STUDYING THE EFFECT OF USING A CONSIDERABLE PROPORTION OF RICE HUSK ASH AS A CEMENT REPLACEMENT ON CONCRETE PROPERTIES

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ABSTRACT

This paper investigates the influence of using a considerable proportion of Rice Husk Ash (RHA) on different properties of concrete containing RHA as a cement replacement material. Four concrete mixtures with RHA and chemical admixtures were selected and designed to have the same degree of workability. The Ordinary Portland Cement (OPC) was replaced with 0%, 20%, and 40% of RHA (by weight) keeping the ratio of the water / cementitious material at a constant value of 0.5. The measured parameters represent properties of fresh concrete such as slump, air content, and unit weight, and those of the hardened concrete such as compressive strength, tensile strength, flexural strength, static Young's modulus, horizontal and vertical dynamic Young's modulus, Poisson's ratio, and pulse velocity. Moreover, the chloride ions permeability and chloride diffusion coefficient were measured using Potentiometric Titration Analysis (PTA). Furthermore, the pore structure, which include total pore volume, total porosity as well as total pore surface area were investigated using Mercury Intrusion Porosimetry (MIP). The obtained test results indicated that RHA can be used as a cement replacement material in concrete with considerable proportion and the use of RHA in the concrete as blending materials improved the different characteristics of the concrete product. Also, RHA concrete showed a significant resistance to chloride penetration. In this paper, experimental program, test results and analysis as well as conclusions are presented.

INTRODUCTION

Rice is one of the agriculture plants that contains a large amount of silicate especially in the husk [1]. The controlled combustion of rice husk makes the resulting ash highly pozzolanic [2,3]. A combustion temperature below 600 ^{o}C is adequate to provide ash containing silica in amorphous pozzolanic state [1,2]. The production of one ton of rice paddy generates about 200 kg of rice husk, which in turns produces 40 kg of ash [3]. Usually the colour of RHA is light gray to black depending on the burning conditions.

Due to growing environmental concerns and the need to conserve energy and resources, efforts have been made to burn the rice husks at a controlled temperature and atmosphere, and to utilize the ash so produced as a supplementary cementing material [4,5]. A state-of-the-art report on RHA was published by Mehta [6] in 1992 that contains a review of physical and chemical characteristics of RHA, the effect of incineration conditions on the pozzolanic properties of the ash, and a summary of the research findings from several countries on the use of RHA as a supplementary cementing material [7].

Most of the published data on chloride penetration are based on investigations which involved exposure of concrete to solutions of individual chloride salts such as calcium chloride or sodium chloride [8]. However, it is known that the rate of chloride diffusion into concrete may be considerably affected by the type of cation associated with the chloride. For instance, the chloride penetration is substantially higher from a solution of calcium chloride than from a solution of sodium chloride of the same chloride concentration [9]. Experiments also indicate that resistance to chloride penetration is affected by the type of cement [10]. It appears, therefore, that the diffusion of chloride into concrete is the result of a more complex mechanism where ion exchange between the permeating solution and the pore solution present in concrete plays an important role.

The porosity of the cement paste is subdivided into large and small pores. The small pores increase in volume with an increase in bound water content and are associated with the gelatinous products of cement hydration. The large pores originate from the space left by the mix water and the space vacated by the hydrated cement. These spaces are partly filled with the products of hydration and their associated small pores. This description of the phases in hydrated cement derives from the work of Powers and Brownyard [11]. The studies of Parrott [12] suggest that the porous gel in hydrated cement will shrink, even with quite moderate drying. The shrinkage of the gel seems to derive from a reduction in volume of the small pores, without any change in total porosity. Thus the volume of large pores is increased and the rate of diffusion is correspondingly increased [13]. Therefore, the pore structure of concrete, perhaps more than any other characteristic of the materials, affects the behavior of the concrete [14]. This influence is such important that the strength, durability, and permeability of certain materials can be estimated.

MAIN PROPERTIES OF RICE HUSK ASH

The specific gravity of RHA (2.25) is about two-thirds the specific gravity value of OPC (3.16). Analysis of the chemical composition of the RHA showed that the combined proportion of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) in the RHA was 93.25%. This satisfies the ASTM C618-78 requirement for chemical composition, which stipulates a minimum combined proportion of 70% [15]. The carbon content of the RHA determined as loss on ignition, was 3.3%. This also satisfies the ASTM requirement for loss on ignition, which should not exceed 12%.

The grinding time of RHA was investigated by increasing it gradually from 5 to 120 minutes to study the change in the specific surface area. The specific surface area was determined by using Blaine fineness test. From the results of the fineness and the grinding time, it is concluded that the prolongation of grinding time more than 60 minutes does not affect the specific surface area by significant value. Whereas, the effect of increasing the grinding time from 5 to 10 minutes is significant, which is reflected in the results of the particle size. The RHA grinding time is abbreviated here as RHA_{10} and RHA_{60} , where 10 and 60 in the subscript indicate the time in minutes. The specific surface area of RHA_{10} and RHA_{60} are 18460 cm^2/g and 28790 cm^2/g, respectively.

The pozzolanic activity of RHA was examined by the method based on variation in electric conductivity of RHA in a saturated $Ca(OH)_2$ solution [16]. In this procedure, the electric conductivity of saturated $Ca(OH)_2$ solution [200 ml at 40 ^{o}C] was initially measured and then 5 grams of the RHA was added to the solution, stirred and the variation in electric conductivity after 2 minutes was determined. The variation in electric conductivity relates the possibility to show the pozzolanic activity. According to Sugita et al [1], the pozzolanic activity can be estimated using the variation in electric conductivity. The variation in electric conductivity of RHA_{10} and RHA_{60} are 0.7 mS/cm and 0.9 mS/cm, respectively, indicating that RHA_{10} and RHA_{60} fall within the range of variable pozzolanic [17].

