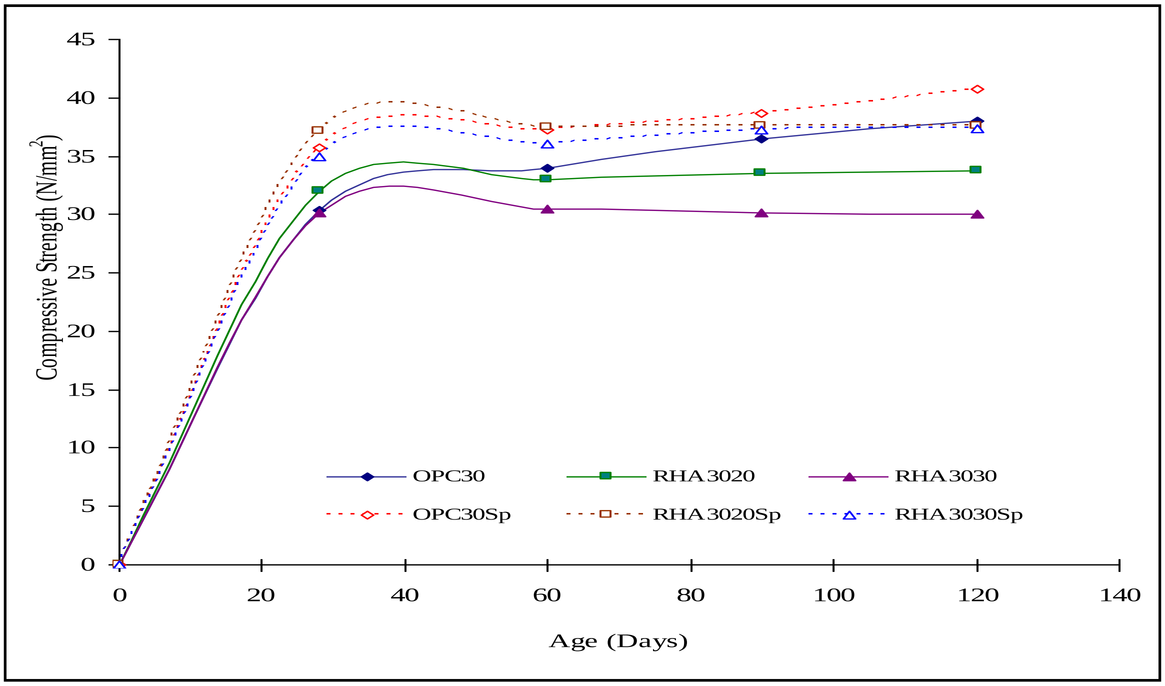

Figure 4: Compressive strength of RHA concrete of Grade 30

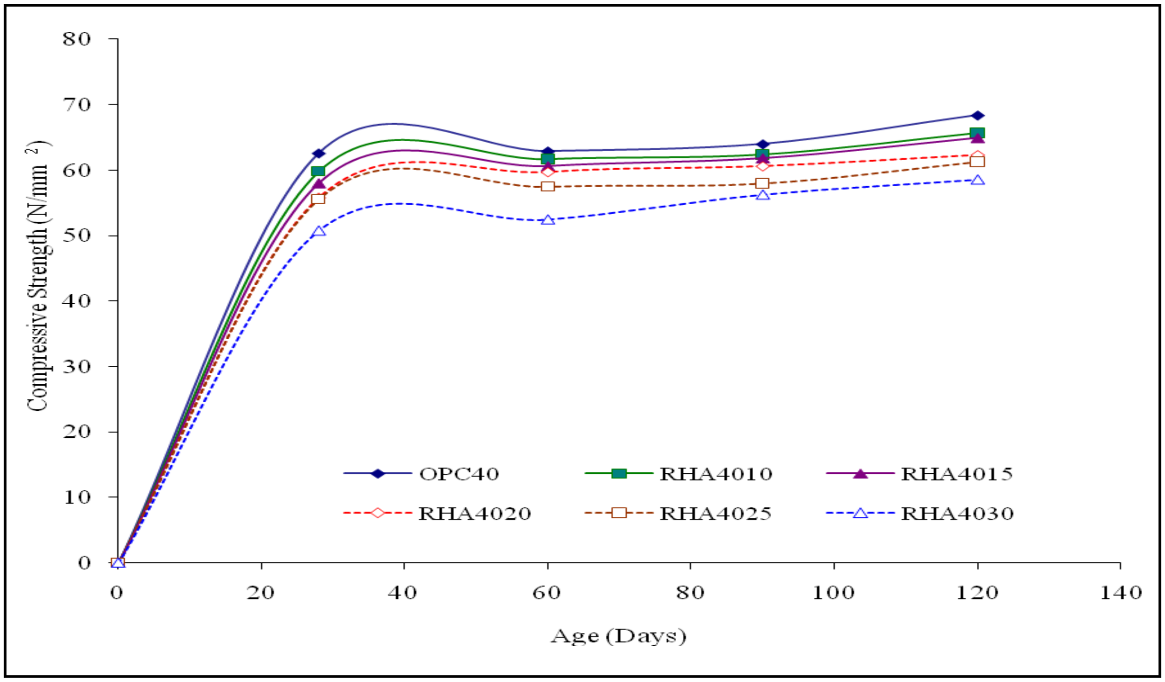

Figure 5: Compressive strength of RHA concrete of Grade 40

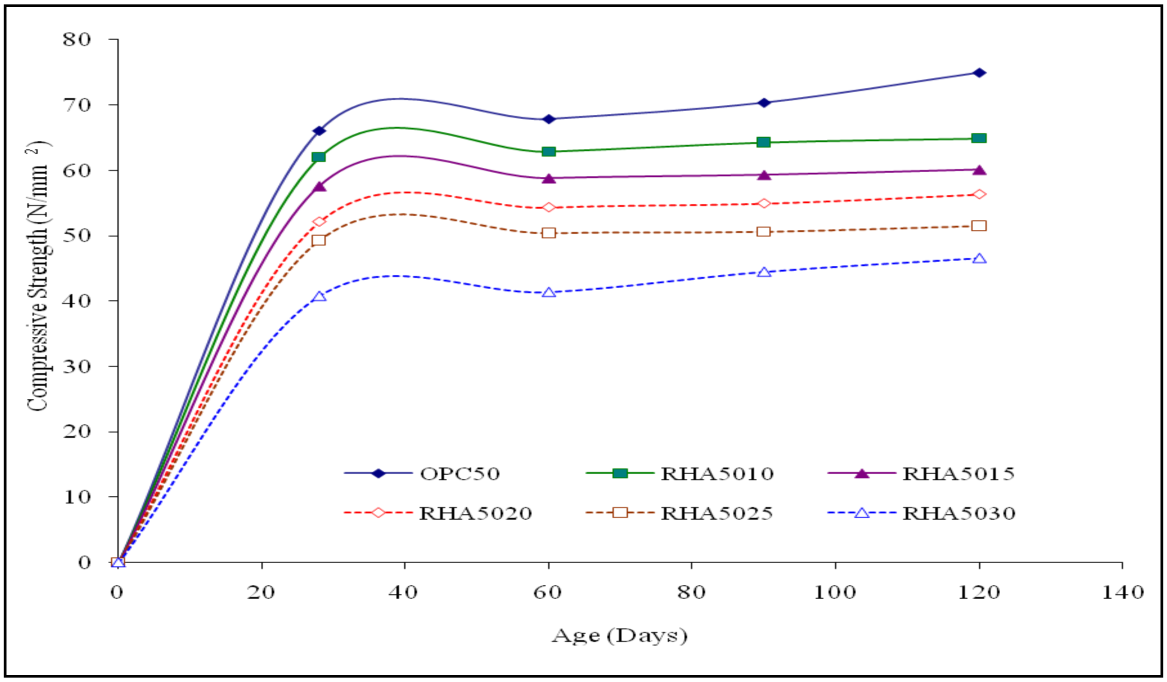

Figure 6: Compressive strength of RHA concrete of Grade 50

3.3 Water Permeability

Table 3 shows the coefficient of permeability of the concrete mixes taken at 28 days for Grade 30, Grade 40 and Grade 50. From Table 3, it can be seen that RHA concretes were less permeable than the OPC control concretes for all the three (3) grades. In fact for concrete mixes of higher grade and with lower w/b ratio, the depth of water penetration or the coefficient of permeability of RHA concretes further reduces, i.e. less permeable with increased in the percentage of replacement of OPC with RHA. The reason is that the pozzolanic material (RHA) occupies the empty space in the pore structure and substantially reduces the permeability of the concrete. It is also obvious that the dosage of Sp in the mixes played an important role in enhancing the fluidity of RHA concrete, and maximizes the compaction resulting in high impermeable of RHA concrete. Studies by Sugita et al. [1997], Speare et al. [1999] and Cook [1984] also show that the presence of RHA resulted in lower coefficient of permeability.

