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Recycled Rice & Wheat Straw Ash as Cement Replacement Materials

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Authors' contributions

This work was carried out in collaboration among all authors. All authors made equal contributions in conceptualization, formal analysis, validation, visualization, reviewing and editing. All authors supervised the manuscript. Author TAES and AME carried out the model calibration and applications and wrote the original draft. All authors read and approved the final manuscript.

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ABSTRACT

In this paper an experimental study was made on the effects of using Rice Straw Ash (RSA) & Wheat Straw Ash (WSA) as partial replacements of cement in mortar. The objects were to produce Nano Silica (NS) form RSA & WSA as agricultural wastes by using chemical acids. Then, control specimens with Ordinary Portland Cement (OPC) was made and in other specimen's cement were replaced with 5%, 10%, 15% and 20% of RS & WS ashes by weight of cement. The workability was measured by the slump test. The pulse velocity and the sorptivity were also computed. The compressive and tensile strengths were also estimated. Experimental result showed that it was feasible to produce silica from WSA by chemical activation method. Also, the highest compressive strength, tensile strength and sorptivity noticed at 15% WSA.

Keywords: Wheat Straw Ash (WSA); Rice Straw Ash (RSA); Nano Silica (NS); X-ray diffraction; chemical analysis; sorptivity.

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1. INTRODUCTION

The Pozzolan is a powdery substance which, when added to the cement in the mixture, reacts with the lime released by moistening the cement to provide compounds which enhance the strength or other properties of the concrete or mortar [1].

According to [2,3] the chemical analysis, when the total iron oxide (Fe2O3) and silica (SiO2) and aluminum oxide (Al2O3) exceed 70%, it is known as the material substance Pozzolanic. Many researchers have observed that the compressive strength of the mortar increases with pozzolan materials. It can increase in performance due to the compression low water content, and the effect of the filler, high reaction pozzolanic reaction. The fine weight of the pozzolan had a stronger pozzolanic reaction, and the small molecules could fill the blanks of the mortar mix and thereby increase the compressive strength of the mortar. The use of additional cement materials, such as fly ash, silicic smoke, slags and blast furnaces have been used in the construction of concrete and widespread. Complementary cement materials significantly improve the strength and durability of concrete [4,5].

Many relatively new complementary cement materials, such as rice husk ash, sewage sludge ash and ashes, have been extensively studied [6,7]. The development of natural materials to produce concrete composite construction materials for construction has been continuous for many years. India is one of the largest rice producers, and per capita rice consumption is higher than in any other country. There are three main producers of biomass that come from rice such as: Rice straw, rice hulls and rice bran. Rice straw and rice husk, rice bran feed have been used for cattle, poultry, fish and others [8]. In the villages, rice straw is also used for cooking and other purposes by burning. After a large amount of rice straw has been burnt, ash is produced and dumped, resulting in an environmental problem, although some time is spent on agricultural land.

To reduce the cost of building materials and raise environmental issues, significant efforts are being made worldwide to use local waste and secondary materials to improve the performance of building materials. Traditional building materials out of reach of most of the world's population because of the weakness of their affordability. Rice straw is one of the most important agricultural products available worldwide. During growth, rice plants pick up silicic acid from the soil and accumulate in their structures. This silica, concentrated burning at high temperatures to remove other elements, making ash very valuable. Among the agricultural wastes, rice straw has a very high potential to produce highly efficient secondary raw materials. This is mainly due to the availability of random, and the silica content is very high and relatively low cost. After incineration of rice straws and husks with a temperature and duration controlled by small plants, 14.6% and 22%, respectively, of rice straws and husks are converted into high value-added ash, which is a secondary substance due to its high silica content [9]. Rice straw and husk consist of both organic and inorganic substances. Organic material consists of cellulose, lignin, hemicellulose, some proteins and vitamins, while the main element of inorganic metals is silica. The actual configuration differs from rice straw and crust with rice type, and the intake of rice bran and broken in the bark, geographical factors, seasonal harvest, and the preparation of samples and relative humidity [10,11]. This is an important waste of rice plant. Silica is absorbed by the soil and collected in the straw, where it is made of a structure and filled with cellulose. If it is burned cellulose, it will only leave silicic acid, which pound into a fine powder, which is used as pozzolan. Rice straw contains 15% of the ash after burning and thus every 1000 kg of rice straw burning produces 150 kg of ash [12].

