REPLACEMENT EFFECT OF CEMENT BY RICE STRAW ASH ON CEMENT MORTAR PROPERTIES

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ABSTRACT

*Rice straw ash (**RSA**) is an agricultural waste product which is produced in large quantities globally every year. Due to the difficulty involved in its disposal, it is becoming an environmental hazard in rice producing countries. In Egypt, **RSA** presents an important environmental impact. One way to reduce the impact of the construction activity is by substitute pozzolanic materials for ordinary Portland cement (**OPC**). In this work, an experimental study was conducted on the effect of partial replacement of **OPC** with **RSA** on the Engineering properties of cement mortar. Control mortar mix with **OPC** was made and in other mixes **OPC** were replaced with **RSA** up to 75 % by weight. The work focused on some physical and mechanical properties of the **OPC- RSA** mortar. It consisted of: density, porosity, water absorption, setting time, flexural, compressive strength, and scanning electron microscopy (**SEM**). The results showed that both initial and final setting times increased with increasing the **RSA** replacement percent. **OPC-RSA** mortar gave excellent enhancement in strength for 15 % replacement. Moreover, up to 20% of **OPC** could be valuably replaced with **RSA** without adversely effecting in strength. Further, hydration reactions of **OPC-RSA** mortars were investigated using **SEM** at 28 days.*

INTRODUCTION

The Egyptian rice yield is one of the highest in the world (3.7 tons per feddan in 2009) (**FAO, 2010**). Thus; rice straw is a major agricultural by-product in Egypt, where its production in 2009 estimated to 4 million tons (**FAO, 2010**). The methods for disposing of the straw and stubble residue remaining in the fields after harvest are either burning or baling. Although some limited uses of rice straw such as animal feed or paper making are maintained, burning is the principal disposal method for most of the rice straw residue.

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It is efficient, effective and cheap, even after being phased out in the Egyptian law of Environment. As a result, most farmers tend to burn the straw in open fields, boosting air pollution and serious human health problems due to the emission of carbon monoxide (**Allam *et al.*, 2011**). On the other hand, the manufacture of ordinary Portland cement (OPC) is a highly energy intensive and environment unfriendly process required about 4 GJ of energy per tone of the finished product in addition to produce 0.8–1.3 ton of CO_2 per ton of cement production. Also, the contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35 billion ton annually or about 7% of the total greenhouse gas emission to the earth atmosphere (**Malhotra and Mehta, 2004**).

Continuous attempts are being made to: (i) reduce the cost of production of Portland cement, (ii) reduce the consumption of the raw materials,(iii) protect the environment and (iv) enhance the quality of cement. One way is to use certain low cost materials for partial replacement of Portland cement clinker. Low cost materials used are industrial and agricultural by-products (wastes). Mixtures of Portland cement with these by-products are known as 'blended cements' or 'composite cements'. By definition blended cements are hydraulic binders in which a part of Portland cement is replaced by other hydraulic or non hydraulic materials. Their general behaviour is quite similar to that of Portland cement since they harden when mixed with water and form the same hydration products. The most common ingredients for blending with Portland cement clinkers are latent hydraulic component (blast furnace slag), a pozzolanic component such as fly ash, rice husk ash, condensed silica fume, burnt clay or filler component such as lime stone and other waste materials (**Singh and Grag, 2006**). As reported by **Taylor, (1990)**, a typical pozzolanic material should satisfy three characteristics: contain high silica content, be amorphous in nature and have a large surface area. Amongst the agricultural waste, rice husk and straw has a very high potential for the production of very effective secondary raw material. It is mainly due to its random availability, very high silica content, and relatively low cost. After burning rice straw and husk in controlled temperature and duration 14.6 % and 22% of mass rice straw and husk, respectively are converted

into high quality value added ash which unique secondary raw material due to the high amount of silica in the ash (**Morsy, 2011**).

Reaction mechanism and OPC-pozzolan properties

Concrete is a structural material which consists of OPC, aggregate (sand and rock), and water. It is believed that the compressive strength of concrete is influenced by the curing conditions, specimen preparation, age at testing, mode of testing, and mode of failure of the specimen (**Taylor, 1990**).

A pozzolanic reaction occurs when a siliceous or aluminous material get in touch with calcium hydroxide in the presence of humidity to form compounds exhibiting cementitious properties (**Papadakis *et al.*, 2002**).

In the cement hydration development, the calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$, or CH) are released within the hydration of two main components of cement namely tricalcium silicate ($3CaO.SiO_2$ or C3S) and dicalcium silicate ($2CaO.SiO_2$ or C2S) where C, S represent CaO and SiO_2 (**Omotosoa *et al.*, 1995**). Hydration of C3S, C2S also C3A and C4AF (A and F symbolize Al_2O_3 and Fe_2O_3) respectively, is important. Upon wetting, the following reactions occur (**Englehard *et al.*, 1995**):

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

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

$$3CaO.Al_2O_3+31H_2O+3CASO_4 \rightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O \quad (3)$$

$$4CaO.Al_2O_3.Fe_2O_3+10H_2O+2Ca(OH)_2 \rightarrow 6CaO.Al_2O_3.Fe_2O_3.12H_2O \quad (4)$$

The C-S-H gel generated by the hydration of C3S and C2S in **Equations (1)** and **(2)** is the main strengthening constituent. Calcium hydroxide and Ettringite ($3CaO.Al_2O_3.3CaSO_4.31H_2O$, **Equation 3**) that are crystalline hydration products are randomly distributed and form the frame of the gel-like products. Hydration of C4AF (**Equation 4**), consumes calcium hydroxide and generates gel-like products. Excess calcium hydroxide can be detrimental to concrete strength, due to tending the crystalline growth in one direction.It is known that by adding pozzolanic material to mortar or concrete mix, the pozzolanic reaction will only start when CH is released and pozzolan/CH interaction exist (**Villar Cocina *et al.*, 2003**). In the pozzolan-lime

reaction, OH and Ca^{2+} react with the SiO_2 or Al_2O_3 - SiO_2 framework to form calcium silicate hydrate (C-S-H), calcium aluminate hydrate (C-A-H), and calcium aluminate ferrite hydrate as the following **Equations (5~7)**:

Tobermorite gel:

$$SiO_2 + Ca(OH)_2 + H_2O \rightarrow CaO.SiO_2.H_2O \quad (5)$$

Calcium aluminate hydrate:

$$Ca(OH)_2 + H_2O + Al_2O_3 \rightarrow CaO.Al_2O_3.Ca(OH)_2.H_2O \quad (6)$$

Calcium aluminate ferrite hydrate:

$$Ca(OH)_2 + Fe_2O_3 + Al_2O_3 + H_2O \rightarrow Ca(OH)_2.Al_2O_3.Fe_2O_3.H_2O \quad (7)$$

The crystallized compound of C-S-H and C-A-H, which are called cement gel, hardened with age to form a continuous binding matrix with a large surface area and are components responsible for the development of strength in the cement paste (**Kassim *et al.*, 2004**). Pozzolan-lime reactions are slow, generally starting after one or more weeks (**Englehard *et al.*, 1995**). The behavior of the delay in pozzolanic reaction will result in more permeable concrete at early ages and gradually becomes denser than plain concrete with time. This behavior is due to two reasons: Firstly, pozzolan particles become the precipitation sites for the early hydration C-S-H and CH that hinders pozzolanic reaction. Secondly, the strong dependency of the breaking down of glass phase on the alkalinity of the pore water which could only attain the high pH after some days of hydration. Pozzolan can partially replace cement in mortar or concrete mix without affecting strength development. The effect of the pozzolanic reaction produces more cement gel (i.e. C-S-H and C-A-H) reducing the pore size, blocks the capillary and produces denser concrete thus making it stronger and more durable.

Literature studies have identified that commonly permeability of blended cement concrete is less than plain cement paste. It was observed that the incorporation of RSA in the composites could cause an extensive pore refinement in the matrix and in the interface layer, thereby decreasing water permeability (**Rodrigues *et al.*, 2006**). One of the main

sources of contamination of concrete in structures is water absorption which influences durability of the concrete and also has the risk of alkali aggregate reactions (**Ithuralde, 1992**). The more impermeable the concrete, the greater will be its resistance to deterioration. The incorporation of pozzolan such as fly ash reduces the average pore size and results in a less permeable paste (**Poon *et al.*, 1997; Chindaprasirt et al., 2005**). The presence of pozzolan leads to greater precipitation of cement gel products (**Feng *et al.*, 2004**) than occurs in Portland cement alone, which more effectively block the pores helping to reduce permeability. The radial expansion of Portland cement hydration products in pozzolanic particles would have a pore modification effect therefore reduces the interconnectedness among pores (**Cook *et al.*, 1987**). This occurrence can be coupled with perfection on the interfacial transition zones among the cement matrix and aggregate (**Toutanji *et al.*, 2004**). The permeability will decrease rapidly with the progress of the hydration. **Saraswathy *et al.*, (2007)** studied the effect of partial replacement of cement with rice husk ash (RHA) at different replacement levels on the porosity and water absorption of concrete and reported that the coefficient of water absorption for RHA replaced concrete at all levels was less than control concrete.

Thus, the objectives of this work were to use RSA as a partial replacement for cement. A series of tests were conducted consisting: physical and chemical properties of RSA, physical and mechanical properties of the OPC-RSA mortars, and hydration reaction of mortars were investigated using SEM at 28 days.

MATERIALS AND METHODS

1. Experimental program materials

1.1. Rice straw ash (RSA)

Locally Egyptian rice straw was collected and burnt under uncontrolled combustion process in earthen oven which used by the rural people for cooking purpose. The burning temperatures usually are in the range of 600 to 700^{0}C **(Elwan *et al.*, 2006)**. The ash obtained from burning was sieved through 200 μm sieve in order to remove any impurity and larger size particles and its appearance colour was grey (**Figure 1**).

Fig. 1. Sample of RSA before and after sieving

1.2. Cement

The cement type used in this research was Ordinary Portland Cement (OPC 43 grade) and it conformed to the requirements of BS (**EN 197-1, 2000**).

1.3. Aggregates

The fine aggregate used in the research was natural sand with fineness modulus of 2.25 and specific gravity of 2.58 g/cm^3.

1.4. Water

The tap water which used during the study was clean and free from any visible impurities.

2. Composition of mortar mixtures

Table (1) presented the used mixture proportions of mortars. Batching of materials was done by weight. The percentage replacements of OPC by RSA were 0, 5, 10, 15, 20, 25, 50 and 75%. The zero percent replacement was to serve as a control for the other mixtures. The OPC- RSA binders (**B**) were mixed with sand with the ratio of 3:1 by weight. The OPC, RSA and sand were mixed together, until a homogeneous mixture was obtained. The measured quantity of water (**W**) was added to the mixture.

Table 1: mixture proportions of OPC-RSA mortars

Experiment	*Cement, g*	*RSA, g*	*Sand, g*	W/B Ratio
100% OPC, 0 % RSA	185	0	555	0.50
95 % OPC, 5 % RSA	175.75	9.25	555	0.52
90 % OPC, 10% RSA	166.5	18.5	555	0.54
85 % OPC, 15% RSA	148	37	555	0.56
80 % OPC, 20% RSA	129.5	55.5	555	0.58
75 % OPC, 25% RSA	111	74	555	0.60
50 % OPC, 50% RSA	92.5	92.5	555	0.64
25 % OPC, 75% RSA	46.25	138.75	555	0.68

It was further mixed for two minutes in a plastic container until a paste of required workability was obtained and filled into a 4 × 4 × 16 cm mould (**Figure 2**) and cured at room temperature for the first 24 hours. After 24 hours the specimen were remoulded and cured under water for 28 days.