Table 3: Coefficient of permeability of the concrete mixes

Mixture Designation	Grade	w/b	Sp (%)	Depth of Penetration, (mm)	Coef. of permeability (m/sec)
OPC$_{30}$	30	0.63	-	102.82	4.073 x 10^{-10}
RHA$_{30}$20		0.68	-	60.84	1.426 x 10^{-10}
OPC$_{30}$Sp		0.63	0.40	100.10	3.860 x 10^{-10}
RHA$_{30}$30Sp		0.63	1.61	38.03	0.572 x 10^{-10}
OPC$_{40}$Sp	40	0.50	-	61.03	1.437 x 10^{-10}
RHA$_{40}$10Sp		0.50	1.0	60.93	1.434 x 10^{-10}
RHA$_{40}$15Sp		0.50	1.0	58.59	1.327 x 10^{-10}
RHA$_{40}$20Sp		0.50	1.0	57.45	1.274 x 10^{-10}
RHA$_{40}$25Sp		0.50	1.0	55.40	1.184 x 10^{-10}
RHA$_{40}$30Sp		0.50	1.0	53.17	1.092 x 10^{-10}
OPC$_{50}$Sp	50	0.43	-	55.01	1.166 x 10^{-10}
RHA$_{50}$10Sp		0.43	1.0	54.95	1.163 x 10^{-10}
RHA$_{50}$15Sp		0.43	1.0	51.46	1.020 x 10^{-10}
RHA$_{50}$20Sp		0.43	1.0	49.34	0.938 x 10^{-10}
RHA$_{50}$25Sp		0.43	1.0	48.67	0.913 x 10^{-10}
RHA$_{50}$30Sp		0.43	1.0	46.68	0.839 x 10^{-10}

3.4 Water Absorption

Table 4 records the percentage by weight of water absorbed for each concrete mixes for Grade 30, Grade 40 and Grade 50. From the table, it shows that the concrete specimens for Grade 30 containing 20% replacement of RHA without Sp attained higher percentage of water absorption (4.83%) when compared to the OPC control concrete (4.21%) at 30 