Khushnood [13], the safe disposal of wheat straw, aiding in the production of eco-friendly cement-based composites, the sustainable consumption of raw material expended during the production of cement, and reducing the costs of construction. It would also add economic value to the wheat straw, thus creating an incentive for the farmer to refrain from open burning of wheat straw. Among the other crop residue, successful investigations have been done on rice husk ash, bagasse ash, etc., for their use in cement based composites [14-19].

2. EXPERIMENTAL PROGRAM

2.1 Materials

1. Cement: Ordinary Portland (OPC) CEM I 42.5 N with a specific gravity 3.15.
2. Fine aggregate: siliceous sand with a fineness modulus and a specific gravity 2.64 and 2.74, respectively.

3. Coarse aggregate: crushed stone aggregate with a specific gravity 2.89.
4. Water: Tapped water for mixing and curing procedures.
5. Rice Straw Ash (RSA) & Wheat Straw Ash (WAS): Agricultural wastes available in Egypt fields as in Fig. 1. The straws were firstly washed with tap water and then dried in an oven as in Fig. 2 for at 80°C for 24hrs. The straws were secondly grinded in bug milling machine as in Fig. 3 and then passed through different sieves using 20-200 mesh size sieves as in Fig. 4. Silica dissolution from ashes powder was carried out using an alkali process using 1M sodium hydroxide (NaOH) and heated for 4hrs at 100°C. The obtained solution was filtered to remove impurities. 10% sulfuric acid (6M H_2SO_4) at the pH=7 used to precipitate silica from sodium silicate solution and left for 24 hours (see Eqs. (1)-(2))

$$SiO_2 + 2NaOH \text{------------------------>} Na_2SiO_3 + H_2O \quad (1)$$

$$Na_2SiO_3 + H_2SO_4 \text{------------->} SiO_2 + Na_2SO_4 + H_2O \quad (2)$$

6. Superplasticizer: with amount of 3.5% of the cement weight.

(a) (b)

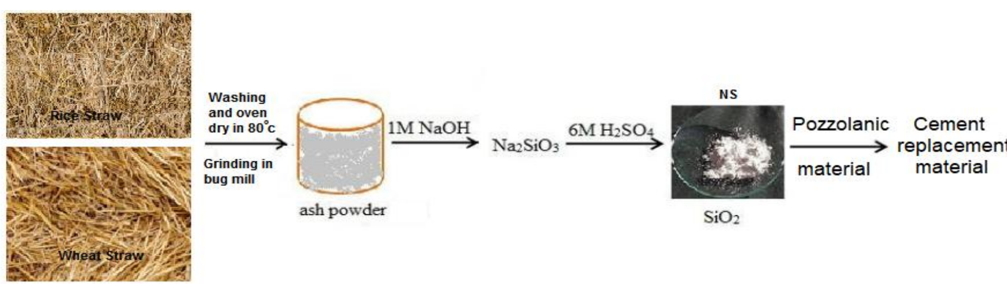

Fig. 1. Agricultural wastes; a) RSA, b) WSA

Fig. 2. Oven carry up to 1200°C

Fig. 3. Bug-milling machine

Fig. 4. Sieving analysis

2.2 Mix Design

The mix design is summarized in Table 1.

Table 1 Mix design in (Kg/m^3)

Mix type	W/C	WSA	RSA	Cement	Water	Fine aggregate	Coarse aggregate	Superplasticizer
Control	0.45	-	-	400	180	750	1225	15
WSA-5%	0.45	20	-	380	180	750	1225	15
WSA-10%	0.45	40	-	360	180	750	1225	15
WSA-15%	0.45	60	-	340	180	750	1225	15
WSA-20%	0.45	80	-	320	180	750	1225	15
RSA-5%	0.45	-	20	380	180	750	1225	15
RSA-10%	0.45	-	40	360	180	750	1225	15
RSA-15%	0.45	-	60	340	180	750	1225	15
RSA-20%	0.45	-	80	320	180	750	1225	15

2.3 Sample Preparation

Cement is partially replaced by RSA & WSA at a different percentage of 0, 5, 10 15 and 20 by weight. Fig. 5 showed the different casted samples for control, RSA & WSA.

a) b)

(c)

Fig. 5. Casted samples; a) Control, b) RSA, c) WSA

2.4 Workability

The workability of the concrete mixes decreases with increase of the percentage of added ashes. That is because, concrete containing ashes need greater water due to high fineness. So, a superplasticizer is added to the mix to improve the workability for a suitable slump. Fig. 6 shows the concrete slump with and without superplasticizer.

