MATERIALS TECHNOLOGY LABORATORY

**Concrete Incorporating Rice-Husk Ash:
Compressive Strength and Chloride-Ion Penetrability**

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MTL 2001-5 (TR)

July 2001

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by

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Abstract

The present report deals with the evaluation of the performance in concrete of an Indian sample of rice-husk that was burnt in an industrial furnace in Ontario, and ground at the CANMET laboratories. This exploratory study was performed under contract with DCR Phoenix Development Corporation Ltd. Ottawa and is divided in two parts. The first part deals with determining the optimum grinding time of the RHA in order to produce a highly-reactive product with a minimum energy of grinding. The performance of the RHA in concrete forms part II of the study. The results show that the rice-husk ash sample used in this study is principally composed of SiO_2 (90.7 %), contains 4.7% loss on ignition and a relatively high K_2O content of 2.2 %. The RHA ground for the optimum grinding time (140 seconds in a pulverizer with a capacity of 30 g) has a median particle size of ~ 8 μm, a water requirement of ~ 104% and a pozzolanic activity index of ~ 100% in the mortar used for determining the pozzolanic activity of the RHA. The results also show that in general, for similar W/CM (0.40), the replacement of 7.5 to 12.5% of the portland cement by the RHA did not affect significantly the compressive strength, but improved significantly the resistance to the chloride-ion penetrability of the concrete with and without the entrained air.

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INTRODUCTION

Rice husks are the shells produced during the dehusking of paddy rice. Each tonne of paddy rice can produce about 200 kg of husk, which on combustion produces about 40 kg of ash (1). According to a recent report by Mehta (2), the current yearly world production of paddy rice is approximately 500 million tonnes that gives approximately 100 million tonnes of rice husks as a waste product from the milling.

Prior to 1970, rice-husk ash (RHA) was usually produced by uncontrolled combustion (2), and the ash so produced was generally crystalline and had poor pozzolanic properties. In 1973, Mehta (3) published the first of several papers describing the effect of pyroprocessing parameters on the pozzolanic reactivity of RHA. Based on his research, Pitt (4) designed a fluidized-bed furnace for controlled burning of rice husks. By burning the rice husks under a controlled temperature and atmosphere, a highly-reactive RHA was obtained.

Studies have shown that burning rice husks at 600 °C produces an ash with an optimum composition for pozzolanic materials (5). Below this temperature the silica formed is of pozzolanic nature, and above that temperature the silica partially changes to cristobalite, quartz, and tridymite, which require fine grinding to exhibit pozzolanicity.

Previous studies have also shown that due to its high surface area the RHA is comparable to other pozzolans used as mineral admixture in cement and concrete, and more precisely to silica fume (1, 2, 5-7). It was, also, reported that the main advantage of using RHA as a mineral admixture in concrete is the significant reduction in the permeability of the concrete (2, 7, 8).

The present report deals with the evaluation of the performance in concrete of an Indian sample of rice husk that was burnt in an industrial furnace in Ontario, and ground at the CANMET laboratories. This exploratory study was performed under contract with DCR Phoenix Development Corporation Ltd. Ottawa and is divided in two parts. The first part deals with determining the optimum grinding time of the RHA in order to produce a highly-reactive product with a minimum energy of grinding. The performance of the RHA in concrete forms part II of the study.

PART I: OPTIMUM GRINDING TIME OF THE RHA

Materials

Portland cement
ASTM Type I portland cement was used. Its chemical composition and physical properties are given in Table 1.

Rice-husk ash (RHA)
The rice-husk ash used was from an Indian-rice husk burnt in an industrial furnace in Ontario. The chemical composition and the physical properties of the RHA are also given in Table 1. Chemical analysis indicates that the material is principally composed of SiO_2 (90.7 %), and contains 4.7% loss on ignition which is an indication of its carbon content. The RHA also contains a relatively high K_2O content of 2.2 % that according to Mehta (2), is mainly due to the use of fertilizers.

RHA has a specific gravity of 2.05. The fineness and the pozzolanic activity index reported in Table 1 are those for the RHA ground for the optimum grinding time.

The scanning electron micrograph (Fig. 1) shows that the material is very porous and its particles are irregular. The X-ray diffraction analysis (Fig. 2) indicates that the RHA mainly consists of amorphous materials, which is an indication of a high reactivity, with a small quantity of crystalline phases as cristobalite (high-temperature phase of SiO_2) and quartz.