days. However, 30% superplasticized RHA (RHA30Sp) concrete gave lower water absorption (3.27%), and that also goes with Grade 40 and Grade 50 concretes at 30% replacement, i.e. 3.43% and 3.31% respectively. The table also shows that as the grade of concrete and the percentage of replacement increase, the degree of water absorption reduces. The reason might be as mentioned earlier, i.e. due to reduction in the pores structure as pozzolanic material (RHA) occupies the empty space and reduces the permeability of the concrete. Besides, for higher grade concrete with lower w/b ratio, the percentage of water absorption reduces as less voids occupies the space in concrete as water evaporates.

Table 4: Water absorption characteristics of OPC and RHA concretes

Mixture Designation	Grade	w/b	Absorption, %	
			30 days	90 days
OPC_{30}	30	0.63	4.21	3.93
$RHA_{30}20$		0.68	4.83	4.46
$OPC_{30}Sp$		0.63	4.12	4.05
$RHA_{30}30Sp$		0.63	3.27	2.86
$OPC_{40}Sp$	40	0.50	3.47	3.08
$RHA_{40}10Sp$		0.50	3.39	2.84
$RHA_{40}15Sp$		0.50	3.36	2.83
$RHA_{40}20Sp$		0.50	3.40	2.79
$RHA_{40}25Sp$		0.50	3.52	2.69
$RHA_{40}30Sp$		0.50	3.43	2.60
$OPC_{50}Sp$	50	0.43	3.40	2.72
$RHA_{50}10Sp$		0.43	3.39	2.63
$RHA_{50}15Sp$		0.43	3.23	2.55
$RHA_{50}20Sp$		0.43	3.30	2.37
$RHA_{50}25Sp$		0.43	3.47	2.34
$RHA_{50}30Sp$		0.43	3.31	2.31

