Performance of Concrete in presence of Supplementary Cementitious Material

M. A. Hossain*, M. H. Rashid, M. M. Rahman and O. U. Laz

***Abstract*— The increasing demand for producing durable construction materials which is essential for green environment. Supplementary cementitious materials have been proved to be effective to meet most of the requirements of durable concrete. Rice husk ash is found to be good performance to other supplementary materials like silica fume and fly ash. The objective of this research is to present the use of Bangladeshi RHA as partial replacement of cement in concrete production. Three different replacement levels namely 0%, 10% and 20% are chosen for the study concern. Long range of curing periods starting from 7 days, 14 days, 28 days, 90 days and 300 days are considered in the present study. Permeability of concrete is measured in terms of current passing through it at 14 days curing. The compressive strength of the concrete with 10% RHA has been increased significantly and for up to 20% replacement level could be beneficially without adversely affecting the strength. In addition, it can be noted that the permeability of concrete was decreased up to 6% in presence of 10% replacement of RHA and for 20% replacement it was decrease up to 14%. Rice husk ash (RHA) added to concrete influences the pH of the samples. In this study it was observed that addition of 10% & 20% RHA with OPC to the concrete, the time required for the equal pH in the anodic and cathodic compartment is more than the control sample which was indicated that rich cement mix exhibits better resistance of water with respect to normal and lean cement concrete.**

***Index Term*— RHA, pH, Permeability, Supplementary Material**

I. INTRODUCTION

Concrete is one of the crucial materials for infrastructure development due to its versatile application, globally its usage is second to water. For last few decades, there are many concerns raised for the continuous increase of cement use because of the reasons that the production of cement causes large amount of carbon dioxide (CO_2) emission and it also consume significant amount of natural rock and minerals that may lead to deplete at one point of time. Manufacture of one ton of Portland cement (PC) generates about one ton of CO_2 to the atmosphere which constitutes 5% global CO_2 emission [1, 2]. To build sustainable environment, it is necessary to control the emission of CO_2. Due to increase in the cost of conventional building materials and environmental hazard, the designers and developers are looking for 'alternative materials' to reduce the use of cement in civil engineering constructions [3]. For this objective, the researcher tries to use various waste products in concrete technology. Rice Husk Ash (RHA) is one of these waste products which is generated as a by product of rice paddy milling industries.

For rice growing countries like Bangladesh, rice husks have attracted more attention due to environmental pollution and an increasing interest in conservation of energy and resources. The concrete industry offers an ideal method to integrate and utilize a number of waste materials, which are socially acceptable, easily available, and economically within the buying powers of an ordinary man. Presence of such materials in cement concrete not only reduces the carbon dioxide emission, but also imparts significant improvement in workability and durability. Considerable efforts are being taken worldwide to utilize local natural waste and by-product materials in making concrete, such as Rice Husk Ash as supplementary cementing materials to improve concrete properties (durability, strength, etc.) [4]. The effect of using RHA as a partial replacement for cement has been investigated in this research.

RHA is a carbon neutral green product [5]. Lots of ways are being thought of for disposing them by making commercial use of this RHA. Rice-husk ash is a very fine pozzolanic material. The utilization of rice husk ash as a pozzolanic material in cement and concrete provides several advantages, such as improved strength and durability properties, reduced materials costs due to cement savings, and environmental benefits related to the disposal of waste materials and to reduced carbon dioxide emissions [6]. The chemical composition of Rice Husk is found to vary from sample to another due to the differences in the type of paddy, crop year, climate and geographical conditions [7]**.** Super-pozzolan can be used in a big way to make special concrete mixes. There is a growing demand for fine amorphous silica in the production of special cement and concrete mixes, high performance concrete, high strength, low permeability concrete, for use in bridges, marine environments, nuclear power plants etc.

Annually about 20 million tons of rice husk ash are produced from rice husks which are a waste product from the rice industry [8]. The silica content of the ash may be as high

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as 80-95% with residual carbon as the remaining ingredient [9]. The permeability of concrete plays an important role in durability because it controls the rate of entry of moisture that may contain aggressive chemicals and the movement of water during wetting or drying. The addition of microporous rice husk ash adsorb large amount of water surrounding the solid matter, producing a low water to binder ratio and refining the pore structure [10].

II. MATERIALS PROPERTIES

A. Rice Husk Ash

Rice husk ash is very rich in silica content. Silica content in RHA is generally more than 80–85%. For RHA to be used as pozzolan in cement and concrete, it should satisfy the requirements for chemical composition of pozzolans as per ASTM C618 [11]. The combined proportion of silicon dioxide (SiO_2), aluminium oxide ($A1_2O_3$) and iron oxide (Fe_2O_3) in the ash should be not be less than 70%, and LOI should not exceed 12% as stipulated in ASTM requirement. The chemical composition of RHA is shown in the Table I.