Laboratory experiments

For determining the optimum grinding time of the RHA, the RHA was ground in a pulverizer with a capacity of 30 g for up to 200 seconds. Samples were taken after 80, 140, and 200 seconds of grinding, and the particle-size distribution, the water requirement, and the pozzolanic activity index of the unground and the ground RHA were determined.

The particle size distribution was determined by the Microtrac X100 particle size analyser using scattered light from laser beams projected through a stream of particles suspended in isopropanol. The water requirement, and the pozzolanic activity of the RHA were determined according to ASTM C 1240.

Results and discussion

Table 2 summarises the physical properties of the RHA as received, and after 80, 140, and 200 seconds of grinding.

Particle size distribution
Figure 3 shows the changes in the particle size distribution of the RHA after up to 200 seconds of grinding. The particle size of the RHA decreased with increasing grinding time. The median particle size for the RHA decreased from 40.0 to 8.3, and 7.5 μm after 140, and 200 seconds of grinding, respectively. The particle size decrease was most significant during the first 140 seconds of grinding. After 140 seconds of grinding, most of the large particles had been crushed so that all the particles were less than 45 μm, and more than 55% of the particles were less than 10 μm. Further increase in the grinding time was less effective in increasing the particle fineness.

Water requirement and pozzolanic activity
The water requirement of the mortar used for determining the pozzolanic activity of the RHA ground for 80 seconds decreased, and this may be due to the break up of the large porous particles which, in turn, decreases the water absorbed by such particles. The water requirement for the mortar made with the RHA that had been ground for 140 seconds increased because of the increased fineness of the RHA. Further increase in the grinding time of the RHA did not affect its water requirement.

The 7-day strength activity index increased marginally with an increase in the grinding time.

Based upon the above and taking into account the limited nature of the study, it was decided to grind the RHA for a maximum of 140 seconds. Such ground RHA would have a median particle size of ~ 8 μm, a water requirement of ~ 104% and a pozzolanic activity index of ~ 100% in the mortar used for determining the pozzolanic activity of the RHA.

PART II: PERFORMANCE OF THE RHA IN CONCRETE

Scope

A total of ten concrete mixtures was made, i.e. five non air-entrained and five air-entrained (6 ± 1%) concrete mixtures. For each set of five concrete mixtures, two control concrete mixtures and three RHA concrete mixtures were made. The control concretes included one using the portland cement only, and one using 7.5 % of silica fume as replacement for cement. The RHA concretes included concretes incorporating 7.5%, 10%, and 12.5% of RHA as replacement for cement. All concrete mixtures were made with a water-to-cementitious materials ratio (W/CM) of 0.40 for durability considerations.

For each concrete mixture, the properties of the fresh concrete, the compressive strength at 1, 3, 7, and 28 days, and the chloride-ion penetrability at 28 days of the concrete were determined following the relevant ASTM standards. For the chloride-ion penetrability of the concrete, two curing modes were used. The first curing mode consisted at 28 days of moist curing (23 ± 2°C and 100 % relative humidity), and the second curing mode consisted at 3 days of moist curing followed by 25 days of air curing (23 ± 2°C and 50 % relative humidity). The second curing mode is more representative of the field curing of concrete.

Materials

Cement
The ASTM Type I, normal Portland cement used in Part I of the study was used in this Part as well.

Rice-husk ash
RHA ground for the optimum grinding time determined in Part I of the study was used in this part. Its chemical analysis and physical properties are given in Table 1.

Admixtures
A sodium salt sulfonate polymer was used as a superplasticizer (SP), and a synthetic resin type air-entraining admixture (AEA) was used for the air-entrained concrete mixtures.

Aggregates
Crushed limestone with a maximum nominal size of 19 mm was used as the coarse aggregate, and a local natural sand derived from granite was used as the fine aggregate in the concrete mixtures. The coarse aggregate was separated into different size fractions and recombined to a specific grading shown in Table 3. The coarse and fine aggregates each had a specific gravity of 2.70, and water absorption of 0.4 and 0.8%, respectively.

Mixture Proportions

The proportions of the concrete mixtures are summarized in Table 4. For all the mixtures, the coarse and fine aggregates were weighed in a room dry condition. The coarse aggregate was then immersed in water for 24 hours. The excess water was decanted, and the water retained by the aggregates was determined by the weight difference. A

predetermined amount of water was added to the fine aggregate that was then allowed to stand for 24 hours.