(a) (b)

Fig. 6. Slump test; concrete a) without Superplasticizer, b) with Superplasticizer

2.5 Compressive Strength

Compressive strength was tested by digital compression testing machine of 200 kN capacity as shown in Fig. 7. Cube specimens of dimensions 150x150x150 mm were used to determine the compressive strength for concrete mixes.

Fig. 7. Compression testing machine

2.6 Tensile Strength

Cylindrical specimens of 150 mm diameter and 300 mm height were used for getting tensile strength from indirect tension test as shown in Fig. 8. The splitting tensile strength is calculated using Eq. 3:

$$T = 2P/\pi LD \quad (3)$$

Fig. 8. Splitting test

2.7 Ultrasonic Pulse Velocity

The longitudinal pulse velocity is obtained using Eq. 4 and the ultrasonic equipment shown in Fig. 9:

$$V= L /T \quad (4)$$

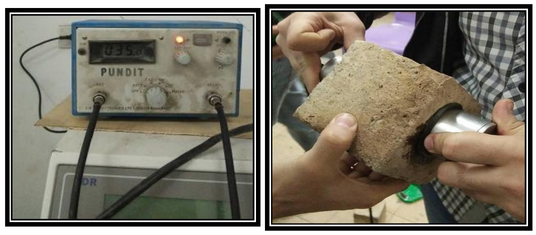

Fig. 9. Ultrasonic test

2.8 Sorptivity

The sorptivity of the tested specimens is obtained using Eq. 5 and the equipment shown in Fig. 10.

$$i = St^{1/2} \tag{5}$$

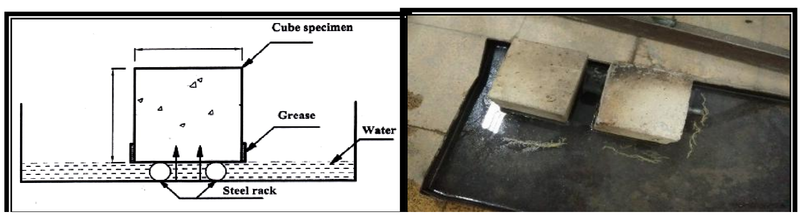

Fig. 10. Sorptivity test

3. RESULTS AND ANALYSIS

3.1 Compressive Strength Results

Table 2 and Fig. 11 showed the results of compressive strength after 7 days and 28 days for control sample and RSA & WSA cement replacement samples.

After 7 days, increasing RSA & WSA from 5% to 15% led to increase in compressive strength from 21.00 N/m^2 to 28.00 N/mm^2 & 27.00 N/mm^2 to 35.00N/mm^2 respectively. Higher compressive strengths were observed at 15% RSA & WSA with compressive strength of 28.00 N/mm^2 & 35.00 N/mm^2. While at 20% RSA & WSA compressive strength deceased to be 26.00 N/mm^2 & 32.00 N/mm^2.

The same trend was found after 28 days, increasing RSA & WSA from 5% to 15% led to increase in compressive strength from 42.00 N/mm^2 to 51.00 N/mm^2 & 49.00 N/mm^2 to 63.00 N/m^2 respectively. Higher compressive strengths were observed at 15% RSA & WSA with compressive strength of 51.00 N/mm^2 & 63.00N/mm^2. While at 20% RSA & WSA compressive strength deceased to be 45.00N/mm^2 & 56.00 N/mm^2.

3.2 Tensile Strength Results

Table 3 and Fig.11 showed the results of tensile strength after 7 days and 28 days for control sample and RSA & WSA cement replacement samples.

