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Abstract

Rice husk ash (RHA) is an agricultural waste which is a pozzolanic material that can be blended with the cement for manufacturing concrete. Its use can reduce the environmental impact of the cement industry. The present study investigates the chemical and morphological nature of RHA and silica fume (SF). Both can be used to improve strength and durability properties of concrete. Particle size distribution, loss on ignition (LOI), X-ray diffraction analysis, scanning electron microscopic were conducted. The effect of replacement of cement 5%, 10% and 15% by weight with SF and RHA on compressive strength and workability has also been investigated for 32 MPa grade concrete blended with 30% Fly ash. The results show that concrete mixed with RHA had better strength than a similar mix with Silica Fume. RHA required additional amount of superplasticizer to improve the workability of concrete. In order to reduce the carbon footprint associated with cement industry, this paper gives satisfactory results to use RHA in sustainable construction.

Keywords

effect, workability, ash, husk, concrete, rice, strength

Disciplines

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Effect of Rice Husk Ash on workability and strength of concrete

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Abstract: Rice husk ash (RHA) is an agricultural waste which is a pozzolanic material that can be blended with the cement for manufacturing concrete. Its use can reduce the environmental impact of the cement industry. The present study investigates the chemical and morphological nature of RHA and silica fume (SF). Both can be used to improve strength and durability properties of concrete. Particle size distribution, loss on ignition (LOI), X-ray diffraction analysis, scanning electron microscopic were conducted. The effect of replacement of cement 5%, 10% and 15% by weight with SF and RHA on compressive strength and workability has also been investigated for 32 MPa grade concrete blended with 30% Fly ash. The results show that concrete mixed with RHA had better strength than a similar mix with Silica Fume. RHA required additional amount of superplasticizer to improve the workability of concrete. In order to reduce the carbon footprint associated with cement industry, this paper gives satisfactory results to use RHA in sustainable construction.

Keywords: Rice husk ash, RHA, silica fume, Fly ash, concrete, compressive strength.

1. Introduction

"Concrete is second most substance consumed on earth next to water, with almost one tonne of it being used for each human every year" (1). The active ingredient in concrete is cement which typically makes about 10-15% of the concrete. Global cement production reached 3,400 million tons in 2011 and is predicted to exceed four billion tons over the next few years (2). In relation to carbon footprint associated to cement production many researchers are studying the use of waste products as supplementary cementitious materials (SCMs) in concrete. Examples include coal combustion fly ash (from burning coal in power plants), silica fume (from silicon industry), blast furnace slag (from iron and steel production), and rice husk ash or RHA (from rice mills) (3). Generally, mineral admixtures have favorable influence on the strength and durability of concrete (4).

Rice husk is a major agricultural waste and is considered a worthless by-product of the rice milling industry. About 70 million tons of RHA is produced annually worldwide (5). During milling, about 78% of weight is received as rice, broken rice and bran and the rest of the 22% is received as husk (6). The resultant husk contains about 75% organic volatile matter and the remaining 25% of the weight is converted into ash during burning process, which is known as rice husk ash (RHA) (6). Table 1 shows the World production for the year 2009 for Rice paddy, Rice husk and RHA in Million tonnes. Many researchers believe that burning temperature is a critical point in the production of amorphous reactive ash. Chindaprasirt and Rukzon (8) have suggested that RHA with cellular microstructure and highly pozzolanic activity is formed, when rice husk is burnt at temperatures lower than 700^0C. It contains high silica content in the form of non-crystalline or amorphous silica up to 95% (4). The chemical composition of RHA depends on type of paddy, crop year, climate, geographical conditions (6) incinerating conditions, rate of heating and fineness (9). The reactivity is also favored by particle size of RHA. Mehta (10) states that at least about 75% of RHA particles size should range from 4 μm to 75 μm, with a mean particle diameter between 8 μm to 6 μm, and a surface area of at least 20 m^2/g and also grinding of the RHA to high degree of fineness should be avoided as it derives its pozzolanic activity from the internal surface area of the particles.