Preparation and Casting of Test Specimens

All the concrete mixtures were mixed for five minutes in a laboratory counter-current mixer. From each concrete mixture, sixteen 100×200-mm cylinders were cast for the determination of the compressive strength and the resistance to chloride-ion penetration.

The specimens were cast in two layers and were compacted on a vibrating table. After casting, all the molded specimens were covered with plastic sheets and water-saturated burlap, and left in the casting room for 24 hours. They were then demolded and the cylinders were transferred to the moist-curing room at 23 ± 2°C and 100 % relative humidity until required for testing. Two cylinders from each concrete mixture were transferred to the air-curing room (23 ± 2°C and 50 % relative humidity) after spending 3 days in the moist-curing room.

Testing of the Specimens

The slump and air content of fresh concrete were determined in accordance with the relevant ASTM standards. For each mixture, the compressive strength was determined on three cylinders at 1, 3, 7, and 28 days according to ASTM C 39. For each mixture and curing mode, the chloride-ion penetrability was determined on two cylinders at 28 days according to ASTM C 1202

Results and Discussion

Properties of fresh concrete
The unit weight, slump, and air content of the fresh concretes are given in Table 5.

Non-air entrained concrete
The slump of the control concrete made with portland cement only and that of concrete incorporating silica fume was 120 and 155 mm, respectively (Mix 1 and 5, Table 5), and that of RHA concretes ranged from 130 to 155 mm (Mix 2 to 4, Table 5). For similar W/CM ratio (0.40) and approximately similar slump, the dosage of superplasticizer of the control concrete made with cement only and that of concrete incorporating silica fume was 3.3, and 4.7 L/m^3, respectively, while that of the RHA concretes ranged from 3.1 to 3.8 L/m^3. The results show that the dosage of superplasticizer of RHA concretes was similar to slightly higher than that of the control concrete made with the portland cement only. Whereas, the dosage of superplasticizer of the silica fume concrete was significantly higher than that of the control concrete made with the portland cement only and that of RHA concretes. This is probably due to the high fineness of the silica fume compared to both the portland cement and the RHA used in this study (Table 1). The results show also that the dosage of the SP required to maintain the same workability increased with increasing the RHA content in the concrete mixture.

No air-entraining admixture was added to these concrete mixtures (Mix 1 to 5, Table 4). Therefore, the air content of the concretes ranged from 1.4 to 2.5%.

Air entrained concrete
In general, for similar W/CM ratio (0.40), the incorporation of air-entraining admixture in the concrete decreased the dosage of superplasticizer required to obtain a certain slump. For example, the incorporation of AEA in the silica fume concrete decreased the dosage of SP from 4.7 to 3.9 L/m^3 to obtain a concrete with a slump of approximately 150 mm.

Table 4 (Mix 6 to 10) shows that the use of RHA as a replacement for cement did not affect significantly the dosage of SP, whereas, the use of silica fume as a replacement of cement increased significantly the dosage of SP needed to maintain the required workability.

To obtain an air content of approximately 5%, the dosage of AEA of the control concrete made with the portland cement only, and that of concrete incorporating silica fume was 61 and 101 mL/m^3, respectively, while that of RHA concretes ranged from 142 to 262 mL/m^3 (Mix 6 to 10 Table 4). The RHA concretes required higher dosage of AEA compared to both control concretes, which is probably due to the higher carbon content of RHA compared to both portland cement and silica fume (Table 1). The results show also that the dosage of AEA required to obtain the target 5% air increased with increasing the RHA content in the concrete mixture.

Compressive strength
The compressive strength of the different concretes are shown in Table 6.

Non-air entrained concrete
The control concrete developed compressive strengths of 34.1, 40.9, 43.7 and 51.8 MPa, at 1, 3, 7, and 28 days, respectively (Mix1). The RHA concretes developed compressive strengths ranging from 31.2 to 34.1, 38.9 to 39.7, 44.0 to 44.4, and from 51.4 to 54.9 MPa at 1, 3, 7, and 28 days, respectively (Mix 2 to 4). The silica fume concrete developed compressive strengths of 35.1, 43.3, 49.1 and 60.9 MPa, at 1, 3, 7, and 28 days, respectively (Mix 5).