The water / cementitious material ratio of the standard OPC - RHA pastes increases with increasing the RHA content and water / cementitious material ratios of OPC - RHA_{10} pastes are larger than those of OPC - RHA_{60} pastes. The initial and final setting times of OPC-RHA_{10} pastes increase with increasing of the replacement percent but the initial setting time of OPC - RHA_{60} pastes decreases when the replacement percent increases. On the other hand, the final setting time of OPC - RHA_{60} pastes increases with the increase in the replacement percent. The results indicated that the setting times were still within the recommended range for OPC paste [18]. Also, The results agree with the findings of Cook et al [19] who reported increases in setting times of OPC-RHA pastes over those of plain cement paste. Determination of these properties was undertaken at the facilities of Structural Materials Laboratory (Civil Engineering Department, Kyoto University, Kyoto, Japan) according to the specifications provided by Japanese Industrial Standard (JIS).

EXPERIMENTAL PROGRAM OUTLINE

Four concrete mixtures were studied using a constant value of water / cementitious material ratio of 0.5 and sand / aggregate ratio of 0.5. The measured parameters represent : (a) properties of fresh concrete including slump, air content, and unit weight, (b) properties of hardened concrete including compressive strength, tensile strength, flexural strength, static and dynamic Young's modulus, Poisson's ratio, pulse velocity, (c) chloride ion permeability, which involve total and soluble chloride contents as well as the chloride ion diffusion coefficient, and (d) pore structure, which include cumulative pore volume, total porosity, pore size and its distribution as well as total pore surface area. The concrete mixtures were designed to achieve slump of 10 ± 1 cm. The mix proportions details of concrete mixtures are summarized in Table 1. The materials that are involved in the experimental work have been selected from local sources in Japan. The properties of the used Ordinary Portland Cement (OPC) comply with JIS. The used sand has 2.58 specific gravity, 2.76 of fineness modulus and 1.37 % of the water effective absorption. The coarse aggregate is crushed basalt of 2.61 specific gravity, 15 mm of nominal maximum size, and 6.9 of fineness modulus. The used chemical admixture is high performance type of superplasticizer (high range water reducing agent).

Table 1: Mix proportions details of the studied concrete.

Mix No.	1	2	3	4
Replacement, percent	0.0	20	20	40
RHA type	---	RHA_{10}	RHA_{60}	RHA_{60}
OPC, kg/m^3	336	304	272	216
RHA, kg/m^3	----	76	68	144
Water, $litre/m^3$	168	190	170	180
Sand, kg/m^3	900	825	879	836
Gravel, kg/m^3	911	835	890	846
Admixture (ml/m^3)	2520	15200	6800	14400
Sand/total aggregate, ratio	0.5	0.5	0.5	0.5
Water/(OPC +RHA), ratio	0.5	0.5	0.5	0.5

The materials batched into the mixer are as follows : first; coarse aggregate followed by sand, then OPC and RHA, previously mixed adequately together, added to the mixer. The total mixing time is five minutes divided into two stages, starting with two minutes dry mixing and then the required water (mixed with chemical admixture) is added for the next three minutes of mixing. After casting, the concrete specimens were compacted by the use of a vibrator. The samples were finished, stripped from their molds the day after casting and kept in moisture for 28 days. The compressive strength was measured at 3, 7, 28 and 90 days while the tensile strength, flexural strength, static Young's modulus, Poisson's ratio, dynamic Young's modulus as well as the pulse velocity were measured at 28 days.

After 28 days of water curing, concrete specimens (Prisms of 10 x 10 x 40 cm^3) were firstly used to measure the non-destructive parameters (pulse velocity and dynamic modulus of elasticity). Secondly, the flexural test was performed. The parts of prism were put in 5% of sodium chloride solution. Three samples were taken from the outer 30 mm of concrete prisms surfaces which represent the concrete cover (from depths of 0~10, 10~20, and 20~30 mm) after 1, 2, 3, 4, and 5 months. The procedures, equipment, and apparatus used to measure pore structure and chloride contents are described in details in reference [17].

FRESH AND HARDENED CONCRETE PROPERTIES

The obtained test results of the measured properties of fresh concrete which include slump, air content, and unit weight are listed in Table 2. The measured values of slump fall within the range of 10 ± 1 cm. The Values of slump were achieved with trial mixes and incorporating different dosages of the used chemical admixtures. The percentages of air content ranged from 2.3 % to 1.8 % and it decreased with increasing the percentage of RHA. Also, the measured unit weight of RHA concrete decreased with increasing the replacement percent due to the change in the specific gravity of both OPC and RHA as shown in Fig. 1.

Table 2 : Properties of fresh concrete.

Mix No.	Slump (mm)	Air content (%)	Unit weight (t/m^3)
1	9.7	2.3	2.392
2	10	2.1	2.319
3	9.5	2.0	2.312
4	11	1.8	2.262

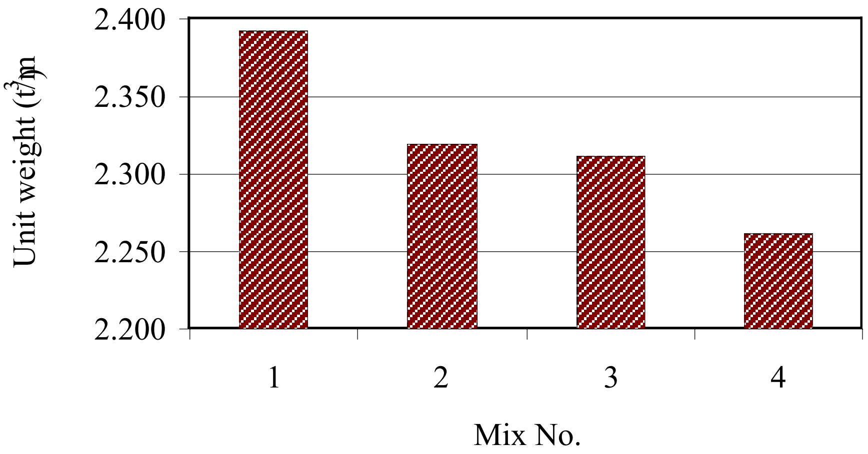


Fig. 1 : Unit weight of studied concrete mixtures.