Table 1: World production rate for Rice paddy, Rice husk and RHA in Million Tonnes (7, 6)

	Rice Paddy	Rice husk	Rice husk ash
Bangladesh	27	5.4	1.35
Brazil	09	1.8	0.45
Burma	13	2.6	0.65
China	180	36.0	9.0
India	110	22.0	5.5
Indonesia	45	9.0	2.25
Japan	13	2.6	0.65
Korea	09	1.8	0.45
Philippines	09	1.8	0.45
Taiwan	14	2.8	0.7
Thailand	20	4.0	1.0
US	07	1.4	0.35
Vietnam	18	3.6	0.9
Others	26	5.2	1.3
Total	500	100	25

In Australia, rice is produced mainly in southern New South Wales and small amount in Northern Victoria, Northern NSW, and Queensland. The total rice production in Australia for the year 2000-01 was 1.6 million tonnes (11) and approximately 80 killotonnes of RHA can be expected.

Rice husk ash has unique pozzolanic property which means it provides reactive SiO_2 to react with water and $Ca(OH)_2$ that forms from the hydration of calcium silicates in cement (Equation (1) and (2)) , to yield calcium silicate hydrate, which is responsible for the strength in cement-based materials.

Hydration reactions (4):

$$2(3CaO.SiO_2) + 6H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \quad (1)$$

$$2(2CaO.SiO_2) + 4H_2O \longrightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2 \quad (2)$$

One of the advantages of using RHA in concrete would be reduced waste to landfill. In the absence of utilization of this huge quantity of RHA it would be disposed to the land fill (6). Another advantage is the reduction in the CO_2 emissions to atmosphere by reducing cement production. It is estimated that to produce 1 tonne of cement causes approximately 0.7 to 1.0 tonne of CO_2 to be emitted (6) both directly and indirectly by burning fuel and in transportation. Using RHA can reduce the cement cost in concrete by utilizing the waste product in concrete as partial replacement of cement. RHA can increase the compressive strength of the concrete since RHA is a fine particle and pozzolanic in nature which fills the small voids in concrete and forms C-S-H bonds which requires very high energy to break this bond thus increasing the strength of the concrete. From an energy viewpoint, it has been reported that to produce one tonne of cement, 4GJ of energy is required and 1.7 tons of raw materials (namely limestone and shale) which leads to environmental degradation and pollution problem (6) by utilizing RHA to replace some of the cement we can save natural resources and energy.

The present study investigates the chemical and morphological nature of RHA. Particle size distribution, Loss on Ignition, X-ray diffraction analysis, scanning electron microscopic experiments were carried and also both compressive strength and workability of the plastic concrete test were performed to allow comparison between the rice hush ash and silica fume and to develop a structure with most favorable properties.

2. Materials and methods

In order to assess the suitability of RHA for use as a supplementary cementitious material, samples were obtained from a rice mill in Thailand. The study was developed in two stages. In the first stage, physical and chemical properties of RHA were studied in order to compare with SF. In the second stage the concrete specimens with different percentage of RHA and SF were test for workability and compressive strength at 3 and 7 days.

2.1 Materials and mixtures

The materials and standard complied used in the mix design are tabulated in Table 2 and there chemical composition in Table 3. The materials used in the mix design were GP cement, fly ash, RHA, SF, fine aggregates and coarse aggregates size of 10mm and 20mm. The chemical composition of cement, RHA, SF and FA are tabulated in Table 3. Chemical composition indicated that both SF and RHA mainly composed of SiO_2 and the proportions of the component were almost same in both the samples.