There were insignificant differences in the strengths of both the control (Mix 1) and the concrete made using RHA. On the other hand, the use of the silica fume as a replacement of cement increased the compressive strength slightly at 1 and 3 days and significantly at 7 and 28 days, compared to that of the control concrete made with the portland cement and the concretes incorporating RHA. The silica fume concrete developed higher compressive strength than that of the RHA concretes due to the higher fineness of the silica fume compared to that of the RHA.

Air entrained concrete
It is generally recognized that for moderate strength portland cement concrete, each percent of entrained air reduces the compressive strength by about 5%. In this case, each percent of entrained air reduced the compressive strength of the control concrete made with portland cement only by about 4%, that of the RHA concretes by about 2.5%, and that of the silica fume concrete by about 3%. In fact, the control concrete developed compressive strengths of 32.3, 39.5, 40.7, and 48.2 MPa, at 1, 4, 7, and 28 days, respectively (Mix6). The RHA concretes developed compressive strengths ranging from 27.1 to 30.1, 36.0 to 39.0, 39.3 to 42.0, and from 49.1 to 51.3 MPa at 1, 4, 7, and 28 days, respectively (Mix 7 to 9). The silica fume concrete developed compressive strengths of 29.1, 39.5, 44.5 and 54.3 MPa, at 1, 4, 7, and 28 days, respectively (Mix 10).

The results show that the 1- and 3-d compressive strengths of RHA concretes were lower than those of the control concrete made with the portland cement only. This is probably be due to the higher air content of the RHA concretes compared to that of the concrete made with the portland cement only. The 28-d compressive strength of the RHA concretes was similar to that of the control concrete made with the portland cement only. For the silica fume concrete, the 1-d compressive strength was lower than that of the control concrete made with the portland cement only, while the 7-d and 28-d compressive strengths were higher than those of the control concrete made with the portland cement only. The silica fume concrete developed higher compressive strength than that of the RHA concretes but only after 7 days.

Chloride ion penetrability
The 28-d chloride ion penetrability of the different concretes are given in Table 7.

Non-air entrained concrete
The results show that the RHA and the silica fume concretes largely outperformed the control concrete. For the concrete cured in the moist curing room, the control concrete (Mix 1) developed a 28-d chloride-ion penetrability of 2470 Coulombs that is considered to be moderate penetrability according to ASTM 1202. Whereas, the concrete incorporating 7.5 to 12.5% of RHA developed a low to very low chloride-ion penetrability (600 to 1210 Coulombs), and that incorporating 7.5% of silica fume developed a very low chloride-ion penetrability (430 Coulombs). This is mainly due to the fact that the incorporation of the RHA and silica fume in concrete result in a finer pore structure in the hydrated cement paste especially at the aggregate/paste interface. This decrease is much higher with fine material such as silica fume due to its high pozzolanicity.

When the air curing was applied to the concretes, the chloride ion penetrability increased for all concrete mixtures especially for the control concrete (Mix 1). In fact, for this curing mode, the chloride ion penetrability of the control concrete approached the value considered as high according to ASTM C 1202 (3940 Coulombs). While for the RHA concretes, the chloride ion penetrability increased from very low to low and from low to moderate, for the silica fume concrete the chloride ion penetrability remained very low.

The results also show that the increase of the RHA content decreased the 28-d chloride-ion penetrability of the concrete.

Air entrained concrete
In general, the incorporation of entrained air in the concrete increased slightly the chloride-ion penetrability of the concrete.

For the concrete cured in the moist curing room, the control concrete (Mix 6) developed a moderate chloride-ion penetrability of 2790 Coulombs. Whereas, the concrete incorporating 7.5 to 12.5% of RHA developed a low to very low chloride-ion penetrability (700 to 1300 Coulombs), and that incorporating 7.5% of silica fume developed a very low chloride-ion penetrability of 410 Coulombs. When the air curing was applied to the concretes, the chloride ion penetrability of the control concrete increased from moderate to high, that of the RHA concretes, increased from very low to low, and that of the silica fume concrete remained very low.

CONCLUSIONS

Based on the present study, the following conclusions can be drawn:

· The rice-husk ash sample used in this study is principally composed of SiO_2 (90.7 %), contains 4.7% loss on ignition and a relatively high K_2O content of 2.2 %. The RHA ground for the optimum grinding time (140 seconds in a pulverizer with a capacity of 30 g) has a median particle size of ~ 8 μm, a water requirement of ~ 104% and a pozzolanic activity index of ~ 100% in the mortar used for determining the pozzolanic activity of the RHA.