Table 3 represents the obtained test results of the hardened concrete properties. The measured values of the compressive strength indicate that RHA has significant effect on the results especially in the early ages. The compressive strength results of RHA concrete mixtures after 28 days show higher values than that of OPC concrete and it is possible to get compressive strength over 500 kg/cm^2 at 28 days with 20 % replacement percent of RHA as shown in Fig. 2. The results of tensile strength and flexural strength at 28 days are shown in Fig. 3. In general, RHA concrete mixtures show higher values than that of OPC concrete for both the tensile strength and flexural strength. From the data listed in Table 3, RHA$_{60}$ concrete mixture shows higher values of compressive, tensile, and flexural strengths than those of RHA$_{10}$ concrete mixture for the same replacement percentage (mix 2 and 3 of 20 %).

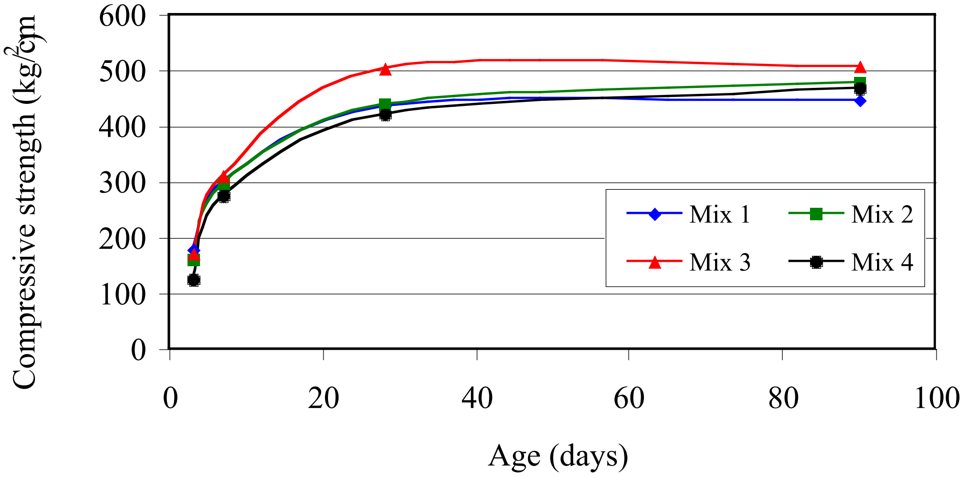


Fig. 2 : Compressive strength of studied concrete mixtures with time.

Table 3 : Properties of hardened concrete.

Property		Age	Mix 1	Mix 2	Mix 3	Mix 4
Strength (kg/cm^2)	Compressive	3-days	180	159	170	125
		7-days	299	295	309	276
		28-days	436	441	502	422
		90-days	446	478	507	468
	Tensile	28-days	39	46	51	40
	Flexural		61	76	80	72
Young's Modulus (x10^5 kg/cm^2)	Static (E_s)		3.62	3.59	3.93	3.61
	Dynamic (E_h)		4.10	4.01	4.09	3.40
	Dynamic (E_v)		4.29	4.18	4.27	3.53
Poisson's ratio			0.210	0.212	0.214	0.206
Pulse velocity (km/sec)			4.52	4.51	4.48	4.35

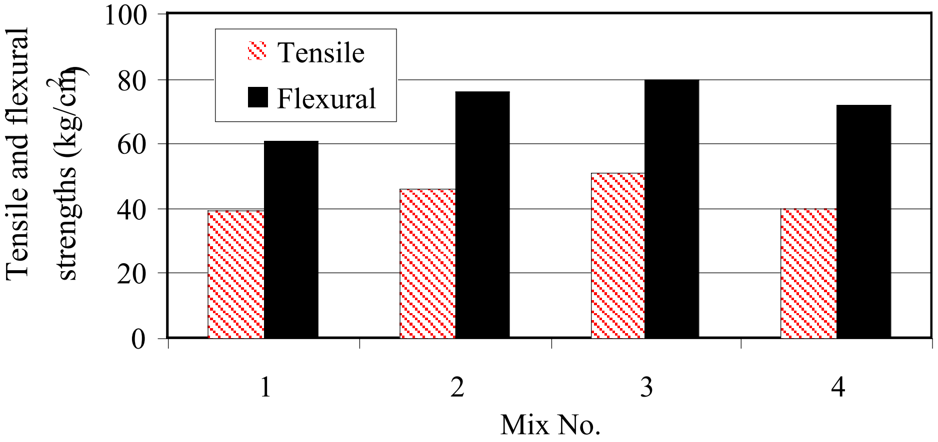


Fig. 3 : Tensile and flexural strengths of the studied concrete mixtures at 28 days.

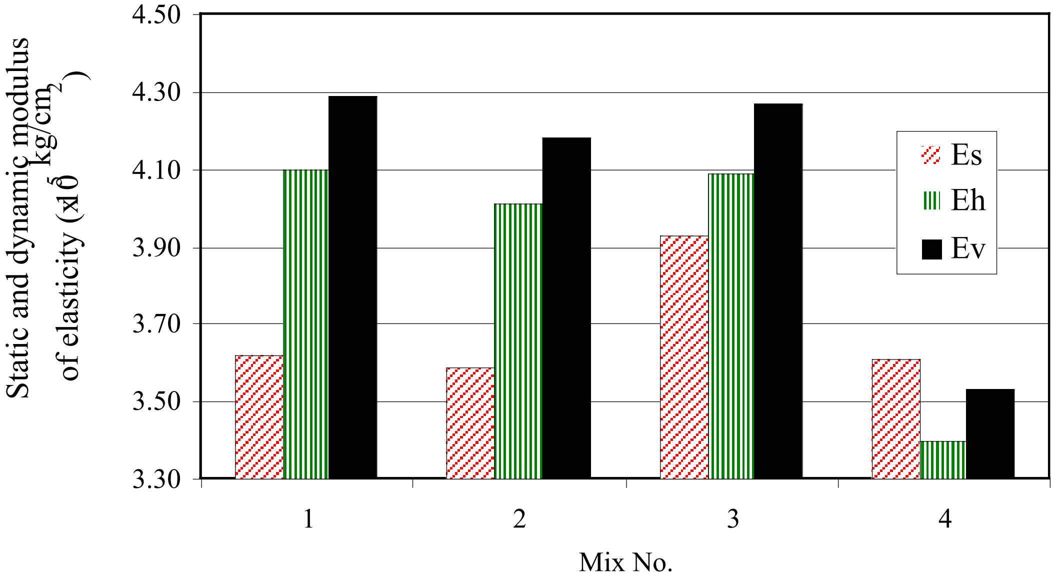


Fig. 4 : Static and dynamic Young's modulus of the studied concrete mixtures at 28 day.