Table 2. Compressive strength at 7 & 28 days in (N/mm^2)

Mix type	Average compressive strength at 7 days	Average compressive strength at 28 days
Control	23.00	50.00
RSA-5%	21.00	42.00
RSA-10%	25.00	44.00
RSA-15%	28.00	51.00
RSA-20%	26.00	45.00
WSA-5%	27.00	49.00
WSA-10%	30.00	53.00
WSA-15%	35.00	63.00
WSA-20%	32.00	56.00

After 7 days, increasing RSA & WSA from 5% to 15% led to increase in tensile strength from 21.00 N/mm^2 to 28.00 N/mm^2 & 27.00 N/mm^2 to 35.00 N/mm^2 respectively. Higher tensile strengths were observed at 15% RSA & WSA with tensile strength of 28.00 N/mm^2 & 35.00

N/mm^2. While at 20% RSA & WSA tensile strength deceased to be 26.00 N/mm^2 & 32.00 N/mm^2.

The same trend was found after 28 days, increasing RSA & WSA from 5% to 15% led to increase in tensile strength from 42.00 N/mm^2 to 51.00 N/mm^2 & 49.00 N/mm^2 to 63.00 N/mm^2 respectively. Higher tensile strengths were observed at 15% RSA & WSA with tensile strength of 51.00 N/mm^2 & 63.00 N/mm^2. While at 20% RSA & WSA tensile strength deceased to be 45.00 N/mm^2 & 56.00 N/mm^2.

Table 3. Tensile strength at 7 & 28 days in (N/mm^2)

Mix type	Average tensile strength at 7 days	Average tensile strength at 28 days
Control	1.96	4.25
RSA-5%	1.79	3.57
RSA-10%	2.13	3.74
RSA-15%	2.38	4.34
RSA-20%	2.21	3.83
WSA-5%	2.30	4.17
WSA-10%	2.55	4.51
WSA-15%	2.98	5.36
WSA-20%	2.72	4.76

3.3 Ultrasonic Test Results

Table 4 showed the pulse velocity for control sample and RSA & WSA cement replacement samples. Increasing RSA & WSA from 5% to 15% led to increase in pulse velocity from 4600 m/s to 5000 m/s & 4800 m/s to 5200 m/s respectively. Higher pulse velocity was observed at 15% RSA & WSA with tensile strength of 5000 m/s & 5200 m/s. While at 20% RSA & WSA pulse velocity deceased to be 4800 m/s & 5000 m/s.

Table 4. Pulse velocity in (m/s)

Mix type	Pulse velocity (m/s)
Control	5400
RSA-5%	4600
RSA-10%	4900
RSA-15%	5000
RSA-20%	4800
WSA-5%	4800
WSA-10%	5100
WSA-20%	5000

3.4 Sorpitivty Test Results

Table 5 showed the sorpitivity for control sample and RSA & WSA cement replacement samples. Increasing RSA & WSA from 5% to 15% led to increase in sorpitivty from 1.62*10^{-3}*cm.s$^{-0.5}$ to 1.87*10^{-3}*cm.s$^{-0.5}$ & 1.73*10^{-3}*cm.s$^{-0.5}$ to 2.05*10^{-3}*cm.s$^{-0.5}$ respectively. Higher sorpitivty was observed at 15% RSA & WSA with sorpitivty of 1.87*10-3*cm.s$^{-0.5}$ & 2.05*10^{-3}*cm.s$^{-0.5}$. While at 20% RSA & WSA sorpitivty deceased to be 1.59*10^{-3}*cm.s$^{-0.5}$ & 1.94*10^{-3}*cm.s$^{-0.5}$.