· For similar W/CM (0.40) and slump, the dosage of the superplasticizer of the RHA concrete (7.5, 10, and 12.5% of RHA as replacement for cement) was similar to slightly higher than that of the control concrete made with the portland cement only, but significantly lower than that of the concrete incorporating 7.5% of silica fume. This is probably due to the high fineness of the silica fume compared to that of the RHA.

· For similar W/CM (0.40) and air content, the dosage of the AEA of the RHA concrete (7.5, 10, and 12.5% of RHA as replacement for cement) was significantly higher than that of the control concrete made with the portland cement only, and that of the concrete incorporating 7.5% of silica fume. This is probably due to the high carbon content of the RHA compared to that of both portland cement and silica fume.

· For similar W/CM (0.40), the replacement of 7.5 to 12.5% of the portland cement by the RHA did not affect significantly the compressive strength of the concrete with and without the entrained air. The slower rate of reactivity of the RHA compared to that of the silica fume is probably due to the coarser size of RHA particles compared to that of the silica fume particles.

· For similar W/CM (0.40), the replacement of 7.5 to 12.5% of the portland cement by the RHA improved significantly the resistance to the chloride-ion penetrability of the concrete with and without the entrained air.

RECOMMENDATIONS

Based on the results of the present study, it is recommended that:

· Investigations should be undertaken to determine the effect of increasing the RHA content (for up to 20% or more) on the properties of concrete, since such sample of RHA seems to not significantly increase the dosage of superplasticizer of the concrete to achieve a certain slump.

· Research is needed to develop data on the mechanical properties and durability characteristics of the concrete using such sample of RHA, before drawing any general conclusions on the performance of this RHA sample in the concrete.

REFERENCES

1. Mehta, P.K., "Structure, Properties, and Materials", Englewood Cliffs, NJ: Prentice-Hall, 1986.
2. Mehta, P.K. "Rice-husk Ash - A unique Supplementary Cementing Material", Advances

in Concrete Technology, MSL Report 94-1 (R), CANMET 1994, pp. 419-444. (ed. V.M. Malhotra).

3. Mehta, P.K. "Siliceous Ashes and Hydraulic Cements Prepared Therefrom", Belgium Patent 802909, July 1973, U.S. Patent 4105459, Aug. 1978.
4. Pitt, N., "Process for Preparation of Siliceous Ashes", U.S. Patent 3959007, May 1976.
5. Mazlum, F., and Uyan, M., "Strength of Mortar Made with Cement Containing Rice-husk Ash and Cured in Sodium Sulphate Solution", ACI-SP 132 , 1992, pp. 513-531. (ed. V.M. Malhotra).
6. Al-Khalaf, M.N., and Yousif, H.A., "Use of Rice-husk Ash in concrete", Journal of Cmenet Composites, Vol. 6, 1984, pp. 241-248.
7. Zhang, M.H., and V.M. Malhotra, "High-Performance Concrete Incorporating Rice-husk Ash as a Supplementary Cementing Material", ACI Materials Journal, Vol. 93, No. 6, 1996, pp. 629-636.
8. Mehta, P.K., "Highly Durable Cement Products Containing Siliceous Ashes", U.S. Patent No. 5, 346, 548, Sept. 13, 1994.

Table 1 - Physical Properties and Chemical Analyses of the Materials Used

	ASTM Type I Cement	Rice-Husk Ash	Silica Fume
Physical tests			
Specific gravity	3.15	2.05	2.16
Fineness			
-passing 45μm, %	94.0	-	97.2
-specific surface, Blaine, cm^2/g	4100	-	-
-median particle size, μm	-	8.3	-
-nitrogen adsorption, m^2/g	-	20.6	19.5
Compressive strength of 51 mm cubes, MPa			
-7-day	26.0	-	-
-28-day	31.9	-	-
Water requirement, %	-	104	116
Pozzolanic Activity Index, %			
-7-day	-	99	109
Time of setting, Vicat test, min			
-initial setting	220	-	-
-final setting	325	-	-
Air content of mortar, volume %	5.5	-	-
Chemical analyses, %			
Silicon dioxide (SiO$_2$)	19.5	90.7	94.0
Aluminium oxide (Al$_2$O$_3$)	4.6	0.4	0.1
Ferric oxide (Fe$_2$O$_3$)	2.0	0.4	0.1
Calcium oxide (CaO)	62.2	0.4	0.4
Magnesium oxide (MgO)	2.8	0.5	0.4
Sodium oxide (Na$_2$O)	0.2	0.1	0.1
Potassium oxide (K$_2$O)	0.9	2.2	0.9
Equivalent alkali (Na$_2$O+0.658K$_2$O)	0.8	1.5	0.7
Phosphorous oxide (P$_2$O$_5$)	0.2	0.4	0.1
Titanium oxide (TiO$_2$)	0.2	0.03	<0.01
Sulphur trioxide (SO$_3$)	3.1	0.1	0.3
Loss on ignition	2.4	4.8	2.7
Bogue potential compound composition			
Tricalcium silicate C$_3$S	62.4	-	-
Dicalcium silicate C$_2$S	8.8	-	-
Tricalcium aluminate C$_3$A	8.8	-	-
Tetracalcium aluminoferrite C$_4$AF	6.1	-	-