Also, concrete mixes 2 and 3 show higher values of strengths than that of OPC concrete mix. The measured values of static Young's modulus (E_s) of RHA concrete mixes were approximately the same as the value of OPC concrete mix except for mix 3 that shows (E_s) higher than those of mixes 1, 2, and 4 as shown in Fig. 4. Also, Fig. 4 shows that RHA concrete mixes give approximately the same values of the horizontal (E_h) and vertical (E_v) dynamic Young's modulus as the control mix except mix 4 which shows lower values than those values of mixes 1, 2, and 3. This could be attributed to the use of high replacement percentage of RHA_{60} (40%) in mix 4. The results of Poisson's ratio and pulse velocity of OPC and RHA concrete mixes are approximately the same.

CHLORIDE ION PERMEABILITY

With the increasing use of RHA as a cement replacement materials in recent years, the data regarding mechanical properties and durability has become essentially required. The important items related to the mechanical properties of RHA concrete are presented in Table 3. Powdered samples for chloride analysis were obtained by the procedure explained in reference [17] in details. The powdered samples were analyzed for their soluble and total chloride contents by the titration method. The results of chloride contents which are listed in Table 4 and Table 5 were the average of two tested samples. From the chemical analysis results, the distribution of chloride concentration at different depths were plotted to obtain the chloride concentration profiles as shown in Fig. 5 and Fig. 6 for total and soluble chloride contents, respectively.

Table 4 : Total chloride ion as percentage by weight of concrete.

Mix No.	Depth (mm)	Exposure period (months)				
		1	2	3	4	5
1	0~10	0.28104	0.37076	0.29452	0.46930	0.50263
	10~20	0.00778	0.06328	0.19127	0.18629	0.23909
	20~30	0.00673	0.00699	0.02266	0.05746	0.09366
2	0~10	0.31591	0.33030	0.36929	0.39707	0.37215
	10~20	0.00713	0.0079	0.00791	0.00735	0.06674
	20~30	0.00707	0.00735	0.00755	0.00713	0.00955
3	0~10	0.19734	0.25421	0.39895	0.42593	0.44056
	10~20	0.00639	0.02227	0.01035	0.06434	0.03386
	20~30	0.00621	0.00859	0.00749	0.00720	0.00788
4	0~10	0.09833	0.10012	0.10025	0.13627	0.12428
	10~20	0.00775	0.00816	0.00650	0.00670	0.02424
	20~30	0.00653	0.00579	0.00575	0.00611	0.00753

The results which are presented in Fig. 5 and Fig 6 and listed in Table 4 and Table 5 indicate that there were large reductions in levels of total and soluble chloride ions as the depth of the surveyed concrete zones increased. They also indicate that the first 10 mm of concrete zone provides little barrier to chloride ion penetration and underscores the importance of concrete cover to the reinforcement. Furthermore, the effect of RHA content with regard to chloride penetration tend to be more noticeable as the replacement percent of RHA increased. The second and third zones (i.e., 10~20 and 20~30 mm) of RHA mixtures show significant reduction in the total and soluble chloride ions contents compared with the OPC concrete. The rate of increase in chloride ions concentrations with time in the mentioned zones in the case of OPC concrete is larger than those of RHA concrete mixes.

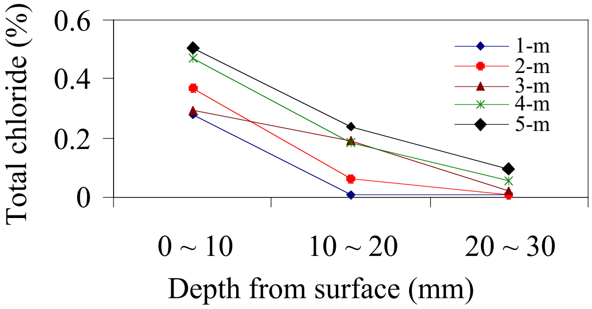
Table 5 : Soluble chloride ion as percentage by weight of concrete.

Mix No.	Depth (mm)	Exposure period (months)				
		1	2	3	4	5
1	0~10	0.09030	0.146170	0.13071	0.18365	0.25206
	10~20	0.00638	0.03983	0.05889	0.06653	0.08716
	20~30	0.00599	0.00607	0.00760	0.02558	0.04016
2	0~10	0.13026	0.13530	0.13248	0.15858	0.26799
	10~20	0.00674	0.00751	0.00751	0.00664	0.01922
	20~30	0.00600	0.00604	0.00683	0.00600	0.00869
3	0~10	0.07794	0.08999	0.17922	0.19994	0.222271
	10~20	0.00625	0.00832	0.00731	0.02751	0.00823
	20~30	0.00603	0.00590	0.00633	0.00640	0.00748
4	0~10	0.04028	0.06225	0.04485	0.06230	0.05784
	10~20	0.00660	0.00595	0.00618	0.00632	0.00815
	20~30	0.00609	0.00534	0.00569	0.00573	0.00618

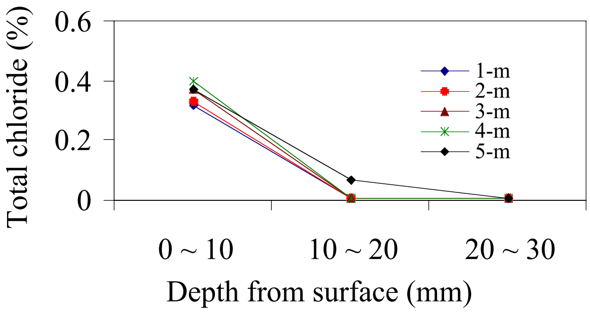
Table 6 : Diffusion coefficient of the studied concrete (x10^{-7} cm^2/sec).