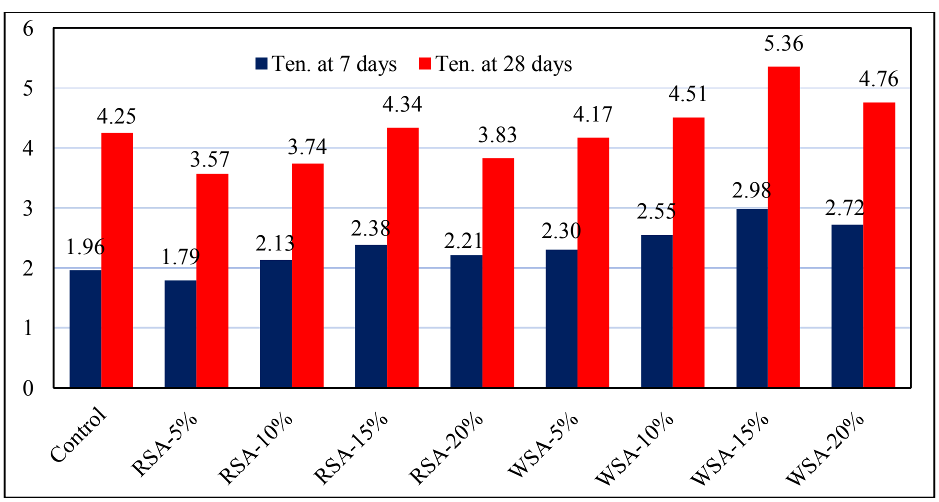

Fig. 11. Tensile strength at 7 & 28 days

Table 5. Pulse velocity in (m/s)

Mix type	Sorpitivity for 10 Minute 10^{-3} *cm.$s^{-0.5}$
Control	0
RSA-5%	1.62
RSA-10%	0.00
RSA-15%	1.87
RSA-20%	1.59
WSA-5%	1.73
WSA-10%	1.88
WSA-15%	2.05
WSA-20%	1.94

3.5 X Ray Diffraction

Figs. 12 & 13 showed X-ray diffraction analysis for RSA and WSA. Figures indicated that the structure of silica presented in RSA and WSA is of amorphous material.

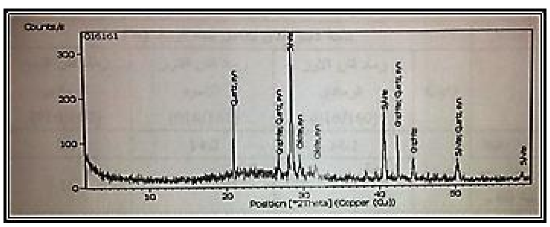

Fig. 12. XRD for RSA

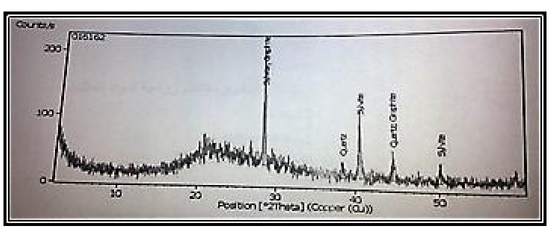

Fig. 13. XRD for WSA

3.6 Chemical Analysis

Table 6 showed the pozzolanic reaction for RSA & WSA cement replacement samples. The results showed that samples of RSA were interacted with 14% of quicklime and samples of WSA was interacted with 16% of quicklime.

Table 6. Pozzolanic reaction

Interaction duration	Quicklime %	
	RSA	WSA
After 30 minutes	14.2	16.0
After 5 days at 60^{o}c	14.2	16.0

4. CONCLUSION

Based on the results of experimental study, it is concluded that WSA is a natural agricultural waste that can be used as a very good cement replacement material due to silica produced by chemical activation method. The production of silica from agricultural wastes provide an environmentally sociable result with exactly suitable and economically product. Using the RSA & WSA Ash enhanced the compressive strength and tensile strength of concrete samples. WSA showed the maximum value of the compressive strength and tensile strength at 7 days with 35.00 N/mm2 2.98 N/mm2 respectively and 63.00 N/mm2 5.36 N/mm2 at 28 days respectively. The optimum replacement of cement with WSA & RSA at 28 days strength was 15%. WSA with 15% cement replacement had the maximum value of the compressive strength, tensile strength and sorptivity comparing with 5%, 10%, and 20% cement replacement. Cement replacement with WSA reduced concrete permeability of water. Therefore, recommended that the existence of WSA in higher grade concrete mix, so the durability of concrete improved. The presence of Superplasticizer in RSA & WSA concrete mix improved the slump & the workability of the concrete. X-ray diffraction for WSA indicated that the structure of silica is of amorphous material. WSA is a pozzolanic material that had the potential to be a cement replacement material and could contribute to the sustainability of the construction material.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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