Table 2: Materials used in the experiment

<table>
<tr><td colspan="2">Materials</td><td>Standard complied with</td></tr>
<tr><td colspan="2">GP Cement</td><td>AS3972</td></tr>
<tr><td colspan="2">coal combustion fly ash</td><td>AS3582.1</td></tr>
<tr><td colspan="2">Rice Husk Ash</td><td>-</td></tr>
<tr><td colspan="2">Silica Fume</td><td>AS3582.3</td></tr>
<tr><td rowspan="2">Fine aggregate</td><td>Coarse sand</td><td rowspan="2">AS2758.1</td></tr>
<tr><td>Fine sand</td></tr>
<tr><td rowspan="2">Coarse aggregate</td><td>20 mm</td><td rowspan="2">AS2758.1</td></tr>
<tr><td>10 mm</td></tr>
<tr><td colspan="2">Pozzolith 370C</td><td>AS1478.1</td></tr>
</table>

3. Results and discussion

3.1 Particle size distribution

The particle size of the cement and SCM's materials were determined using Mastersizer 2000 which uses laser diffraction principles to determine the size of the particle. The particle size distributions curves of cement and SCM's are shown in Figure 1. The average particle size of RHA is 8 μm which is almost two and half times smaller than SF. Ferraro and Nanni (12) have suggested smaller particles could fill in the voids of the mortar mixture and thus improves the compressive strength and durability of concrete.

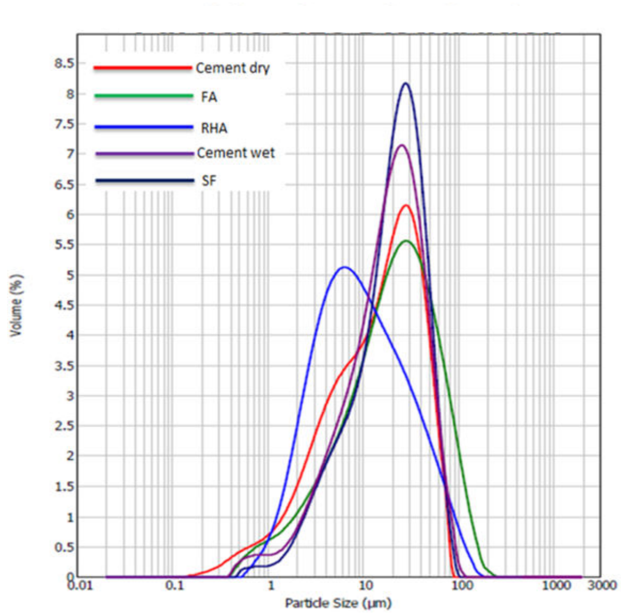

Figure 1: Particle size distribution of Cement and SCM's

Table 3: Chemical composition of cement and SCM's (2, 9)

Component	Portland cement	Fly Ash	Silica fume (2)	RHA (9)
CaO	62 – 65	0 – 5	0.1 – 0.5	-
SiO_2	19 – 26	50 – 70	85 – 95	91
Al_2O_3	4.5 – 5.5	20 – 30	0.1 – 3	0.35
Fe_2O_3	2 – 5	2 – 10	0.1 – 4	0.41
TiO_2	-	1 – 2	-	0.81
Mn_3O_4	-	0 – 0.5	-	-
MgO	1 – 3	0 – 2	0.1 – 1	0.81
Na_2O	0.2 – 0.7	0.2 – 2.5	0.1 – 1	0.08
K_2O	0.5 – 2.5	0.2 – 2.5	0.1 – 1	3.21
P_2O_5	0.1 – 0.2	0 – 2	-	0.98
SO_3	2 – 3.5	0 – 2	0.1 – 0.5	1.21

3.3 Loss on Ignition

Loss on Ignition is designed to measure the absence of residual combustion carbon. LOI test for SCM's was conducted as per AS 3583.3-1991 on dried samples. The LOI value is proportional to unburnt carbon content and they have larger surface area and hence water demand is higher for a given level of workability (6). The results are listed in Table 4 and indicate that LOI for RHA is three times higher compared to MSDS. This suggests that it might contain other impurities.

Table 4: Moisture content and LOI values for SCM's

Sample	Moisture content	LOI	LOI from MSDS (22, 2)
RHA	2.71	3.15	<1
SF	0.19	3.57	1-6

FA	1.49	1.46	0.5-5

3.3 X-ray diffraction analysis

X-ray diffraction analysis (XRD) of the SCM's was performed using GBC MMA X-ray diffractometer with copper radiation at a scan rate of 1^{o}/ min. This analysis was carried to ascertain the mineralogical phases (amorphous or crystalline) of the SCM's. Figures 2 and 3 show the XRD pattern of RHA and SF which both have broad smooth humps indicating it is amorphous structure. Previous studies have shown that if RHA is amorphous than most of its silica is in amorphous form. This amorphous silica is very reactive and improves the strength and durability of concrete (12). Figure 4 shows the pattern for fly ash (FA), indicating the peaks of SiO_2 which proves that FA is in crystalline form.