Mix No.	1-month	2-months	3-months	4-months	5-months
1	1.340	0.914	0.885	0.857	0.763
2	1.180	0.617	0.378	0.296	0.285
3	1.390	0.787	0.395	0.248	0.243
4	2.160	0.871	0.502	0.362	0.336

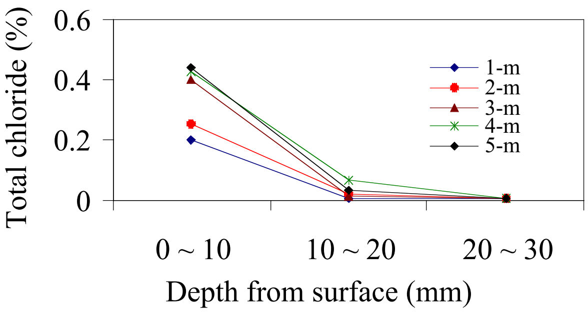
Marusin [20] mentioned that the corrosion threshold limit for soluble chloride ion concentration in normal weight reinforced concrete is about 0.03 percent by weight of concrete.



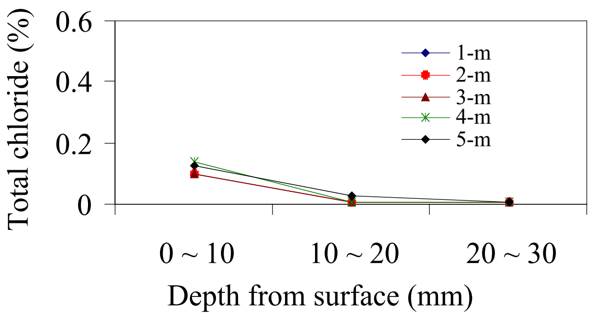
(a) Mix No.1



(b) Mix No.2

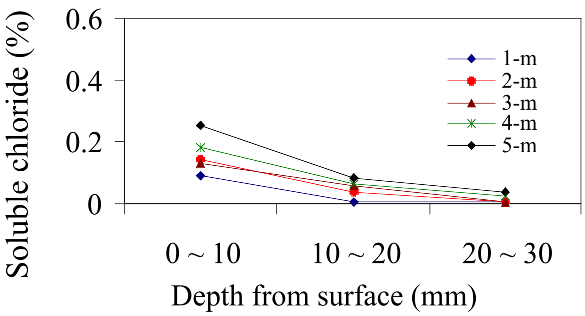


(c) Mix No.3

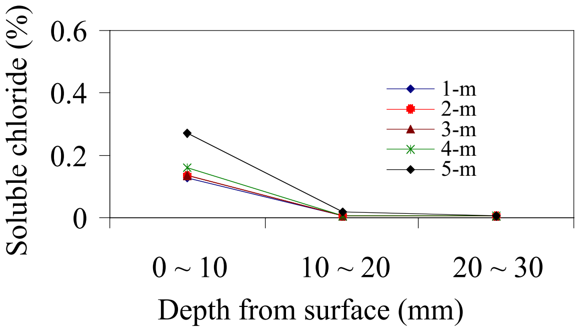


(d) Mix No.4

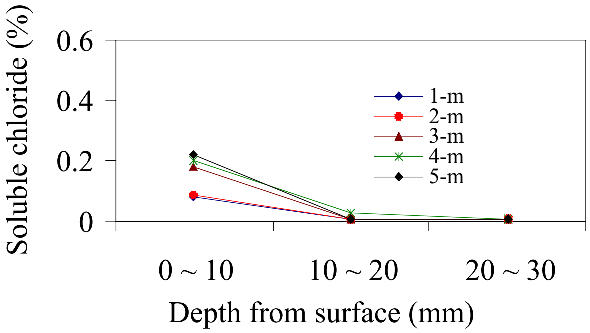
Fig. 5 : Total chloride content profiles.



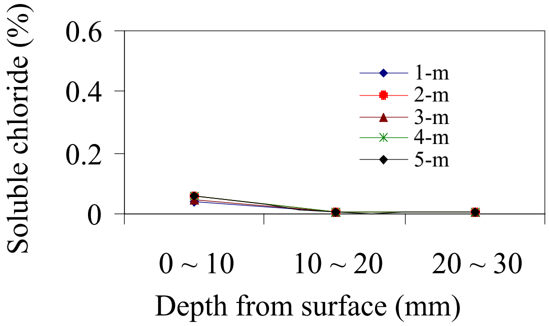
(a) Mix No.1



(b) Mix No.2



(c) Mix No.3



(d) Mix No.4

Fig. 6 : Soluble chloride content profiles.

The chloride ion contents for all the tested samples after 1, 2, 3, 4, and 5 months at the depth 20~30 mm of RHA concrete mixes are lower than the previously mentioned limits for corrosion threshold. This concludes that RHA concrete RHA may require less depth of cover to protect the reinforcing steel than that of OPC. Gaynor [21] reported that one-half or three-fourths of penetrated chlorides in hardened concrete are soluble in water and free to contribute to corrosion, but RHA mixes shows lower percent than that reported by Gaynor. RHA_{60} concrete has strong resistant with respect to concrete durability on studied exposure condition.

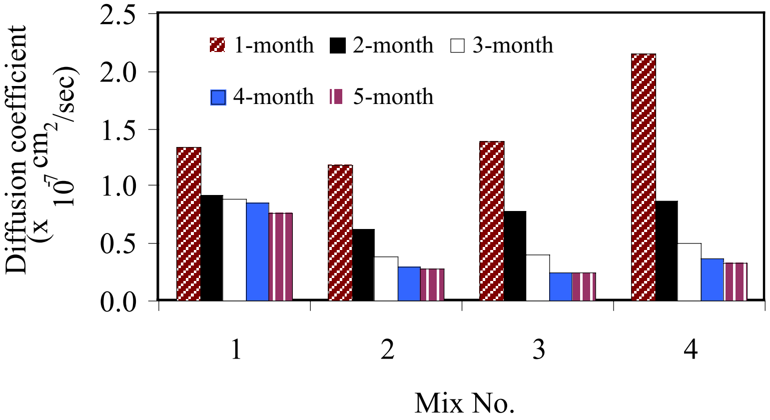


Fig. 7 : Chloride ions diffusion coefficient of studied concrete mixtures.