3. Methods

3.1. Physical and chemical properties of RSA

3.1.1. Particle size, shape, and sieve analysis

The ash particle size and shape were determined with the help of JSM-5300 scanning electronic microscope (SEM). The device was located in the lab at faculty of science, Alexandria University. It operated at 20KV as shown in **Figure (3).**

3.1.2. Bulk and true density of RSA particles

The true density of RSA was measured as a ratio between the oven dry weight and its volume. Volumes samples were measured by using helium pycnometer as shown in **Figure (4)**.

Fig. 2. Samples of casted presumes

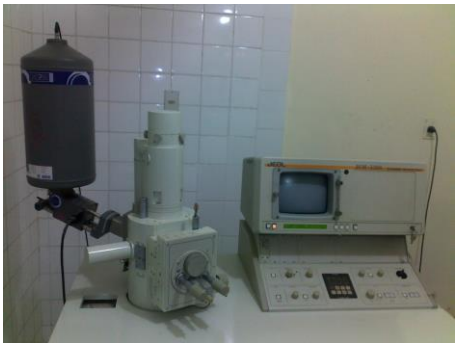


Fig. 3. JSM-5300 Scanning microscope

On the other hand, straw particles bulk density was determined by filling a 5 litter plastic tank with oven dried straw particles. Then straw particles bulk density was calculated using the following equation:

$$S = \frac{W_1 - W_2}{5000} \quad (8)$$

Where:

S: Bulk density of RSA particles (g/cm^3), W_1: Weight of the plastic tank with RSA particles (g), W_2: Weight of empty tank (g).

3.1.3. Chemical analysis of RSA

Chemical analysis of RSA samples were carried out in the laboratory of national institute of oceanography and fisheries, Alexandria by the recommended methods using X-ray Diffraction (XRD) and X-ray fluorescence (XRF).

3.2. Physical and mechanical properties of OPC-RSA mortars

3.2.1. Setting times test

The initial and final setting times of the samples were determined in the laboratory of Agricultural and bio system engineering department, faculty of agriculture, Alexandria university by using of Vicat apparatus (**Figure 5**) according to British standard (**BS 4550-3-3.6, 1978**) on all samples using the 1mm and 5mm diameter needles.

Fig. 4. Helium pycnometer device to measure the true density

Fig. 5. Vicat apparatus

3.2.2. Bulk density of OPC-RSA mortars

For determination of density of hardened composite, a set of samples measured 4×4×16 cm were used. Three replicates of each sample were tested after 28 days. All samples were dried at 105 ± 5ºC until constant

weight achieved and then placed in desiccators to cool down. Density was measured

based on the oven dry weight and its volume, as explained in **equation (9)**.

$$C = \frac{W_d}{V} \quad (9)$$

Where:

C : Bulk density composite (g/cm^3), W_d : Weight of the oven dry sample (g), V : Green volume of the sample (cm^3).

3.2.3. Water absorption and porosity tests

A set of samples measured 4×4×16 cm were used. Three replicate samples were used for each test. Samples were tested after 28 days. All samples were dried at 105±5ºC until constant weight achieved and then placed in desiccators to cool down. Water absorption was determined according to American standard testing method **(ASTM D-1037, 1984**) as follow: After conditioning, the test specimens were weighed to the nearest 0.01 gram. Then the test specimens were soaked in water at the room temperature. After 24-hour, the specimens were suspended to drain the water for 10 minutes and the excess surface water was removed and immediately weighed to the nearest 0.01 gram. The amount of water absorbed after 24-hour water soak was calculated as a percentage of the original weight of test specimens. The porosity was also calculated after 7 days from soaking in water, using **equation (10).** This method has been used to measure cement based materials porosity successfully (**Gonen** and **Yazicioglu, 2007**).

$$P = \frac{W_a - W_d}{W_a - W_w} \times 100 \quad (10)$$

Where:

P : Saturated porosity (%), W_a : Weight of saturated sample in air (g), W_d : Specimen dry weight after 24 h in oven at 105 ± 5ºC (g), W_w : Specimen weight in water (g).

3.2.4. Scanning electron microscopy

JSM-5300 Scanning electron microscopy, (**SEM**) was used in the study to investigate the morphology of the OPC–RSA mortars. The device was operated at 20KV as shown in **Figure 3**.

3.2.5. Compressive test

Compressive test was used to evaluate the strength development of OPC-RSA mortars at 7, 14, and 28 days. Compressive strength of cubic specimens 40×40×40 mm accordance with the standard European standard **DIN EN (196-1, 2005)** was performed using servo hydraulic material testing system with maximum load of 100 kN, the device was located in the lab of testing of materials, faculty of engineering, Alexandria university, **Figure (6a)**. The compressive strength is calculated using the following equation:

$$CS = \frac{P}{B \times L} \tag{11}$$

Where:

CS: Compressive strength (MPa), *P*: Maximum load (N), *L*: Length of sample (mm), *B*: Width of sample (mm).

3.2.6. Flexural test

Three point Flexural test was used to evaluate the strength of OPC-RSA mortars at 28 days. Flexural specimens have a rectangular shape measuring approximately 4×4×16 cm. The flexural test was carried out in accordance with the standard **DIN EN (196-1, 2005)** using a universal testing machine (**Figure 6b**). Maximum load reading was taken and FS calculated using the following formula for three point bending test:

$$FS = \frac{3PL}{2BD^2} \tag{12}$$

Where:

FS: Flexural strength (MPa), *P:* Maximum load (N), *L:* Length of sample (mm), *B:* Width of sample (mm), *D:* Thickness of sample (mm).