The Rice Husk Ash used in this research was made in the laboratory by simply burning rice husk over a steel box of 1.5 m X 1.5 m in dimension without controlling the burning temperature and time shown in Figure 2. In Figure 2, T is the position of thermocouple which was connected to the data logger and B is the position of briquette which was used as fuel to start and maintain a fire [12]. The temperature of the thermocouple was recorded with respect to time which is shown in figure 3. Rice husk was burnt for approximately 120 hours under uncontrolled combustion process. The burning temperature was within the range of 150 to 350^{0}C. The ash obtained was grinded in a ball mill for 30 minutes and its appearance color was grey as shown in figure 1(b). After completion of burning the ash was grinded by grinding machine and finally collected the ash which was paned through 200 No. BS sieve.

Fig. 1. (a) Rice Husk (b) Rice Husk Ash.
This rice hush were used to produce rich hush ash which is used further in this research.

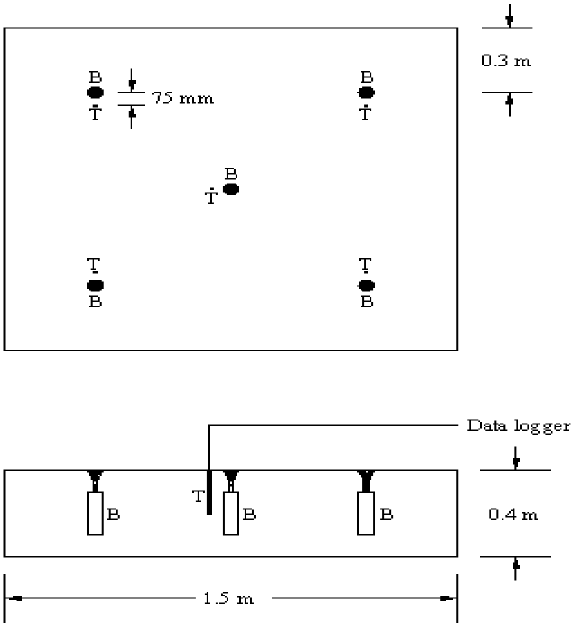

Fig. 2. Placement of briquette and thermocouple.

It was rich in amorphous silica (86.9%). The loss on ignition was relatively high (4%). Rice Husk ash has the potential to be used in concrete technology as substitute of silica fumes as a much lower cost without compromising on the quality aspect.

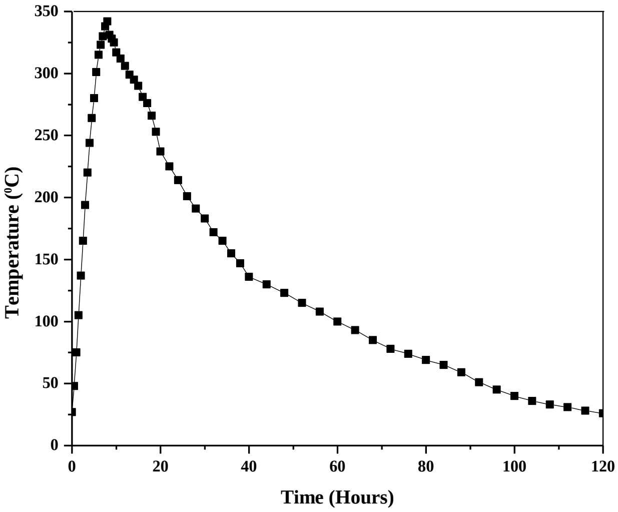

Fig. 3. Variation of Temperature in time during burning of rich husk. Figure 3 shows that the temperature gradually increase up to 25 hours burning and reached peak temperature of around 340°C. Then the temperature decrease gradually up to 100 hours. Latter on it is becomes stable in ambient temperature.

B. Aggregate

The fine aggregate used in this project was river sand with Fineness Modulus of 2.73, absorption of 3.0 %, unit weight of 1.68 gm/cc and specific gravity of 2.55 gm/cc. Crushed stone was used in this study as coarse aggregate which possess maximum size of 20 mm with specific gravity of 2.83 and water absorption of 1.53 %. A grain size distribution curve for coarse aggregate is shown in Figure 4.