Speare et al. [1999] study also in agreement with the statement that addition of RHA resulted in reduction of the absorption characteristic and this reduction increased with increasing RHA content. Generally, the values of water absorption obtained for all the grades taken at 30 minutes absorption can be considered as an average absorption as stipulated by BS 1881: Part 122 :1983 [the concrete Society, 1988].

3.5 Rapid Chloride Ion Penetration (RCPT)

Figure 7 shows the steps involved in the preparation of the specimen before conducting the RCPT. After the conditioning, the test specimens were then placed in the specimen mounting and clamped the two halves of the test cell together to seal. Chloride ions are forced to migrate out of a NaCl solution subjected to a negative charge through the concrete into a NaOH solution maintained at a positive potential. A direct current voltage of 60 ± 0.10 volts was applied across the specimen faces and maintained at regular intervals, i.e. 30 minutes over the period of 6 hours. The total charge passed in Coulombs (current in Amperes multiplied by time in seconds), is used as an indicator of the resistance of the concrete to the passage of chloride ions.

Figure 7: Steps involved in the preparation of the specimen before conducting the RCPT

The results of the coulomb charge on the selected concrete (Grade 30 only) taken up to age of 365 days are shown graphically in Figure 8. From Figure 8, the coulomb charge for the OPC concrete without and with Sp after tested for up to 6 hours was higher than those of RHA concrete. The coulomb charge of the OPC concrete without Sp (OPC) were 5114 and 4081, while OPC concrete with Sp (OPCSp) were 4925 and 3218 taken at age of 7 and 28 days respectively. By referring to ASTM C1202: 1997, the values of the charge passed obtained from the OPC concrete indicates a rather high chloride penetrability characteristic for OPC and OPCSp concrete at age of 7 and 28 days. However, the charge coulombs for these concrete improved as the age of curing increases, i.e. 2565, 2517 and 1986 for OPC concrete and for OPCSp concrete the charge coulombs are 2450, 1855 and 1839 taken at age of 90, 180 and 365 days respectively.