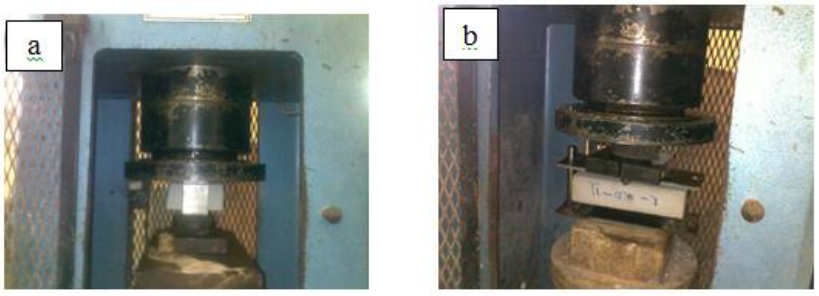


Fig. 6. **a:** Compressive test machine **b:** Flexural test machine

3.2.7. Relative strength

The relative compressive and flexural strength (RS) of RSA-OPC mortars compared to OPC mortar (control mortar) were calculated at 28 day using the following equation:

$$RS = R_i / R_o \times 100 \quad (13)$$

Where:

R_i :the strength of OPC-RSA mortar, R_o:the strength of the OPC mortar

3.2.8 Strength gain

The compressive and flexural strength gain (SG) of OPC-RSA mortars at 28 days were calculated taking into account the percentage replacement of OPC by pozzolan; the strength of OPC-RSA mortar (R_i) was compared with the strength of the OPC mortar (R_o), which was corrected by means of the ratio between OPC mass (W_{cem}) and the binder mass (sum of OPC and pozzolan, W_{cem} + W_{puz}). In this case, relative values were calculated as percentages as follows (**Moraes *et al.*, 2015**):

$$SG = R_i - \left[R_o \times \frac{W_{cem}}{W_{cem} + W_{puz}} \right] \times 100 / \left[R_o \times \frac{W_{cem}}{W_{ce}m + W_{puz}} \right] \quad (14)$$

RESULTS AND DISCUSSION

1. Physical and chemical properties of RSA

1.1. Chemical analysis of RSA

The chemical composition of RSA as determined with XRF teqnice was presented in **Table (2)**. The total percentage composition of iron oxide ($Fe_2 O_3$ = 0.90%), Silicon dioxide (SiO_2 = 69.20%) and Aluminum oxide (Al_2O_3 = 5.30%) was found to be 75.4%. This value is within the required value of 70% minimum for pozzolanas (**ASTM C618, 1997**). The value is higher than the value obtained by **Dashan and Kamang, (1999)** for acha husk ash (48.36%) and as such the RSA is more pozzolanic. Also this value is less than the 87.55% obtained by **Al-Khalaf and Yousif, (1984)**. The slight difference in percentage composition might have resulted from the method of preparation of the ash. The loss

on ignition obtained was 8.5%. This value is within the required value of 12% maximum as required for pozzolanas. It means that the RSA contains little unburnt carbon. The unburnt carbon it self is not pozzolanic and its presence serves as filler to the mixture. The obtained value is higher than 3.30% obtained by **Al-Khalaf and Yousif, (1984)** and as such the pozzolana is less effective compared to that obtained by them. The loss on ignition obtained was less than the obtained value by **Dashan and Kamang, (1999)** for acha husk ash (43.57%). This indicates that Acha husk produces greater unburnt carbon compound compared to rice straw. Therefore rice straw is a better material for making pozzolana compared to acha husk. The magnesium oxide content was 2.81%. This value satisfies the required value of 4 percent maximum.

Table 2. Chemical composition of RSA

Constituent	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	K_2O	NaO	L.O.I
Composition,%	0.90	69.20	3.46	5.30	2.81	6.40	3.43	8.50

The XRD analysis was performed to determine the silica phase of the produced RSA powder sample, they were scand by an X-ray diffraction using CuKa radiation at 40 kV/20mA, speed 2^o/min and scanning with angel of 2Ɵ from 3-70^o. According to the XRD graph, the RSA was mainly in amorphous form due to the broad peak on 2Ɵ angle of 22^o as shown in **Figure 7**. Many recearchers showed that the minimum temprature for crystalliyation of silika in rice husk ash is to be 800 ^{o}C (**Chandrasekhar *et al.*, 2003 and Zhang *et al.*, 1996**).

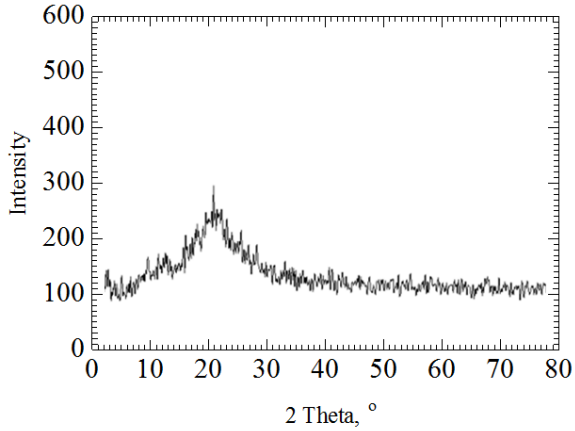


Fig. 7. The X-ray spectrum of RSA.

1.2.Particle size, shape, and sieve analysis of RSA

The grain size analysis of RSA was done by using 300, 150, 90, and 75 μm sieve sizes. The sieves contain RSA were put on the shaker for 15 minutes. The weights of the ashes retained in the sieves were taken. The sieve analysis result of the RSA is shown below in **Table 3**.