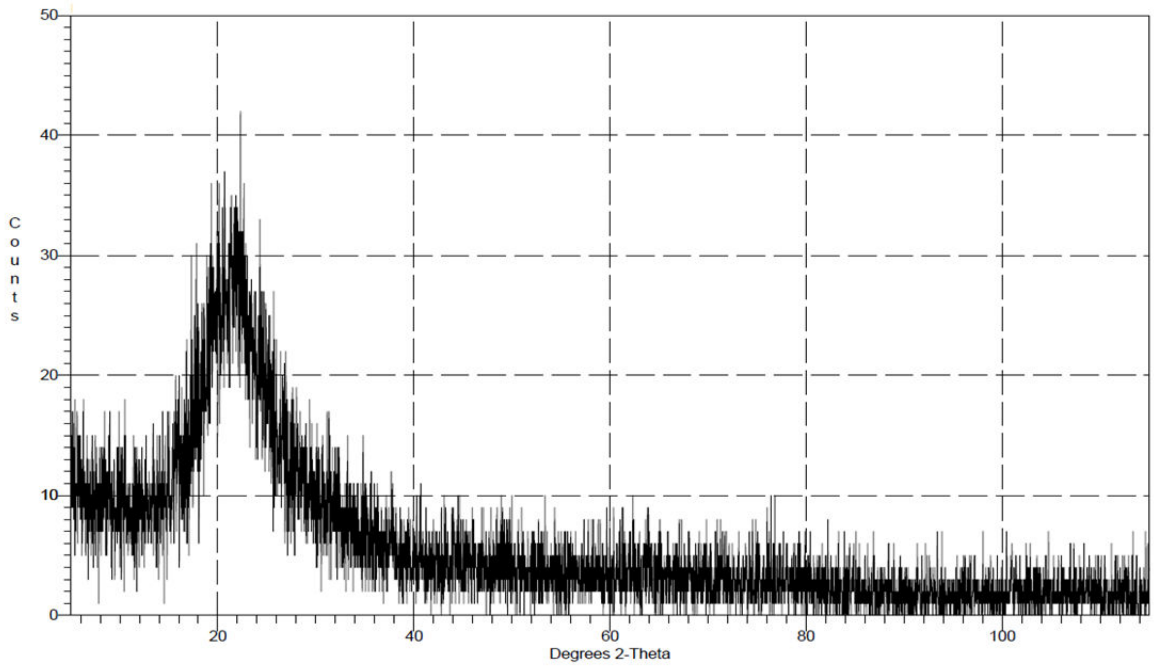

Figure 2: XRD of RHA

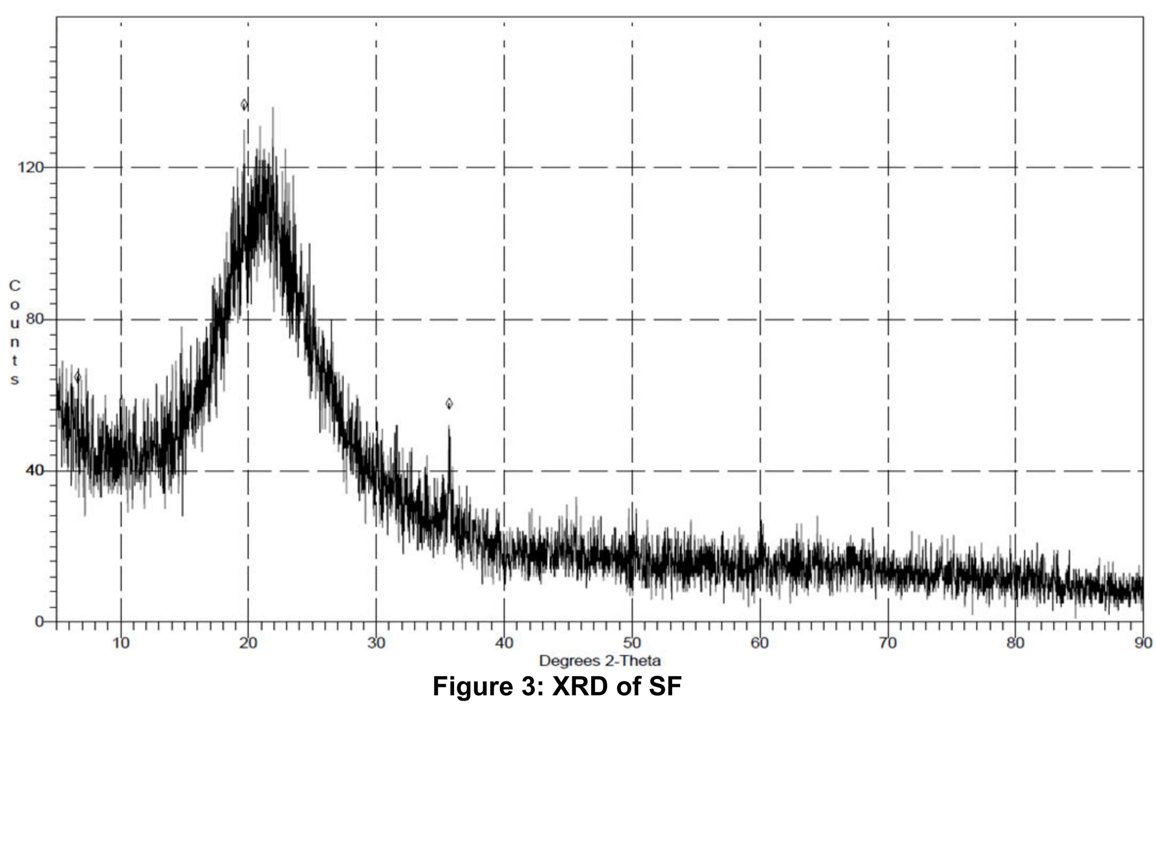

Figure 3: XRD of SF

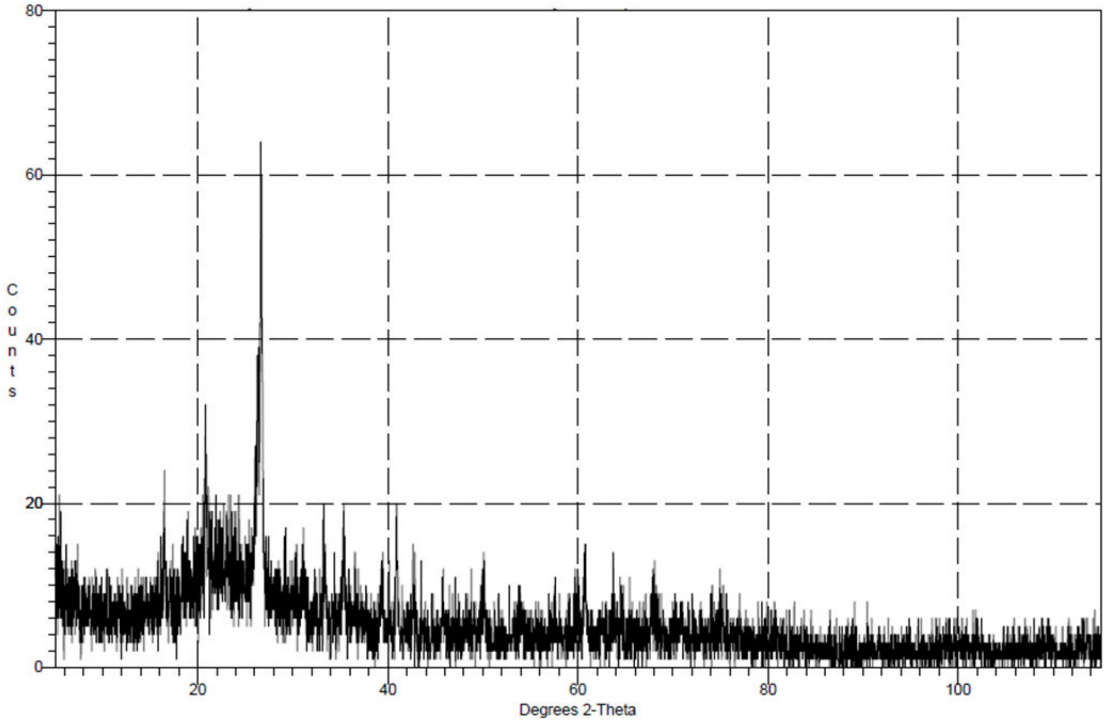

Figure 4: XRD of FA

3.4 Scanning electron microscopic analysis

The morphology of all SCM's samples was obtained using JEOL JCM-6000 scanning electron microscope. The samples were mounted on the specimen stub using double - sided conductive tapes and placed inside the SEM to analysis and the working distance was 12mm. Figures 5 and 6 show the SEM images of the sample. Inspection of these figures reveals that SF was spherical, FA was mostly spherical and RHA was irregular in shape similar to previous research (9, 12). These irregular shaped particles could significantly affect the properties of the finished product (6).