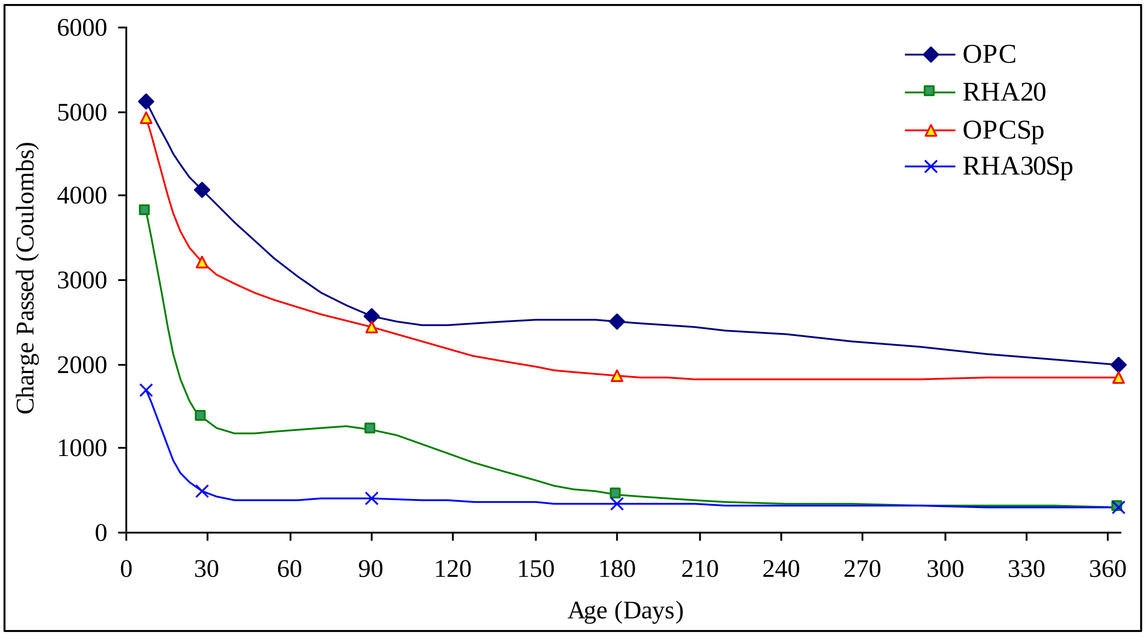

Figure 8: Charge coulomb of Grade 30 RHA concrete without and with Sp

It can also be seen from Figure 8 that the coulomb charge for RHA20 were 3818, 1377, 1212, 460 and 295 and for RHA30Sp were 1684, 494, 398, 341 and 293 respectively taken at 7, 28, 90, 180 and 365 days of curing. These suggested that RHA concrete have moderate to low chloride penetrability characteristic thus, RHA in the mixes gave a pore refining effect, therefore resulted in reductions in the coulomb charges and the reduction further improved with the addition of Sp. From the figure, it is also clear that for OPC and RHA concretes without and with Sp, the charge passed was decreasing with increasing curing period. It was generally agreed (ASTM C1202-1997) that when the value of electrical charge passed through concrete specimen is below 1000 coulombs, the concrete has high resistance to chloride-ion penetrability.

The rate of improvement of resistance to chloride ion penetration of the selected mixes is shown in Table 5. It can be seen from the table that the rate of improvement for RHA concrete (RHA20) was higher, and with the addition of Sp (RHA30Sp), the rate of improvement improved further. The impermeability of RHA20 concrete was about one-third of the permeability value of the OPC concrete taken at 28 days, while for RHA30Sp the permeability dropped almost to one-eighth. Thus, these suggested that the resistance to chloride ion penetration of concrete as measured by the charge coulomb was significantly increased with incorporation of RHA.

Table 5: Rate of improvement of RHA concrete with respect to OPC concrete

Mixture Designation	Improvement Chloride Ion Penetrability (%)				
	7 Days	28 Days	90 Days	180 Days	365 days
OPC_{30}	-	-	-	-	-
$RHA_{30}20$	25.34	66.25	52.75	81.72	85.15
$OPC_{30}Sp$	3.70	21.15	4.48	26.30	7.40
$RHA_{30}30Sp$	67.07	87.90	84.48	86.45	85.25

4. CONCLUSIONS

From the investigation carried out, the following conclusions can be made:-

1. Increased in the amount of RHA in the mix resulted in a dry and unworkable mixtures unless Sp is added. The inclusion of Sp in RHA concrete while maintaining the w/b ratio increased the slump and improved the cohesiveness of the concrete.
2. The optimum replacement of OPC with RHA taken at 28 days strength for Grade 30 and Grade 40 was 30%, while for Grade 50 was 20%.
3. Replacement of OPC with RHA reduced the water permeability of the concrete. Thus, suggested that the presence of RHA in the mix and with concrete of higher grade, the coefficient of permeability reduces, thus improves the durability of concrete. This is due to pore refinement attributed to RHA fineness or a transformation of large permeable pores to a small impermeable pore. The effect is more pronounced with the addition of Sp.
4. The water absorption values of RHA concrete are lower than the OPC control concrete. These results emphasize the beneficial effect of incorporating RHA to increase the durability of concrete, irrespective of their concrete grade. The percentage of water absorption obtained for all the grades are between 3% - 5% which can be considered as average absorption.
5. The resistance to chloride ion penetration of concrete as measured by the charge coulomb was significantly increased with incorporation of RHA. Thus, suggested that the presence of RHA resulted in lower coefficient of permeability, thus improves the durability of concrete.
6. From the study conducted, it was clearly shown that RHA is a pozzolanic material that has the potential to be used as partial cement replacement material and can contribute to the sustainability of the construction material.

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REFERENCES

ASTM C 1202: 1997. Test for electrical indication of concrete's ability to resist chloride ion penetration.

ASTM C 430: 2008. Standard Test Method for Fineness of Hydraulic Cement by the 45 µm (No. 325) sieve.