Table 3. Particle size analysis

Sieve No.	**300**	**150**	**90**	**75**	**Pan**
% of Sample Retained	9.8	25.64	21.54	28.65	14.37
Cumulative percentage retaind	9.8	35.64	56.98	85.63	100
% of Sample Passing	90.2	64.36	43.02	14.37	0.0

When RSA sample was scanned by SEM, the picture shows the RSA's multilayered, angular and microporous surface, thus explaning its high specific surface area see **Figure (8a,b)**. This result agreed with **Zhang *et al*., (1996), and Habeeb & Fayyadh, (2009**).

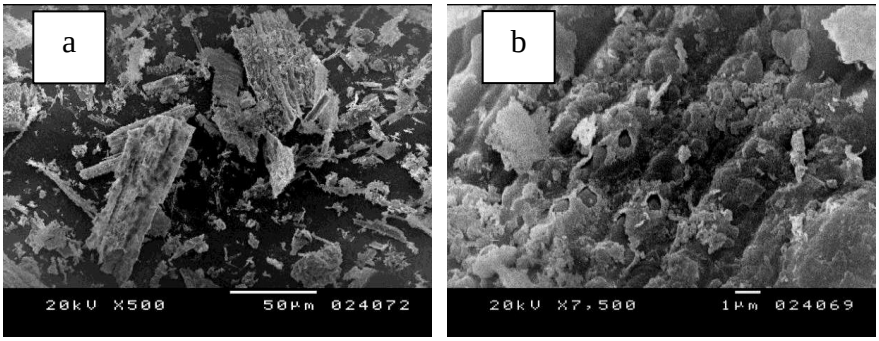


Fig. 8. (**a**) SEM images of RSA particles, and (**b**) SEM image of RSA particle surface

1.3. True and bulk density of RSA

The true density of RSA was found to be 2.13 g/cm^3 as determied by helium pycnometer. This value is close to the values obtained by **Dashan and Kamang, (1999)** of 2.12 g/cm^{3}for Acha Husk Ash (**AHA**), and **Al-Khalaf and Yousif, (1984)** was reported a value of 2.14 g/cm^3 for rice husk ash. The value is within the range for pulverized fuel ash **(FA)**, which is 2.4 g/cm^3 as reported by **Wang *et al*., (2004)**. The value of specific gravity is, however, less than the value for cement, which is 3.15 g/cm^3. The bulk densities of RSA are 0.550 g/cm^3. **Dashan and**

Kamang, (1999) was reported obtained bulk density of 0.740 g/cm^3 for **AHA**. Test result indicates that both materials are lightweight materials.

1.4. Physical of OPC-RSA mortars

1.4.1. Setting times of OPC-RSA mortars

The result for setting times test were presented in **Table 4**. The initial and final setting times increases with increase in rice straw ash content. The reaction between cement and water is exothermic leading to liberation of heat and evaporation of moisture and consequently stiffening of the paste. As rice straw ash replaced cement, the rate of reaction reduced, and the quantity of heat liberated also reduced leading to late stiffening of the paste. As the hydration process requires water, greater amount of water was also required for the process to continue. This result is in consonant with the work obtaind by **Munshi *et al*., (2013)**.

Table 4. Setting times test

RSA replacement of OPC (%)	0	5	10	15	20	25	50	75
Initial Setting Time (minutes)	95	115	130	150	170	215	365	430
Final Setting Time (minutes)	150	180	230	260	275	350	670	860

1.4.2. Bulk densities and total porosity of OPC-RSA mortars

The Bulk densities of the OPC-RSA mortars at 28 days of curing are illustrated in **Figure 9**. The results of the bulk densities showed that, bulk density increased as the percentage RSA increases up to 20% RSA. This could be attributed to the particle packing effect of voids with RSA particles which producing denser matrix. On the other hand, replacing OPC by more than 20% RSA, a reduction on the bulk density of OPC-RSA mortars was occurs. This could be due to the increase in voids in the mortars matrix as the percentage RSA increases with increasing of water to binder ratio as shown before in **Table (1**). **Figure 10.** shows the effect of RSA content on the total porosity of RSA-OPC hardened mortars. When the percent of the RSA is increased, the total porosity is decreased up to 20% RSA content. This decrease in the total porosity is attributed to the change occurring in the pore size distribution as a result of using RSA which could react with the calcium hydroxide to form Calcium silicate hydrate (C-S-H) gel. On the other hand, total porosity of RSA-OPC mortars increased by replacing the OPC with more than 20% RSA. This is due to increasing the amount of voids in the matrix, because

RSA particles had microporous surface than OPC particles as shown before in **Figure 8.** Also, This is in agreement with the denisty results. There is a consensus among several researchers that with partial replacement of cement by pozzolans, porosity decreases in concrete. Blended or pozzolanic cements are being used worldwide to produce more homogenous hydration products by filling and segmentation of the capillary voids and produce ultimately more denser and impermeable concrete (**Guneyisia *et al.*, 2007**).

1.4.3. Water absorption of OPC-RSA mortars

Figure 11. shows the effect of RSA content on the water absorption of RSA-OPC hardened mortars at 28 day of hydration. When the percent of the RSA is increased, the water absorption is decreased up to 20% RSA content. This is due to the reduction in total porosity which occurs as shown before in **Figure 10.** Then, the more RSA contend, the more water absorption. Also, This is in agreement with the denisty and prosity results.