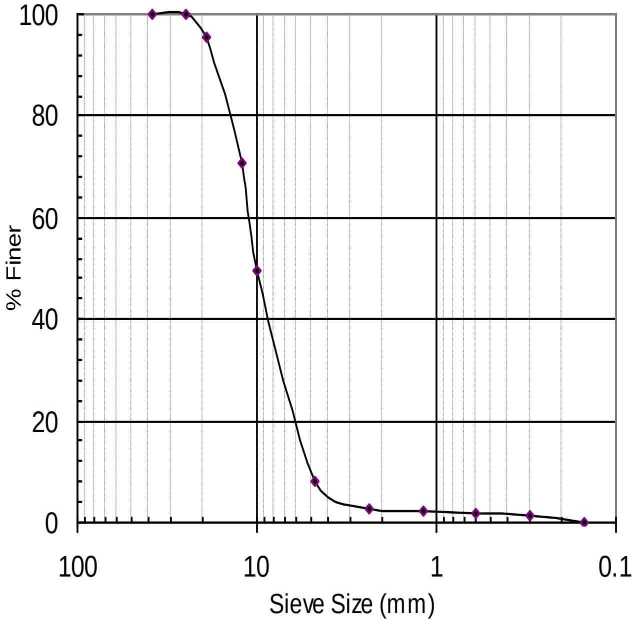

Fig. 4. Gradation curve of coarse aggregate. This curve was also obtained after sieve analysis which was performed according to ASTM C136 [13].

C. Cement

In this research Ordinary Portland Cement (ASTM Type-1) [14] was applied with 3 days compressive strength of 17.7 MPa, 7 days compressive strength of 21.2 MPa, 28 days compressive strength of 35.9 Mpa. The physical properties and chemical composition of cement is shown in Table I and Table II respectively.

TABLE I
Physical Properties of Cement

	Description	ASTM Standard Requirement	Test Result
Fineness	Sieve No. 200 residue (%)	-	1.96
	Blaine (m^2/Kg)	280	441.2
Setting Time	Consistency (%)	-	25.00
	Initial Setting (min)	Not Less Than 45 min.	86
	Final Setting (min)	Not More Than 375 min.	235
Compressive Strength (MPa)	Age (Day)	MPa	MPa
	3	Min 12	17.7
	7	Min 19	21.2
	28	Min 28	39.5

TABLE II
Chemical Composition of Cement and RHA

Compound	Cement (%)	RHA (%)
SiO_2	31.51	86.9
Al_2O_3	4.14	0.68
Fe_2O_3	3.28	0.49
CaO	52.76	0.89
MgO	1.27	1.47
SO_3	2.48	0.82
LOI	2.08	3.88
IR	0.45	2.39
Free Lime	1.064	1.016

D. Water

Drinkable tap water was used in this research.

III. Composition of Concrete Mixes

The total mixing period was maintained 5 minutes. The samples were casted and left for 24 hrs before demoulding [. These were then placed in the curing tank at 23 ± 2°C until the day of testing. The water cement ratio 0.55 was constant for all samples. Mixing proportion of concrete samples was given in the Table III.

TABLE III
Proportion of Investigated Mixtures

Mix	Cement (kg)	RHA (kg)	% of RHA	FA (kg)	CA (kg)
RC0	500	0	0	600	1100
RC10	450	50	10	600	1100
RC20	400	100	20	600	1100
NC0	500	0	0	1000	1750
NC10	450	50	10	1000	1750
NC20	400	100	20	1000	1750
LC0	500	0	0	1750	2750
LC10	450	50	10	1750	2750
LC20	400	100	20	1750	2750

IV. Experimental Investigation

A. *Permeability Testing Procedures*

Khulna is one of the coastal regions in Bangladesh and the salinity concentration of this region is very high. The concrete which is exposed to a salt environment is subject to chloride penetration, resulting in extensive deterioration and premature failure. An effective preventive measure is to use high performance concrete with very low permeability, thus minimizing the intrusion of aggressive solutions. The concept of a low-permeability concrete created a need for a rapid and reliable material test method for quality assurance and quality control purposes. The lower quality concrete at a constant voltage the greater charge passed. Hence its permeability is high.

Durability of concrete is very sensitive to presence of water in its hardened body and water is also the carrier of aggressive material such as chloride ions through it. The rapid chloride permeability test (RCPT) was originally developed for the Federal Highway Administration (FHWA) by the Portland

Cement Association. The results were found to correlate well with those of the commonly accepted ponding test, which take approximately 90 days to complete [15]. RCPT integrates current passing through a disk of saturated concrete over a 6 hour period, resulting in an electrical charge measurement expressed numerically in coulombs. The test has been adopted as a specification tool by many agencies concerned with preventing chloride-induced damage to reinforced concrete.

A schematic diagram of the device used in this study is shown in Figure 6. Instrument used for measuring the permeability of concrete was a voltage generator, potentiometer analyzer, magnetic agitator and diffusion cell. The diffusion cell is a cylindrical PVC tank covered with a lid. The test tube is a cylindrical core of concrete (100-mm diameter and 100-mm height) in which a secondary drilling produces a central cavity of 40-mm diameter as presented in Figure 5.