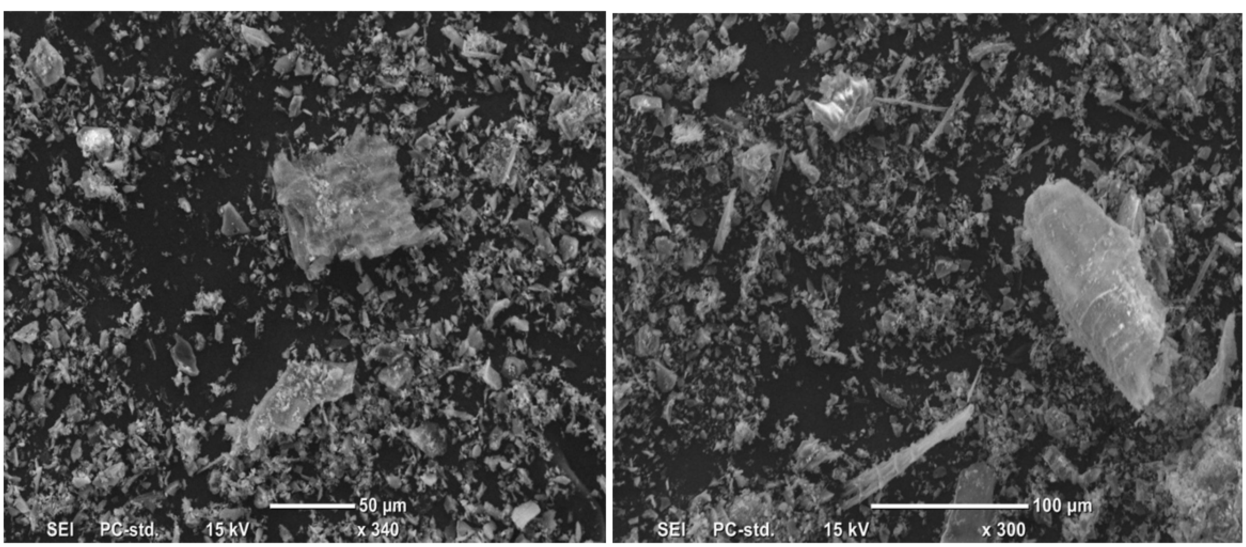

Figure 5: SEM image of RHA samples

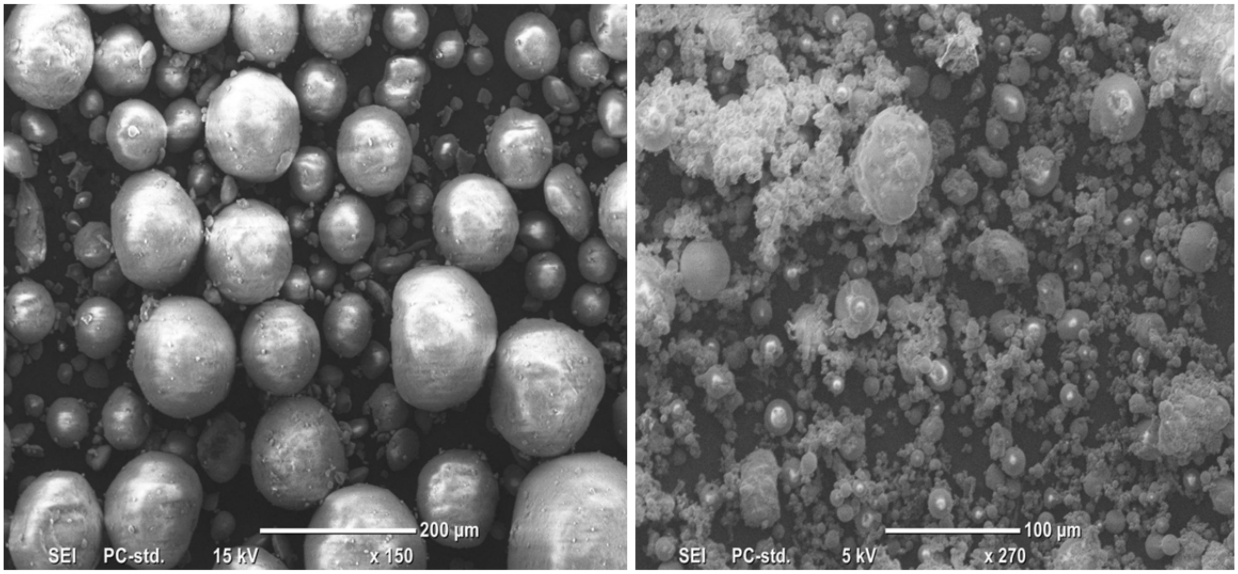

Figure 6: SEM image of SF (left) and FA (right)

3.5 Summary

The results of first stage have proven RHA is a material with high amorphous silica and average particle size around 8µm. These results allow us to predict how the materials will behave when mixed in concrete. In second stage we will test concrete for both compressive strength and slump test of plastic concrete to compare the results with SF.

3.6 Mix and specimen characteristics

The specification of the mix design is that the concrete gains 32 MPa at 28 days. In this paper nine mixes with different proportions, including one control mix were prepared. These mixes were tested for slump test and compression test at 3 days and 7 days. The replacement was straight the amount of cement taken out of the mix was replaced by the equal amount of SF or RHA. The concrete mix design details are summarized in Table 5.

3.7 Slump test

The slump test was performed to measure the workability of the concrete. The tests were done according to AS 1012.3.1-1998 Australian Standard. The concrete was filled in three layers; each layer was roughly one third the height of the slump cone and each layer was stroked 25 times with the rounded end of the rod. After the cone was filled with concrete, the cone was lifted vertically in 3 seconds and slump value of the concrete was determined of each batch.

The water demand increased as the percentage of RHA increased. The increasing demand for water may be due to fine particle or larger surface area or its irregular shape. Similar pattern was observed by few authors (6). Whereas the slump for concrete with SF was almost the same as the percentages of SF varied. The results are tabulated in Table 6.

3.6 Compressive strength test

Plain concrete cylinders 100mm in diameter and 200mm in height were used to determine the compressive strength of each batch. The specimens were cast in two layers, compacted with reference to AS 1012.8.1-2000 and moist cured at $23^{o}C \pm 2^{o}C$.