ASTM C 494/C 494M: 2010. Standard Specification for Chemical Admixtures for Concrete.

ASTM C 618:1992. Specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.

British Standard Institution - BS 1881-122:1983, Testing Concrete – Method for Determination of Water Absorption, London.

British Standard Institution - BS EN 12390-3:2000. Testing Hardened Concrete. Compressive Strength of Test Specimen. London.

British Standard Institution - BS EN 12390-8:2000. Testing Hardened Concrete. Depth of Penetration of Water under Pressure. London.

British Standard Institution - BS EN934: Part 2: 2009. Admixture for Concrete, Mortar and Grout: High range Water Reducing / Superplasticizing. London.

Chandra, S. (1997). Waste materials used in concrete manufacturing. Edited: Chandra, S. USA: Noyes Publication, ISBN 0-8155-1393-3, 1997, pp. 184-231.

Chopra, S.K., Ahluwalia, S.C., and Laxmi, S. (1981) Technology and Manufacture of Rice Husk Ash Masonry (RHAM) Cement. Proceeding of ESCAP/RCTT - 3rd. Workshop on Rice Husk Ash Cement, New Delhi.

Cook, D.J. (1984) Development of microstructure and other properties in rice husk ash –OPC systems. Proceeding of 9th Australasian Conference Mechanics of Structures and Materials, Sydney, pp. 355-360.

Department of Environment (DOE). (1988) Design of Normal Concrete Mixes. BRE Publication, UK.

Gambhir, M.L. (2006) Concrete Technology. 3rd Edition, New Delhi: Tata McGraw-Hill Publishing, ISBN 0-07-058374-9.

Hwang, C.L and Chandra, S. (1997) The Use of Rice Husk Ash in Concrete. Waste Materials Used in Concrete Manufacturing. Edited: Chandra, S., Noyes Publications, USA, p. 198.

Kartini, K, Mahmud, H.B., and Hamidah, M.S. (2004) The Influence of Superplasticizer on the Workability and Strength of RHA Concrete, Proceeding of the 7th International Conference on Concrete Technology in Developing Countries (ICCT) - Sustainable Development in Concrete Technology, ISBN-967-958-162-4, Editors- H.M.A. Al-Mattarneh, A.Ibrahim, Z. Ahmad, Kuala Lumpur, pp. 331-338.

Kartini, K. (2009) Mechanical, Time-Dependent and Durability Properties of Grade 30 Rice Husk Ash Concrete. PhD Thesis, University of Malaya, Malaysia, pp. 1-324.

Kartini, K. (2010) Rice Husk Ash in Concrete. University Publication Centre (UPENA), Shah Alam, Malaysia, ISBN 978-967-363-025-7.

Krishna, R.N. (2008). Rice Husk Ash – An Ideal Admixture for Concrete in Aggressive Environment. Recycling Construction Waste for Sustainable Development. Organized by CREAM, UiTM, ACCI and CSM, Kuala Lumpur.

Mehta, P.K. (1992) Rice Husk Ash – A unique supplementary cement material. Edited: Malhotra, V.M. Proceeding of International Conference on Advance in Concrete Technology – CANMET. Greece, pp. 407-431.

Shimizu, G., and Jorillo, P, Jr. (1990) Study on the use of rough and unground ash from an open heaped-up burned rice husk as a partial cement substitute. Proceeding of 2nd RILEM Symposium on vegetable plants and their fiber as building material, Brazil, Editor: Sobral, H.S., Chapman and Hall, London, pp. 321-333.

Speare, P.R.S., Eleftheriou, K., and Siludom, S. (1999) Durability of Concrete Containing Rice Husk Ash as an Additive, Exploiting Wastes in Concrete, Proceeding of International Seminar on Creating Waste in Concrete, Editors: Dhir, R.K. and Jappy, T.G., Thomas Telford Publication, Dundee, United Kingdom, pp. 283-290.

Sugita, S., Yu, Q., Shoya, M., Tsukinaga, Y., and Isojima, Y. (1997) The resistance of rice husk ash concrete to carbonation, acid attack and chloride ion penetration, High Performance Concrete, Proceeding of ACI International Conference, Malaysia, ACI SP-172(2), American Concrete Institute, Detroit, Michigan, pp. 29-43.