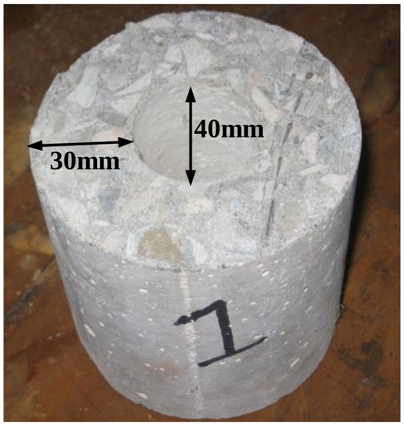

Fig. 5. Sample for the determination of chloride ion permeability and pH.

This tube was fixed firmly in the cell by the intermediary of a hollow PVC roll. The sample delimits two compartments sealed by two elastomer membranes. The external compartment contains 0.1M/L of NaCl. This solution was homogenized periodically by mechanical agitation. A cylindrical stainless steel electrode dips in this solution and was connected to the negative pole of the generator. The internal compartment contains 0.1 M/L NaOH uninterruptedly homogenized by magnetic agitation. A carbon electrode dips in this solution and was connected to the positive pole of the generator.

The amount of chlorides that diffuses through the porous tube of concrete is followed with a great sensitivity using a chloride probe. The detailed fabrication of the testing procedure and device can be followed of AASHTO (1990) [15], ASTM (1993) [16] and also Streicher et. al. (1995) [17]. The overall test setup for determination of pH was shown in Figure 7. The system was then connected and a 30-volt DC current was applied for 6 hours. Readings were taken at every 30 minutes interval and recorded against time. At the end of 6 hours, the sample was then removed from the cell and the amount of coulombs passed through the specimen was calculated.

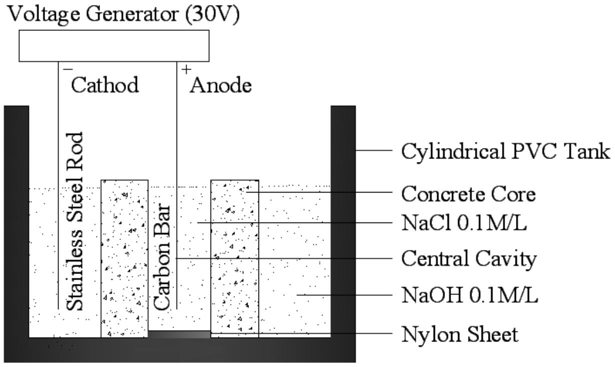

Fig. 6. Schematic diagram of chloride migration.

Fig. 7. Test setup for the determination of pH and charges passed in concrete.

V. RESULTS AND DISCUSSIONS

A. *Compressive Strength*

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses. Therefore, the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength on 100-mm cube specimens at age of 7, 14, 28, 90, 180 and 300 days was tested as accordance to ASTM C 873 [18].

The average compressive strength test results of three concrete samples is shown in Table IV.

TABLE IV
PROPORTION OF INVESTIGATED MIXTURES

Mix	Strength (Mpa)				
	7 Days	14 Days	28 Days	90 Days	300 Days
RC0	11.59	13.72	15.72	18.88	20.77
RC10	11.03	12.72	15.46	21.82	25.97
RC20	10.68	12.55	15.28	19.36	24.20
NC0	14.18	16.15	18.83	20.48	27.14
NC10	13.31	15.21	18.45	24.65	36.85
NC20	12.89	14.99	18.25	23.07	28.93
LC0	5.80	6.81	7.32	9.01	15.55
LC10	5.77	6.8	7.4	10.67	17.34
LC20	5.60	6.42	7.04	9.75	14.22

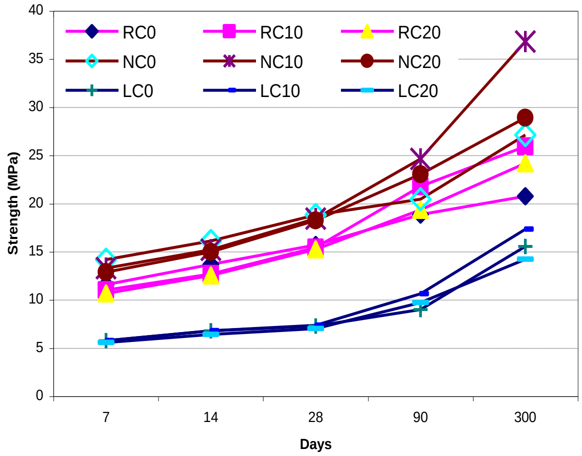

Fig. 8. Variation of Compressive Strength of RC mix.