From Table 6, it is evident that diffusion coefficient values decrease with increasing the RHA content as shown in Fig. 7. Also, the obtained results show that the diffusion coefficient decreases with increasing the concrete age. It is obvious that the difference between the diffusion coefficient results of RHA_{10} and RHA_{60} investigated here is significant. The obtained test results confirm that there is a wealth of evidence supporting the fact that RHA concrete mixtures has a significantly higher resistance to the diffusivity of chloride ions than that of OPC concrete mix.

PORE STRUCTURE OF MORTAR

Pore structure and the surface area of the pores are the most important characteristics controlling the basic properties of concrete such as strength, permeability and durability, also controlling the properties of porous materials. The open pore volume distribution, when plotted against the logarithm of the pore diameter, is generally found to follow a normal distribution. Many materials have more than one size distribution of pores. For example, cement pastes contain two interpenetrating pore systems, with capillary pores originating primarily from the mixing water, and gel pores that represent the inherent structure and porosity of cement hydration products [22].

Table 7 : Summary of pore structure data of tested mortar.

Mix No.	Age (Days)	Pore volume (cm^3/gm)	Porosity (%)	Pore surface area (m^2/gm)	Average pore diameter (μm)
1	28	0.0628	4.5693	10.1871	0.0246
2		0.0817	5.6532	19.0014	0.0172
3		0.0597	4.2217	13.3872	0.0178
4		0.0746	4.8812	20.0518	0.0149
1	90	0.0584	4.3722	9.4246	0.0248
2		0.0706	5.0896	16.4516	0.0172
3		0.0596	4.4251	14.3853	0.0166
4		0.0647	4.5153	15.8562	0.0163

The obtained results of pore structure of tested mortar (the same mix proportions of concrete listed in Table 1 without coarse aggregate) at 28 and 90 days are summarized in Table 7, and Fig. 8. The relationships of the applied pressure with pore diameter, total pore volume, total pore surface area as well as total porosity at 28 days and 90 days are represented in Fig. 9 and Fig. 10, respectively.

The progress of hydration has a direct effect on the pore volume by the increase in gel volume and decrease in pore volume as shown in Fig 8 (a). It is noticed that the measured pore diameters at 90 days are smaller than those measured at 28 days for all mixes. The four mortar mixes show approximately the same profiles of the applied pressure and measured pore diameter for the studied mortars as shown in Fig. 9 (a) and Fig. 10 (a). Furthermore, The results confirm the fact that pore volume and pore size distribution are changed by duration of curing. The profiles of measured pore volume and the applied pressure relationships are shown in Fig. 9 (b) and Fig. 10 (b) at 28 and 90 days, respectively. The mortar with RHA shows smaller average pore diameter than that of OPC mortar at 28 and 90 days as shown in Fig. 8(d). Mix 4 (RHA_{60}) shows the smallest average pore diameter than those of RHA_{10} and OPC mixes.