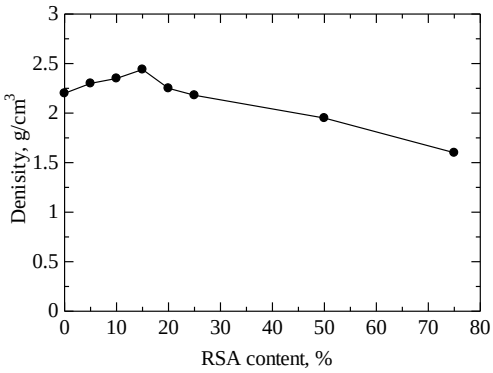


Fig. 9. Variation of OPC-RSA mortars densities at 28 days

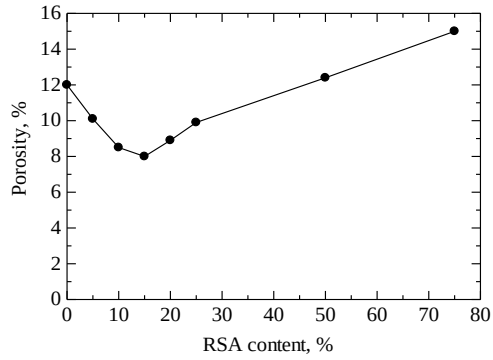


Fig. 10. Variation of OPC-RSA mortars porosity at 28 days

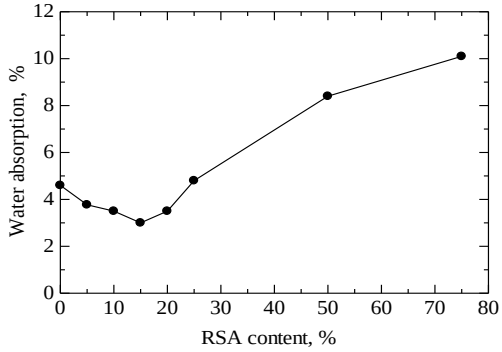


Fig. 11. Variation of OPC-RSA mortars water absorption at 28 days

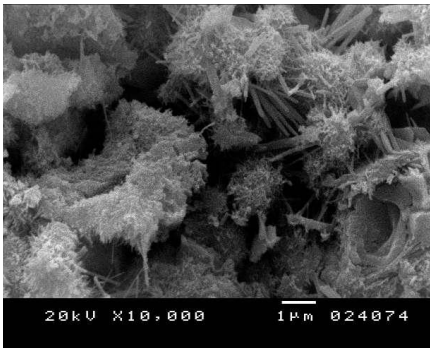
1.4.4. Mechanical properties and SEM of OPC-RSA mortars

Figure 12 shows SEM imeges of OPC and OPC-RSA mortares after 28 days of curing. As expected, an amorphous gel is formed due to the hydration of OPC and the pozzolanic reaction of RSA with CH. In All figures, there is a dense and amorphous structure, but the control OPC paste (**Figure 12a**) presents more CH compared to the OPC-RSA mortares (**Figures 12b and 12c**). Some C–S–H gel appeared in the form of needle-like products up to 15% RSA. At higher RSA content, the presence of needle like products and CH is not noticed (**Figures 12d and 12e**). On the other hand, the amont of voides in the OPC-RSA mortares decresed with the increacment of RSA content (**Figures 12a to 12e**). This is in agreement with the denisty and porosity results. The results of the compressive strength (CS) of OPC and OPC with 5, 10, 15, 20, 25, 50 and 75% RSA at 7, 14, and 28 days were presented in **Table 5** and **Figure 13**. All mortars showed a continuous increase in the compressive strength with curing time as expected. Also, it is visualized from the compressive strength plot that, after 7 days of curing, all mortars containing RSA up to 15% presented compressive strength values hegher than that obtained for the control mortar.

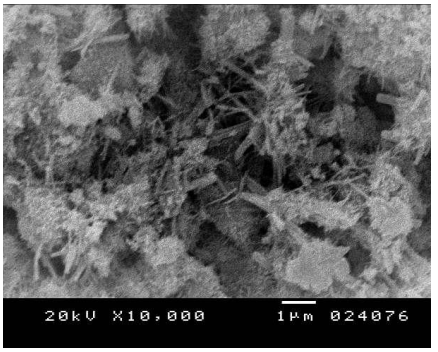
Table 5: Strength values (MPa) of OPC-RSA mortars

RSA %wt.	*CS, 7 days*	*CS, 14 days*	*CS, 28 days*	*Fs, 28 days*
0	13.3	20.2	30.8	3.5
5	13.1	21.2	32.1	3.8
10	12.5	23.4	35.6	4
15	11.6	25.6	38.4	4.2
20	10.8	22.3	33.4	3.7
25	9.7	20.4	29.5	3.4
50	6.5	12.5	20.4	2.5
75	2.5	10.3	13.5	1.5

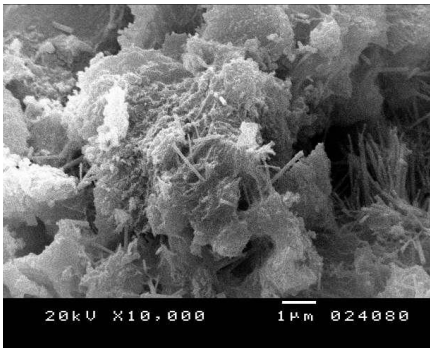
This was related to the high reactivity of the ash, which agreed with the behavior described in the paste studies. The OPC-RSA samples which have RSA more than 20% showed a decrease in the compressive strength, which would be due to lack of availability of calcium hydroxide for the pozzlanice reaction of RSA. This was in agreement with SEM micrographs, density, and prosity results.