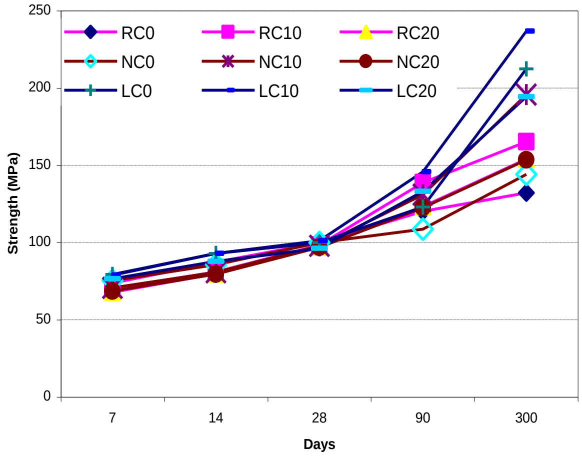

Fig. 9. Variation of Compressive Strength of NC mix.

B. *Permeability*

Permeability is most frequently described by the chloride-ion permeability test, which measures the passage of electrical current through a concrete specimen exposed to a batch of sodium chloride. The permeability of concrete depends on the pore structure of concrete while electrical conductivity of concrete is determined by both pore structure and the chemistry of pore solution [19]. The electric charge passes through the concrete sample is given in Table V.

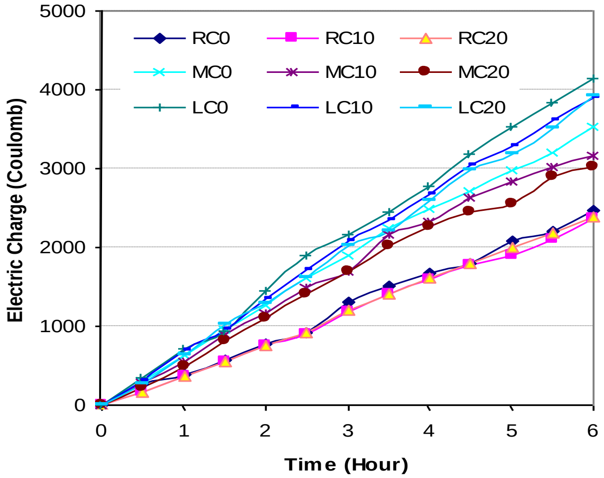

Fig. 10. Electrical Charge Vs. Time curve of different mix.

Figure 10 shows that rich mix proportion that is high cement content shows lower electric charge or chloride ion permeability. While adding rice husk ash to the ordinary portland cement the permeability is also decrease for all compositions. RC mix exhibits lower permeability with respect to NC and LC mix.

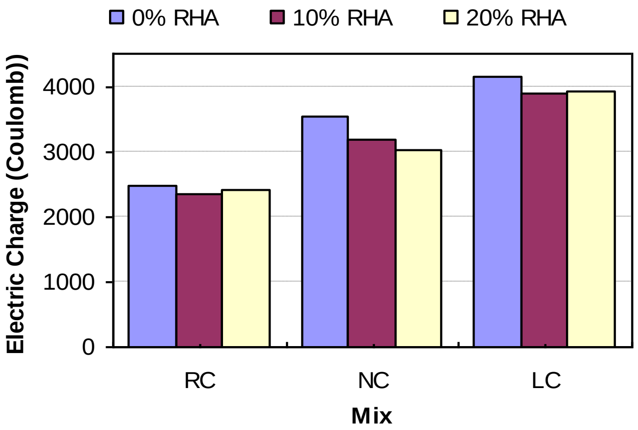

Fig. 11. Variation of permeability of different mix.

Figure 11 shows that rice mix proportion that is high cement content shows lower electrical charge or chloride ion permeability. The permeability of concrete is decreasing with the addition of Rice Husk Ash for all mixing proportions.

C. *pH*

The concentration of hydrogen ions is commonly expressed in terms of the pH scale. pH is a measure of how acidic or alkaline a substance is. The pH scale goes from 0 to 14, where 7 indicate neutral. A low pH value means that the sample is acidic, while a high pH value means that the sample is basic or alkaline. The pH decreases in the anodic compartment but increases in the cathodic compartment while connected to the DC current. These variations are directly related to the nature of the reactions that occur during the test. As the potential is applied between the electrodes, the hydroxide ions migrate toward the anode, where they oxidize by giving oxygen and yielding electrons (Equation 1)

$$2OH^{-} \rightarrow 1/2\ O_2 + H_2O + 2e^{-} \qquad (1)$$

Simultaneously, sodium ions migrate toward the cathode. They do not react directly but the surrounding molecules of water are electrolyzed, giving directly hydroxide and hydrogen. The electrons provided by the cathode are those that comes from the anodic reaction (Equation 2)

$$2H_2O + 2e^{-} \rightarrow H_2 + 2OH^{-} \qquad (2)$$

The electrolysis phenomenon appears to be the main process that occurs during the accelerated test of concrete chloride ion permeability [17].