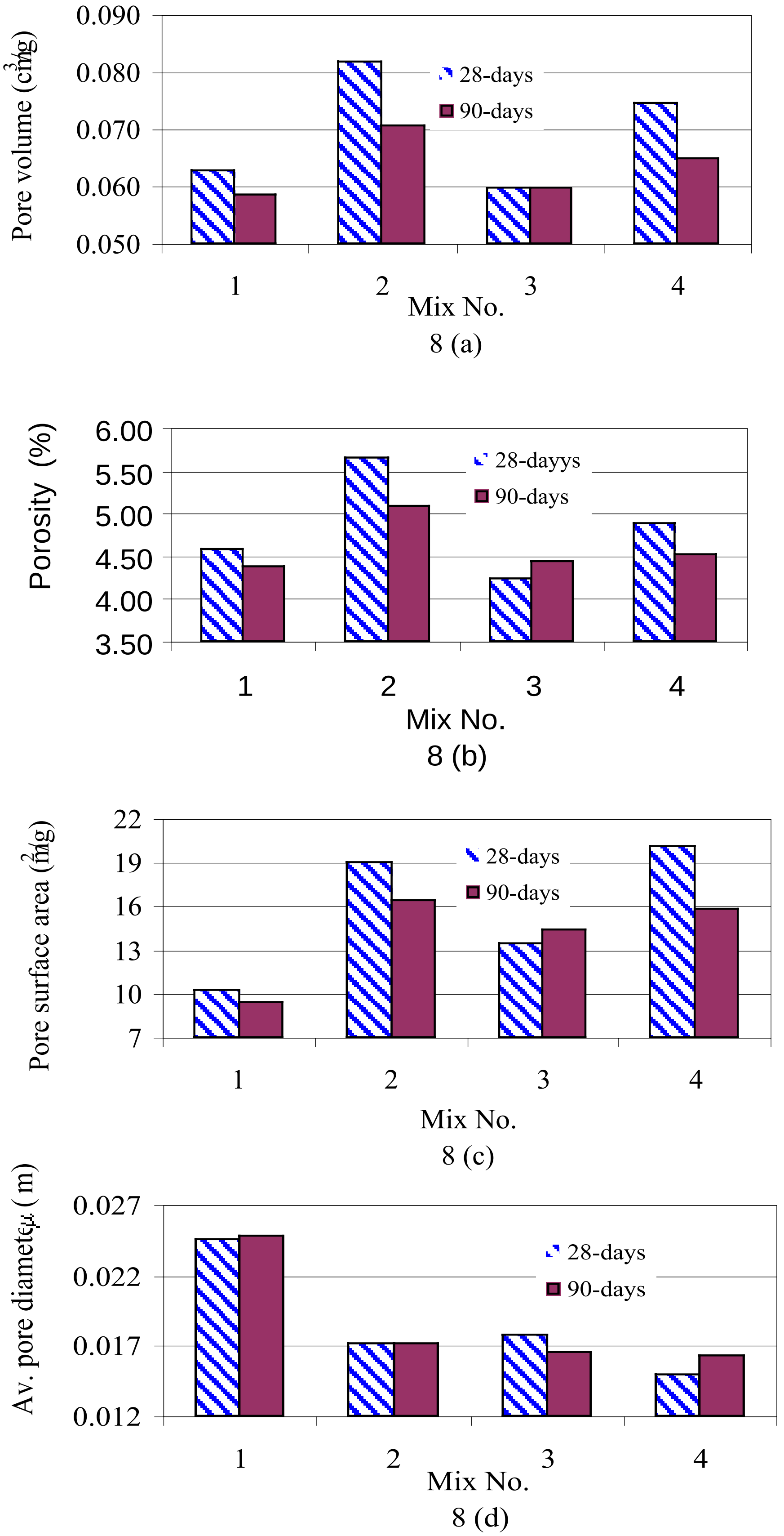
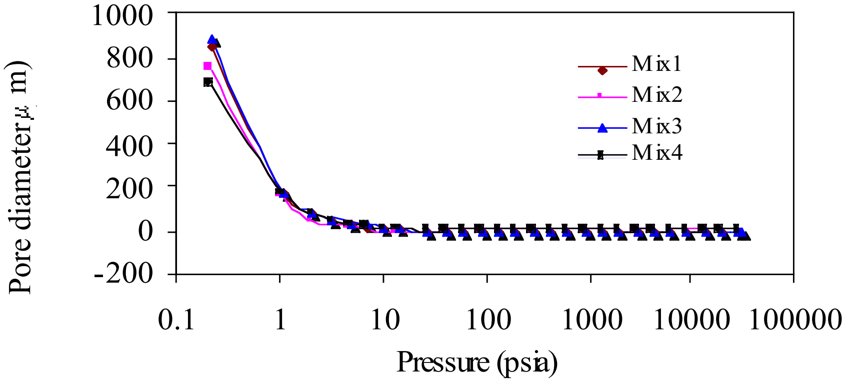
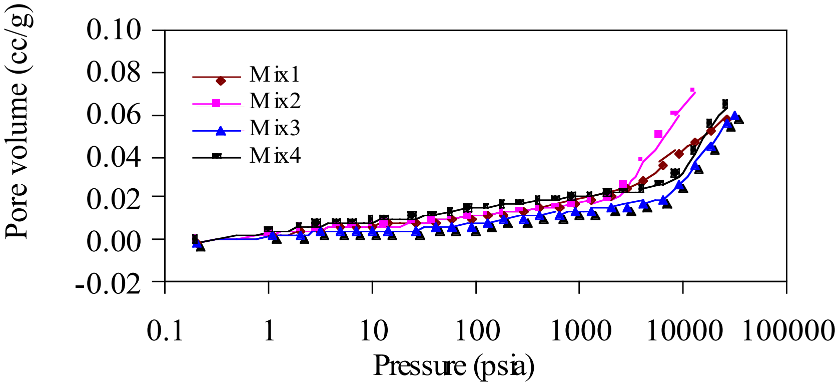


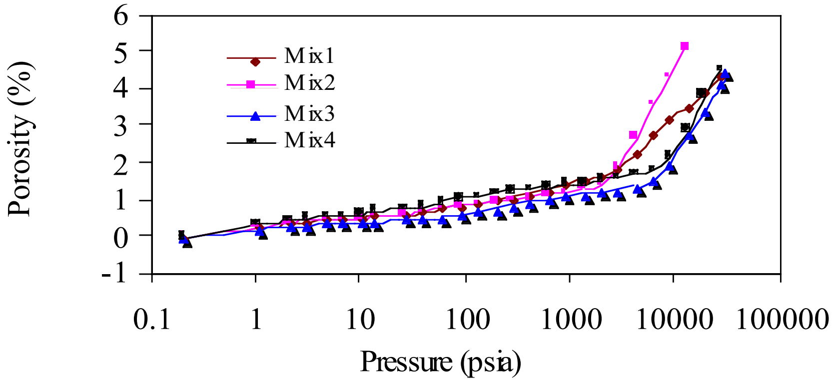
Fig. 8 : Pore structure data of tested mortar at 28 and 90 days.