Table 2 - Effect of Grinding on the Physical Properties of the RHA

		RHA
Median particle-size distribution, μm	before grinding	40
	after 80 seconds grinding	10
	after 140 seconds grinding	8
	after 200 seconds grinding	7.5
Water requirement, %	before grinding	116
	after 80 seconds grinding	101
	after 140 seconds grinding	104
	after 200 seconds grinding	104
Pozzolanic activity index at 7-day, %	before grinding	71
	after 80 seconds grinding	96
	after 140 seconds grinding	99
	after 200 seconds grinding	101

Table 3 - Grading of Coarse Aggregate

Sieve size, mm	Passing, %
19.0	100
12.7	67
9.5	34
4.75	0

Table 4 - Proportions of the Concrete Mixtures

Mix No		Cement	Rice-Husk Ash		Silica Fume		Fine Aggregate, kg/m^3	Coarse Aggregate, kg/m^3	SP^2, L/m^3	AEA^3, mL/m^3
		kg/m^3	%	kg/m^3	%	kg/m^3				
1	No Air	378	0	0	0	0	760	1140	3.3	0
2		354	7.5	28	0	0	763	1145	3.1	0
3		343	10	38			758	1137	3.6	
4		333	12.5	48			758	1136	3.8	
5		354	0	0	7.5	28	763	1143	4.7	0
6	With Air	386	0	0	0	0	732	1099	3.2	61
7		358	7.5	28	0	0	727	1090	3.2	142
8		344	10	38			718	1076	2.9	203
9		335	12.5	48			717	1076	3.0	262
10		357	0	0	7.5	28	726	1090	3.9	101

Table 5 - Properties of the Fresh Concrete

Mix No		Rice-Husk Ash %	Silica Fume, %	Unit Weight, kg/m^3	Slump, mm	Air Content, %
1	No Air	0	0	2432	120	2.5
2		7.5	0	2446	130	1.6
3		10		2432	150	2.0
4		12.5		2432	155	1.6
5		0	7.5	2446	155	1.4
6	With Air	0	0	2375	150	4.2
7		7.5	0	2360	170	4.8
8		10		2330	150	5.6
9		12.5		2330	145	5.4
10		0	7.5	2361	150	4.8

Table 6 - Compressive Strength of Concretes

Mix No		Rice-Husk Ash, %	Silica Fume, %	Density of Hardened Concrete (1-d), kg/m^3	Compressive Strength, MPa			
					1 d	3 d	7 d	28 d
1	No Air	0	0	2463	34.1	40.9	43.7	51.8
2		7.5	0	2440	32.6	39.7	44.0	51.4
3		10		2440	34.1	39.7	44.0	54.9
4		12.5		2440	31.2	38.9	44.4	53.4
5		0	7.5	2457	35.1	43.3	49.1	60.9
6	With Air	0	0	2422	32.3	39.5*	40.7	48.2
7		7.5	0	2390	30.1	39.0*	42.0	51.3
8		10		2360	27.1	36.7*	39.6	49.5
9		12.5		2370	27.2	36.0*	39.3	49.1
10		0	7.5	2377	29.1	39.5*	44.5	54.3

* Tested at 4 days.

Table 7 - 28-d Chloride-ion penetrability of concretes and effect of curing mode.