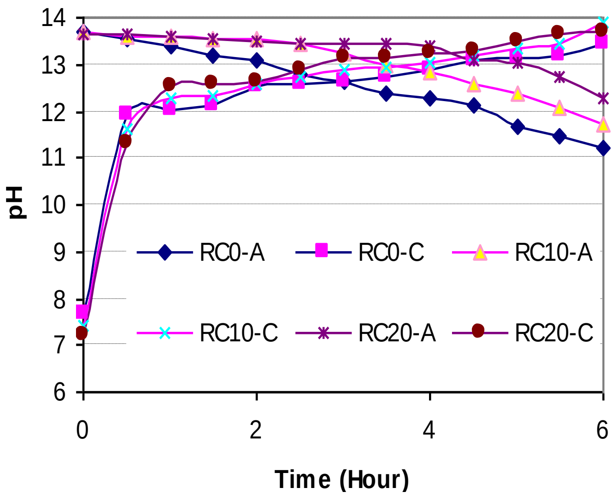

Fig. 12. pH variation over time in anodic and cathodic compartment of RC. In this figure, A mentioning Anodic Compartment and C indicates Cathodic Compartment. The controlled mix takes about 3.0 hours for equal pH values in the two compartments but sample of 10 and 20% RHA addition shows higher time to reach at that equal point.

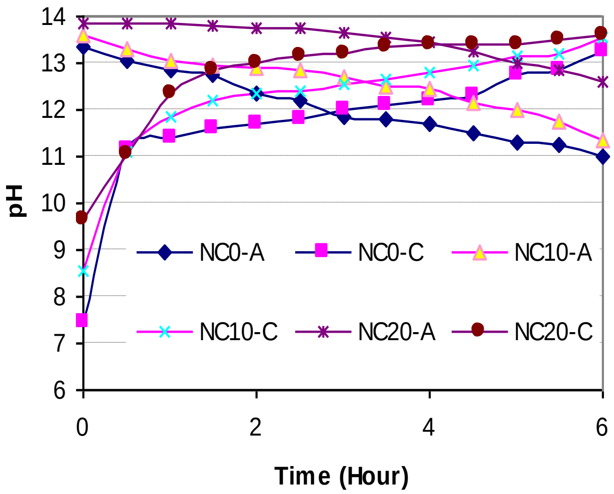

Fig. 13. pH variation over time in anodic and cathodic compartment of NC. In this figure, A mentioning Anodic Compartment and C indicates Cathodic Compartment.

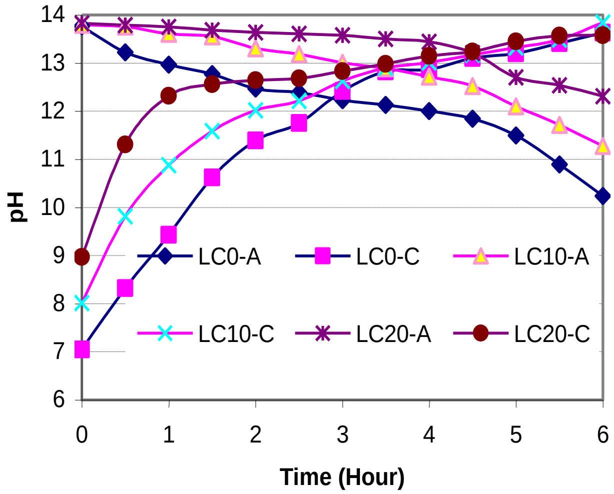

Fig. 14. pH variation over time in anodic and cathodic compartment of LC. In this figure, A mentioning Anodic Compartment and C indicates Cathodic Compartment.

Figures 12, 13 and 14 show that pH decreases in the anodic compartment but increases in the cathodic compartment with increase of time. Time required for equal pH in the anodic and cathodic compartment observed same nature for all mixing proportion. Addition of RHA in the concrete prolonged the time for same values of pH in both compartment regarding the controlled sample. It occurs due to the RHA fills the void spaces of cement particles and thus makes the concrete dense [25].