Table 5: Mix proportions of concrete

Mix Number	M1	M2	M3	M4	M5	M5A	M6	M7	M8
Mix Description	Control mix	30% FA	30% FA+5% RHA	30% FA+5% SF	30% FA+10 %RHA	30% FA+10 % RHA	30% FA+10 % SF	30% FA+15 %RHA	30% FA+15 % SF
w/b ratio	0.62	0.52	0.52	0.52	0.53	0.57	0.52	0.54	0.52
Cement kg/m^3	310	247	234.65	234.65	222.3	222.3	222.3	209.95	209.95
FA kg/m^3	0	103	103	103	103	103	103	103	103
RHA kg/m^3	0	0	12.35	0	24.7	24.7	0	37.05	0
SF kg/m^3	0	0	0	12.35	0	0	24.7	0	37.05
Coarse Sand kg/m^3	700	700	700	700	700	700	700	700	700
Fine Sand kg/m^3	280	280	280	280	280	280	280	280	280
20mm Aggregate kg/m^3	575	575	575	575	575	575	575	575	575
10mm Aggregate kg/m^3	290	205	205	205	205	205	205	205	205
Water kg/m^3	194	181	181	181	187	200	181	190	181
Superplastici- -zer ml	930	1150	1150	1150	1280	1150	1150	1350	1150

Compressive test were performed on two cylinders for each batch and age. The cylinders were capped using high strength plaster 30 minutes prior to testing. The compressive strength of each batch was determined in according to AS 1012.9-1999 at 3 days and 7 days.

The strength results are tabulated in Table 6. Concrete blended with RHA had better strength than SF which was contradictory to Sakr (13) results. This pattern may be due to larger particle size of SF which would have failed to fill in the small voids. The strength decreased as the percentage of RHA increased due to high water demand to maintain workability. The strength could be improved by decreasing the water content in the mix and increasing the Superplasticizer. The concrete mixture containing 10% RHA as a replacement of OPC at 7days had greater than 65% of expected strength at 28 days (14) and hence 10% replacement would be the optimum replacement level of RHA. When compared to control mix the strength was lesser, this decline in early strength is a result of low pozzolanic reaction of RHA. After 28 days, pozzolanic reaction starts to proceed, decreasing the amount of CH and improving densification and thus increasing the strength of concrete in the later stage (9). Table 6 results indicate that replacing cement by 15% RHA decreases the compressive strength to a value lesser then 20.8MPa (lesser then 65% of expected strength at 28 days) (14). This may be due to the fact that quantity of RHA presents in the mix is higher than the amount required to combine with the liberated lime during the hydration process thus leading to excess silica leaching out causing a reduction in strength as it replaces part of cementitious materials but does not contribute to the strength (4).

Two mixes M5A and M5 were prepared with equal amount of RHA and FA by varying w/b ratio and SP and observed that mix M5 had better strength then M5A as lesser water was added to mix M5.

Table 6: Workability and compressive strength of concrete

Mix number and Description	Slump mm	Compressive strength (MPa)	
		3Days	7Days
Control mix (M1)	70	19.28	26.98
30%FA (M2)	130	18.15	27.88
5%RHA+30%FA (M3)	90	16.04	22.79
5%SF+30%FA (M4)	130	15.28	18.21
10%RHA+30%FA (M5)	90	17.19	21.39
10%RHA+30%FA (M5A)	100	14.64	18.97
10%SF+30%FA (M6)	120	14.77	18.03
15%RHA+30%FA (M7)	70	15.54	19.73
15%SF+30%FA (M8)	100	13.18	17.82

3. Conclusions

- RHA is proved as an effective pozzolanic due to high amorphous silica content and finer particle size.
- The average particle size of RHA was almost two and half times smaller compared to SF.
- The SEM shows that RHA was irregular in shape and SF was spherical. This had negative effect on workability of fresh concrete.
- Concrete mixed with RHA had higher compressive strength than that mixed with SF.
- Water demand was higher for concrete containing RHA than SF thus reducing compressive strength compared to control mix. To achieve higher strength and workability SP can be used for concrete blended with RHA.
- Concrete containing 30%FA and 10% RHA as a replacement of cement can be used in practical as the strength were greater than the threshold value thus reducing 30% cement by weight in concrete mix which reduces environmental problems associated with cement production and dumping of RHA.
- Concrete with 30%FA and 15% RHA could be used for non-structural works where strength is not a very important factor.

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