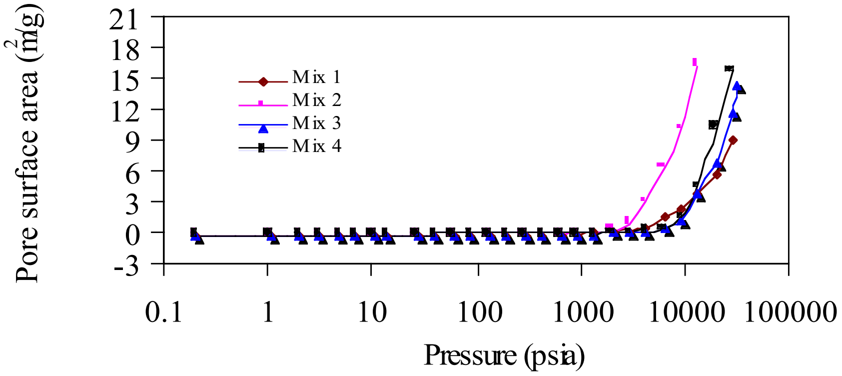
(a) Pressure vs. pore diameter



(b) Pressure vs. pore volume

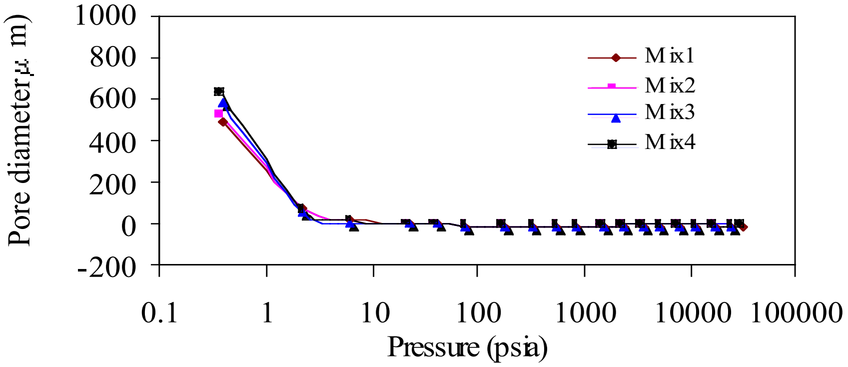


(c) Pressure vs. porosity

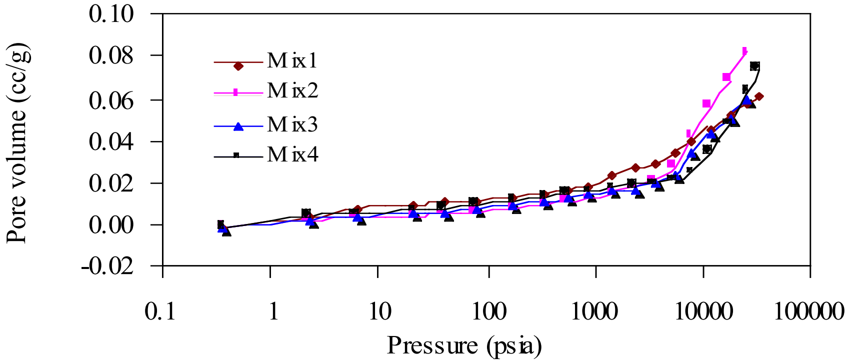


(d) Pressure vs.pore surface area

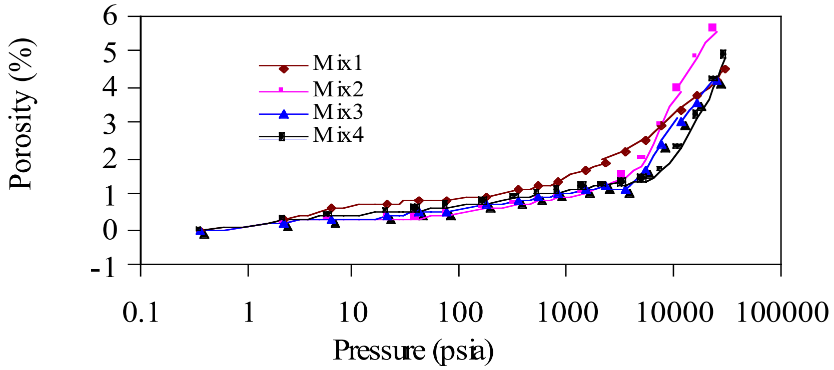
Fig. 9 : Pore structure profile curves at 28 days.



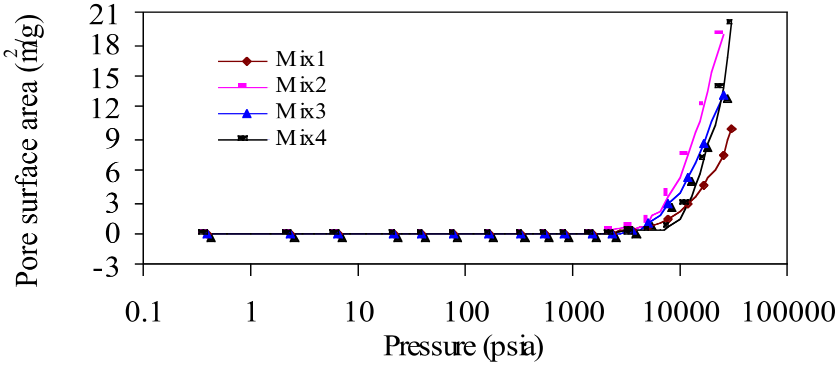
(a) Pressure vs. pore diameter



(b) Pressure vs. pore volume



(c) Pressure vs. porosity



(d) Pressure vs.pore surface area

Fig. 10 : Pore structure profile curves at 90 days.

The range for total porosity of OPC mortar is about 15 to 26 percent, as mentioned in ref. [23]. The measured total porosity indicates that RHA mortar shows approximately the same porosity of OPC mortar at 28 an 90 days as shown in Fig. 8 (b). The correlations between the total porosity and the applied pressure are shown in Fig. 9 (c) and Fig. 10 (c).

The obtained total pore surface area of RHA mortar at 28 and 90 days are higher than those of OPC mortar as shown in Fig. 8 (c). This is due to the use of RHA which forms fine pores during hydration progress. The total pore surface area of 90 days are smaller than those of 28 days. The profiles of the total pore surface area against the applied pressure at 28 and 90 days are shown in Fig. 9 (d) and Fig 10 (d). Therefore, the use of RHA affects the pore structure of mortar. The pores are blocked by the effect of RHA and hydration products, causing change of pore structure such as the formation of fine and discontinuous pores. From the obtained results, it is obvious that the curing period of mortar has a significant effect on the pore structure characteristics.

CONCLUSIONS

1. Investigation of using a considerable proportion of RHA in concrete mixtures as a cement replacement materials (up to 40%) have been carried out to study their effect on concrete properties. The obtained test results proved that the different properties of fresh and hardened concrete product have noticeably been improved. Furthermore, these measured properties are influenced due to changing in the RHA content, fineness of RHA, concrete age, as well as type and dose of the chemical admixture.

2. There are large reductions in contents of total and soluble chloride as the depth of the surveyed concrete zones increased which indicating a significant resistance to chloride penetration. The soluble chloride contents after 5 months at the depth 20~30 mm are lower than the limits of corrosion threshold. Therefore, RHA concrete may require less depth of cover to protect the reinforcing steel.

3. Using RHA as a part of cement content in concrete results in changing the pore structure such as formation of fine and discontinuous pores and the pores are blocked by the effect of RHA and hydration products which improves the durability of concrete.

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