TABLE V
VARIATION OF PERMEABILITY AND PH

Mix	% of RHA	EC*	Time** (Mins)	pH Variation	
				Anode Decrease	Cathode Increase
RC0	0	2473	175	2.49	5.79
RC10	10	2360	218	1.94	6.47
RC20	20	2395	256	1.39	6.50
NC0	0	3532	173	2.33	5.82
NC10	10	3186	202	2.20	5.01
NC20	20	3024	263	1.26	3.36
LC0	0	4147	173	2.53	6.58
LC10	10	3890	210	2.53	5.84
LC20	20	3920	268	1.52	4.61

* Electric Charge in coulomb.
**Time required to equal pH in anodic and cathodic compartment.

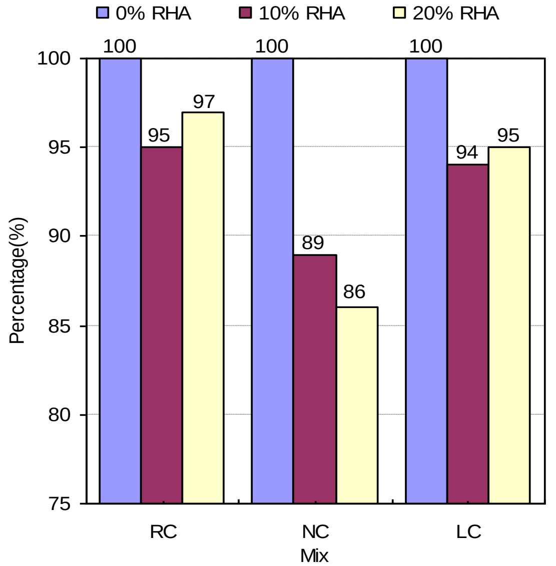

Fig. 15. Percentage Variation of Permeability considering the Permeability of 0% RHA as 100 percentages.

For RC mix, permeability is decreases about 5% and 3% respectively for 10% and 20% replacement of cement with respect to 0% RHA sample. For NC mix, permeability is decreases about 11% and 14% respectively for 10% and 20% replacement of cement with respect to 0% RHA sample. For LC mix, permeability is decreases about 6% and 5% respectively for 10% and 20% replacement of cement with respect to 0% RHA sample. So from the above figure, it is concluded that the permeability of concrete is decreases with addition of rice husk ash for all mixing proportions.

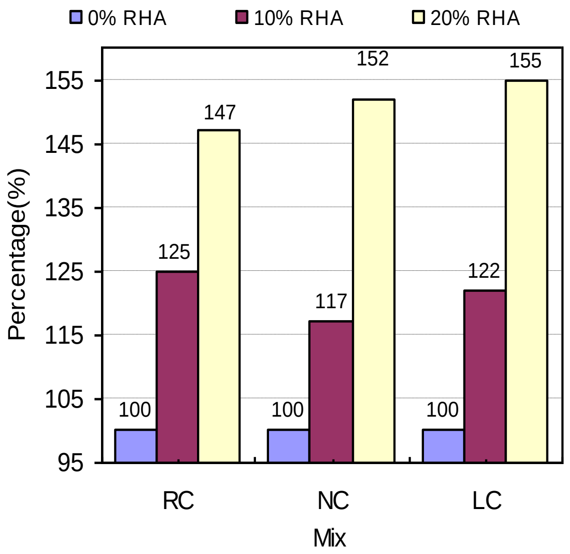

Fig. 16. Percentage Variation of Time requires to equal pH in anodic and cathodic compartment considering the time requires to equal pH in anodic and cathodic compartment of 0% RHA as 100 percentages.

Figure 16 reveals that while RHA is added to the control mixes, times required to equal pH in both compartments is increases. During this test, hydrogen ion moves one compartment to another. By replacing 10% RHA to concrete about 25% more time required compared to 0% RHA mix and for 20% replacement about 47% more time compared to 0% RHA mix for rich cement mix. Similar results are also found for NC mix and LC mix. This result is obtained due to the RHA fills the void between cement particles and thus the movement of hydrogen ion slows down.

VI. CONCLUSIONS

Experimental results show that reasonable improvements in compressive strength and chloride ion permeability resistances of concrete occur while adding RHA to the concrete. For rich and lean cement content mixes, the strength of concrete was decreased due to presence of Rice Husk Ash but increased for normal cement content. The concrete made with RHA had higher compressive strength at 90 days in comparison with that of concrete containing 0% RHA. However, at 14 and 28 days the strength is different. The compressive strength of concrete increased by 15.6% for 10% replacement level of cement by RHA and for 20% replacement, the result was not significant.

Permeability is a complex phenomenon and can not be totally prevented but can be minimized. From the study, it was observed that addition of RHA in the cement content decrease the permeability. For NC samples, the permeability was decreased up to 14 % with the addition of RHA to the concrete. But for the rich and lean mix, permeability was not decreased significantly.

pH is also one of the other indicator for the permeability. In this investigation, it was observed that more time required for equal pH in anodic and cathodic compartments in the core of concrete for using 10% and 20% RHA than 0% RHA samples. It also indicates that the concrete made with RHA was more compact than the concrete with 0% RHA.