Mix No		Rice-Husk Ash, %	Silica Fume, %	Curing Mode*		Chloride-Ion Penetrability at 28-day, Coulomb	
1	No Air	0	0	H		2470	
					D		3940
2		7.5	0	H		1210	
		7.5			D		2300
3		10		H		830	
		10			D		1500
4		12.5		H		600	
		12.5			D		1100
5		0	7.5	H		430	
			7.5		D		670
6	With Air	0	0	H		2790	
					D		5070
7		7.5	0	H		1300	
		7.5			D		1780
8		10		H		900	
		10			D		1250
9		12.5		H		700	
		12.5			D		1720
10		0	7.5	H		410	
			7.5		D		720

* H: cured in the most curing room until required for testing.
   D: cured in the most curing room for three days followed by an air curing at 23 ± 2°C and 50 % relative humidity until required for testing.

Chloride-Ion Penetrability Based on Charge Passed (ASTM C 1202)

Charge Passed, Coulomb	Chloride-Ion Penetrability
> 4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

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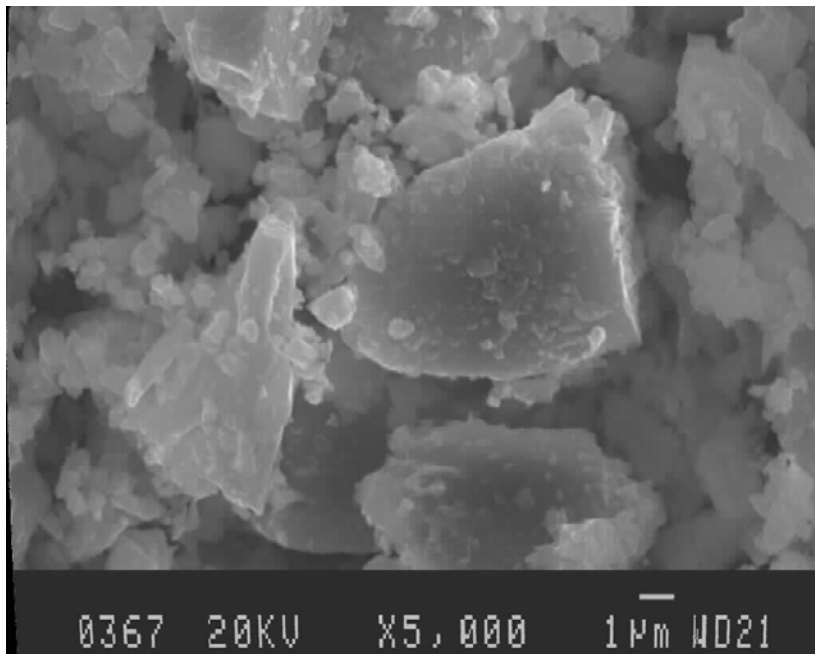Fig. 1 - electron of RHA
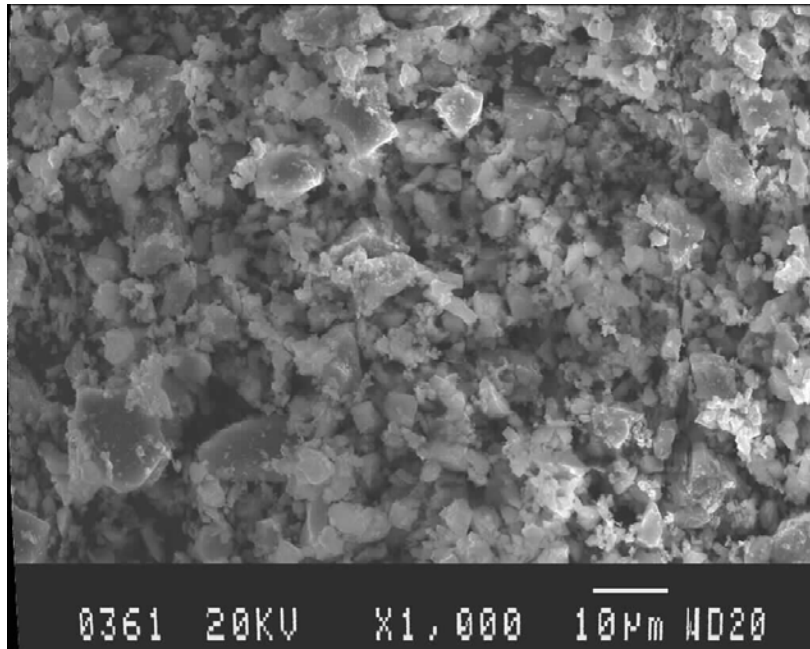
Scanning micrographs particles

Fig. 2 - X-ray spectrum of RHA

Fig.3 Particle size distribution curves for the unground and ground RHA