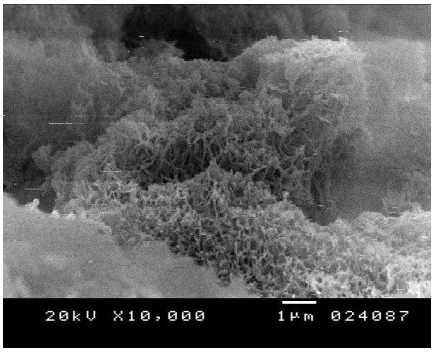
(a) OPC mortar



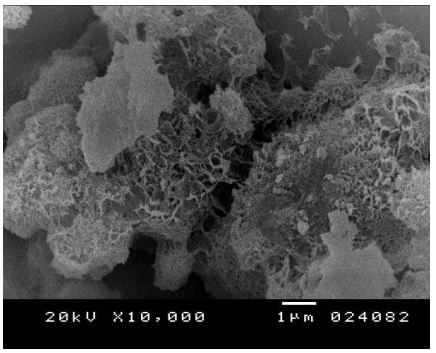
(b) 95% OPC-5% RSA mortar



(c) 85% OPC-15% RSA mortar



(d) 50% OPC-50% RSA mortar



(e) 25% OPC-75% RSA mortar

Fig.12. a~e SEM imeges of OPC and OPC-RSA mortares.

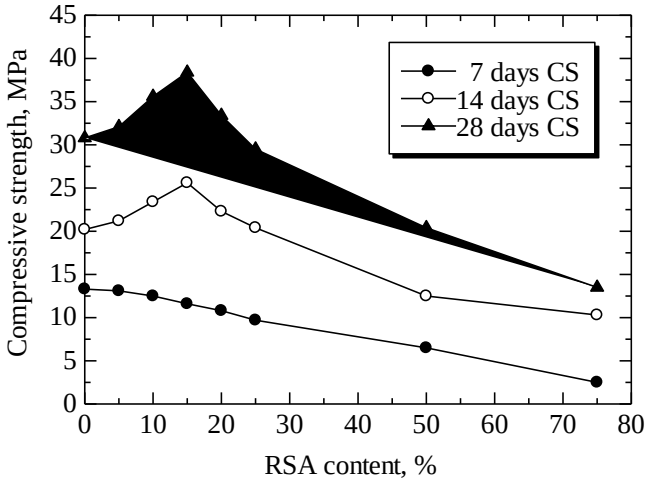


Fig. 13. Variations of compressive strength at different percentages of RSA.

The results of the flexural strength of OPC and OPC with 5, 10, 15, 20, 25, 50 and 75% RSA at 28 days were presented in **Figure 14**. It is visualized from the flexural strength plot that the strength of OPC-RSA mortars increases gradually by replacing OPC with RSA up to 15%, due to the high formation of C-S-H gel than OPC mortar. This is in agreement with CS and SEM micrographs results.

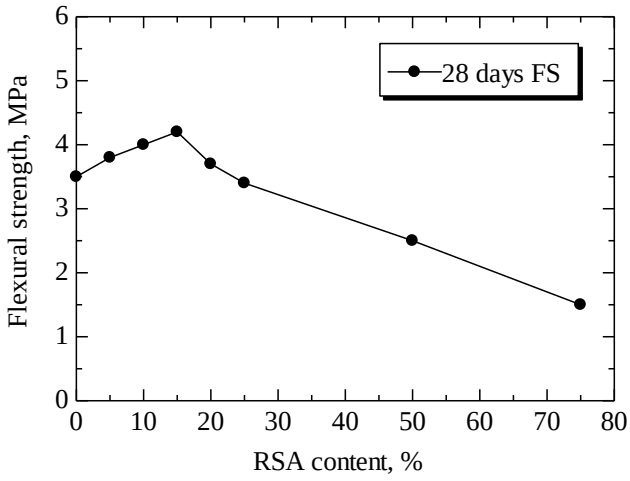


Fig. 14. Variations of flexural strength at different percentages of RSA.

Test results for 28 days compressive and flexural strength of the specimens up to 20% replacement level were higher than OPC mortar strength as presented in **Figure 15**. Compressive strengths were higher by 4%, 15%, 24% and 8% for RSA-OPC mortars of cement replacement ratios 5%, 10%, 15%, and 20% respectively. 28 days compressive strength for the 30%, 50% and 75% RSA replaced mortar was lower by 4%, 38% and 56% respectively when compared with OPC mortar. Also, Flexural strength gives the same trend as shown in **Figure 15**. Flexural strengths were higher by 8%, 14%, 20% and 5% for RSA-OPC mortar of cement replacement ratio 5%, 10%, 15%, and 20% respectively. 28 days flexural strength for the 30%, 50% and 75% RSA replaced mortar was lower by 3%, 28% and 57% respectively when compared with OPC mortar.

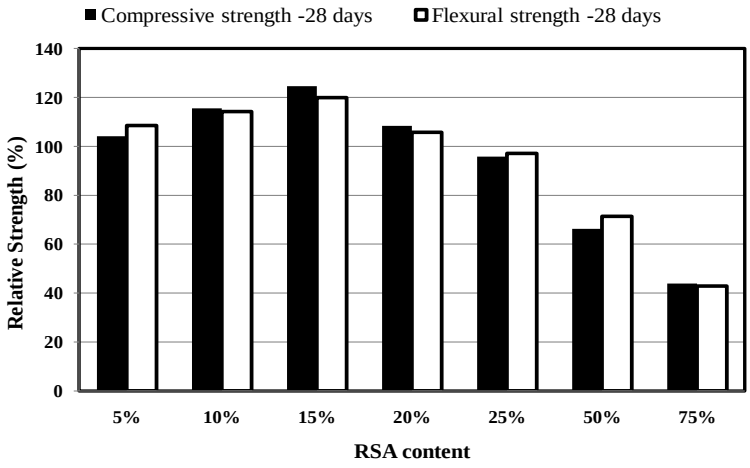


Fig.15. Relative strength (RS) for OPC-RSA mortares at 28 days.