REFERENCES

[1] Nuruddin, M. F., Demie, S., Ahmed M. F. and Shafiq, Nasir, "Effect of Superplasticizer and NaOH Molarity on Workability, Compressive Strength and Microstructure Properties of Self-Compacting Geopolymer Concrete," *World Academy of Science, Engineering and Technology*, pp. 908-915, 2011.

[2] Nuruddin, M. F., Quazi, S., Shafiq, N., Kusbiantoro, A., "Compressive Strength & Microstructure of Polymeric Concrete Incorporating Fly Ash & Silica Fume", *Canadian Journal of Civil Engineering,*1(1), pp. 15-18, 2010.

[3] Elattar S. M. S., "Towards a Global Vision for Building Technology Future," *European Journal of Scientific Research*, ISSN 1450-216X, Vol.30, No.3, pp.495-504, 2009.

[4] Rashid, M. H., Molla, M. K. A. and Ahmed, T. U., "Mortar Incorporating Rice Husk Ash: Strength and Porosity," *European Journal of Scientific Research*, ISSN 1450-216X Vol.40 No.3, pp.471-477, 2010. Available: http://www.eurojournals.com/ejsr.htm

[5] Tuan, L. A., Thuy, N. N., Moon, K. H. and Hung, T. N., "Influence of Blast Furnace Slag and Rice Husk Ash on Strength Properties of Compressed Cement-soil Materials," *The* 3^{rd} *ACF International Conference- ACF/VCA*, 2008 pp. 281-288.

[6] Karim, M. R., Zain, M. F. M., Jamil, M., Lai, F. C. and Islam, M.N., " Necessity and Opportunity of Sustainable Concrete from Malaysia's Waste Materials," *Australian Journal of Basic and Applied Sciences*, ISSN 1991-8178, 5(5), pp. 998-1006, 2011.

[7] Chandrasekhar, S., Pramada, S.K.G. and Raghavan, P.N.," Review Processing, Properties And Applications of Reactive Silica From Rice Husk-An Overview, *Journal Of Materials Science*, Vol. 38, pp. 3159-3168, 2003.

[8] Gidde, M. R. and Javani, A. P., "Waste to Welth- Potential of Rice Husk in India a Literature Riview," in *Proc. of the Int. Conference on cleaner Technologies and Environmental Management PEC*, Pondicherry, India, January 4-6, 2007, pp. 586-590.

[9] Hwang, C. L. and Chandra, S., "The Use of Rice Husk Ash in Concrete," in *Waste Materials Used in Concrete Manufacturing*, William Andrew Publication, 1996, pp. 184-234.

[10] Mehta, P. K.," Pozzolanic and Cementitious By-products as Mineral Admixtures for Concrete-A Critical Review," *ACZSP-79*, Detroit, MI, pp. l-46, 1983.

[11] ASTM. 2008. *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, ASTM C618 – 08a, Annual Book of American Society for Testing Materials Standards, Vol. C 04.02.

[12] Kartini, K., Mahmud, H.B. and Hamidah, M.S," Absorption and Permeability Performance of Selangor Rice Husk Ash Blended Grade 30 Concrete," *Journal of Engineering Science and Technology*, Vol. 5, No. 1, pp.1 – 16, 2010.

[13] ASTM. 2006. *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*, ASTM C136-06, Annual Book of American Society for Testing Materials Standards, Vol. C 04.02.

[14] ASTM. 2003. *Standard Specification for Portland Cement.* ASTM C150 /C150M - 11, Annual Book of American Society for Testing Materials Standards, Vol. C 04.01.

[15] AASHTO.1990. *Rapid Determination of the chloride Permeability of concrete*, AASHTO T 277-86, American Association of States Highway and Transportation Officials, Standard Specifications - Part II Tests, Washington, D. C.

[16] ASTM. 1993. *Electrical Indication of concrete's Ability to Resist chloride Ion Penetration*, ASTM C1202, Annual Book of American Society for Testing Materials Standards, Vol. C 04.02.

[17] Streicher, P.E. and Alexander, M.G.," A Chloride Conduction Test for oncrete," *Cement and Concrete Research*, Vol. 25, No. 6, pp. 1284-1294, 1995.

[18] ASTM. 2010. Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds, ASTM C873 /C873M – 10a, Annual Book of American Society for Testing Materials Standards, Vol. C 04.02.

[19] Prince, W., Pĕrami, R and Espagme, M.,"Mechanisms involved in the accelerated test of chloride permeability," *Cement and concrete Research*, Vol. No. 29, pp. 687-694, 1999.