In general terms, from the point of view of strength development, and taking into account the important replacement levels achieved in this study, it can be established that the RSA containing mortars show an important strength gain. All SG values calculated according to **Eq. (14)** were positive, indicating the high effectiveness of RSA in cement mixtures. Calculated SG values are depicted in **Figure 16.** SG values increased with the percentage replacement up to 15 % due to the formation of more CSH gel and the backing of the voids with RSA, as

expected from the SEM images **Figures 12 a~c**. Replacing OPC by RSA with more than 50% had the highest SG values. This could be due to the pozzlanic reaction of RSA, because at higher replacement ratio of OPC the strength development was more depended on the pozzlanic reaction than the hydration reaction of OPC **(Figures 12d & 12e)**. These results indicating the high activity of the RSA as pozzolanic material. Also, results show that the RSA can replace the OPC up to high percentages.

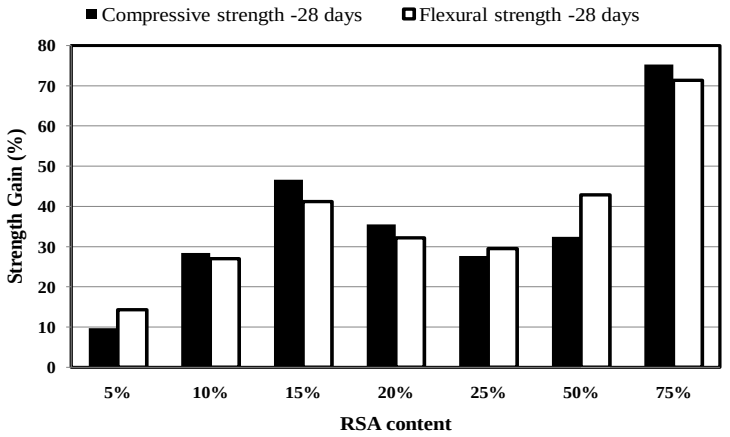


Fig.16. Strength gain (SG) for OPC-RSA mortares at 28 days.

CONCLUSION

From the investigations carried out, the following conclusions can be made:

RSA was chemically and physically characterized. The material presented a relatively high content of SiO_2 (69%). A baseline deviation in XRD results between 15º and 25º showed the presence of amorphous fraction, which was probably reactive from the pozzolanic point of view. Pozzolanic reactivity was confirmed by means SEM images. RSA material completely consumed the available calcium hydroxide. After 28 days of curing, when 15% of the OPC was replaced RSA, SEM images showed a lower presence of portlandite crystals. Finally, from the study of mortars, when OPC was replaced with RSA up to 15%, presented an important contribution to the development of compressive and flexural strength. In the strength gain analysis, the more OPC replacements presented the more strength gain after 28 days of curing, indicating that

RSA can be used as a pozzolanic admixture for high replacement levels in blended mortars.

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الملخص العربى

تأثير إحلال الأسمنت برماد قش الأرز على خواص المونة الأسمنتية

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يعتبر رماد قش الأرز واحدا من المخلفات الزراعية التي تنتج سنويا بكميات كبيرة على الصعيد العالمي. كما ينتج قش الأرز سنويا فى مصر بكميات كبيرة ويتم حرقه إلى رماد في الأراضى الزراعية وفى الأفران التي يستخدمها سكان الريف لأغراض الطهي مما يشكل خطرا كبيرا على البيئة. وعلي الجانب الهندسي فان رماد قش الأرز يقدم حلا بيئيا مهما من ناحية تقليل تأثير التلوث البيئي وذّلك بأحلاله جزئيا محل الأسمنت البورتلاندى العادى. وفي هذا البحث، تم إجراء دراسة تجريبية على تأثير الاحلال الجزئي للأسمنت البورتلاندى برماد قش الأرز على خواص المونة الاتية: الكثافة الظاهرية والحقيقية و المسامية، ومعدل تشرب الماء، علاوة على تعيين زمن الشك الابتدائى والنهائى، وأيضا تم فحص العينات تحت المجهر الإلكتروني ، وتم إجراء إختبارى الضغط عند أعمار٧و ١٤و ٢٨ يوم من صب العينات والانحناء للعينات عند عمر ٢٨ يوم. وذلك عند إحلال الأسمنت برماد قش الارز بنسب ٥، ١٠، ١٥، ٢٠، ٢٥، ٥٠، و ٧٥% بالوزن. وقد أظهرت النتائج زيادة زمن الشك الابتدائى وكذلك النهائى بزيادة نسبة الإحلال، كذلك فإن مونة الرماد والأسمنت أعطت تحسنا ملحوظا فى إجهادي الضغط والانحناء حتى نسبة إحلال ١٥ %. حيث ارتفعت مقاومة الضغط من ٣٠,٨ميجا بسكال (عند نسبة إحلال صفر %) الي ٣٨,٤ ميجا بسكال (عند نسبة إحلال ١٥ %) بمعدل زيادة مقداره ٢٤ % . كما ارتفعت مقاومة الانحناء من ٣,٥ميجا بسكال (عند نسبة إحلال صفر %) الي ٤,٢ميجا بسكال (عند نسبة إحلال ١٥ %) بمعدل زيادة مقداره ٢٠%. وفى النهاية تم التحقق من تأثير التفاعلات الناتجة من الإحلال داخل مونة الرماد والأسمنت باستخدام الميكروسكوب الالكترونى.

***مدرس بقسم الهندسة الزراعية والنظم الحيوية – كلية الزراعة – جامعة الاسكندرية – مصر.**