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Study of Properties of Concrete Containing Recycled Rice Straw and Rice Husk

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Abstract

This research aims to utilize recycled rice straw and rice husk to produce environmentally friendly concrete with optimum properties. An experimental program was conducted which consisted of three phases. Rice straw and rice husk were treated by different methods to obtain rice straw ash (RSA), rice husk ash (RHA) and rice straw (RS) which were used as partial cement replacement in concrete mixes. Chemical treatment was made for rice straw and the test results showed that this treatment managed to produce pure silica without emission of carbon monoxide. Concrete mixes containing RS were exposed to high temperatures of 300°C, 500°C and 700°C for 1 and 2 hours. Fresh and hardened concrete tests were made to investigate the effect of cement replacement with different percentages of RS, RSA and RHA on concrete properties at normal and elevated temperatures. The obtained test results demonstrated the improvement of physical and mechanical properties of concrete, especially at high temperatures.

Keywords: Concrete, rice straw, rice husk, cement replacement, chemical treatment, elevated temperature.

1. Introduction

Rice straw and rice husk are regarded as agricultural wastes and are usually burnt in great amounts to get rid of this waste causing considerable environmentally pollution. Due to the high pozzolanic content in the burnt rice husk ashes, it is possible to use it as partial replacement of cement in concrete mixes and react with lime released by cement hydration to produce concrete with high strength and low permeability [1-4]. Additionally, partial replacement of cement in concrete mixture by mineral additives is favorable, as it protects and conserves the environment by saving energy and natural resources and also lowering the carbon footprint [5].

This research aims to promote the use of waste rice straw ashes (RSA) and rice husk ashes (RHA) as cement replacement material in concrete production. To achieve this aim, an experimental program is conducted to investigate the physical and mechanical properties of concrete containing different percentages of rice straw and rice husk, and subjected to various treatment methods. The experimental program is explained in the following sections, and the results are discussed.

2. Experimental Program

The conducted experimental program consists of three phases. In phase I, rice straw and rice husk were prepared and treated for use in the concrete mixes. Additionally, a laboratory method was applied for optimization of silica extraction procedure from rice straw [6, 7]. Two methods of silica extraction were followed: combustion of rice straw without any treatment, and chemical pretreatment of rice straw followed by combustion. Characterization techniques were applied to describe and prove the structure of the obtained silica samples. In phase II, nine concrete mixes were prepared using rice straw ashes (RSA) and rice husk ashes (RHA) as cement replacement by 5%, 10%, 15% and 20% of cement weight, El-Sayed et

al. [8]. Slump test was made for fresh concrete and 108 specimens are casted: 54 cubes for compressive strength, density and sorptivity tests and 54 cylinders for splitting tensile test. In phase III, rice straw (RS) is added to concrete mixes without any treatment to replace 0%, 1.0%, 3.0%, and 5.0% of cement weight. Specimens are subjected to temperatures of 300, 500 and 700°C for duration 1 and 2 hours. Hardened concrete tests are carried out before and after heating. All experimental work was made at the laboratory of Shoubra Faculty of Engineering, Benha University, Cairo, Egypt.

2.1 Materials used

Coarse aggregate: natural dolomite was used with nominal maximum size 10 mm.

Fine aggregate: natural siliceous sand was used with round particle shape and smooth texture. The grading curve lies between the upper and the lower limits of BS 1377, BS 812 requirements.

Cement: Egyptian Ordinary Portland Cement (OPC) complying with Egyptian specifications was used.

Water: clean drinking water free from impurities was used for concrete mixing and curing of specimens, water / cement ratio is 0.5 for phase II and 0.4 for phase III.

Super-plasticizer: was used only in phase III, with doze 2.0% of cement weight as per manufacturer.

Rice straw and rice husk: were taken from rice fields in Egypt.

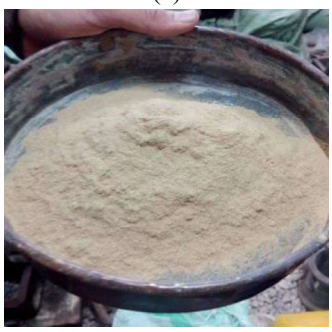
2.2 Preparation and treatment of rice straw and rice husk

To prepare rice straw and husk for use in the concrete mixes, four methods were applied:

i. Grinding: rice straw is washed with water to remove bugs and dust, dried under sun rays for two days, shown in Fig. 1(a), then ground in spices grinding mill and sieved; only straw passing sieve 100-200 is used. The obtained rice straw (RS), shown in Fig. 1(b) is used in phase III of the experimental program.

ii. Burning and grinding: rice straw and rice husk are washed, sun-dried for two days, then burned in an oven at 700°C for 3 hours; then ground to maximum nominal size 200 µm to obtain rice straw ashes (RSA) and rice husk ashes (RHA), shown in Fig. 1(c), to be used in phase II of the experimental program.

(a)



(b)

(c)

Fig. 1: Preparation of rice straw and ashes

iii. Combustion of rice straw for silica extraction: the rice straw is ground and washed with distilled water to remove any dust or impurities, then it is dried in an oven at 70ºC for 24 hrs. Following this, 100 g of the dried straw is burned in the oven at 300ºC for 4 hours in order to remove the carbon by converting it into carbon dioxide. The obtained ash is then burned in a muffle furnace at 800°C for 3 hours in ceramic crucibles; the crucibles were kept to cool gradually inside the furnace.

iv. Chemical treatment of rice straw: To obtain pure silica, the dried rice straw is pretreated with sodium hydroxide followed by an acid, the steps are illustrated in Fig. 2 and can be summarized as follows: 100 g of dried rice straw is treated with a liter of 5 M sodium hydroxide solution (200 g NaOH/ 1.0 liter of distilled water) producing sodium silicate, Fig. 3(a). This solution is stirred for 4 hrs at 100°C using a magnetic stirrer shown in Fig. 3(b) in

presence of a magnet bar; the reaction system is equipped with a glass condenser to avoid evaporation of the solution. The solution containing sodium silicate is then filtered to remove any unreacted silica or impurities, as shown in Fig. 3(c). The obtained filtered solution is neutralized with 10% HCl added and stirred until PH 7, the final mixture was kept at room temperature while stirring for 48 hours. The obtained silica gel is centrifuged using Hitachi centrifuge shown in Fig. 4(c) to separate the silica. The separated silica is washed several times with water to remove any acid or salts, and then kept in an oven at 100° C for 24 hours to dry. The dried silica is then burnt at 800° C for 4 hours in ceramic crucibles to remove any organic residue.

The chemical reactions involved in this method are as follows.

$$SiO_{2\,(\text{in rice straw})} + 2NaOH \rightarrow Na_2SiO_3 + H_2O$$

$$Na_2SiO_3 + HCL \rightarrow SiO_2 + NaCl + H_2O$$

Fig. 2: Flow diagram of preparation of amorphous silica by chemical treatment method

(a) (b) (c)

Fig. 3: Chemical pretreatment of rice straw: a) adding rice straw and NaoH to 1.0 liter of water, b) stirring, and c) filtering to remove nonreactive impurities

(a) (b)

(b) (d)

(e)

Fig. 4: Chemical treatment of the rice straw: a) diluted HCl 10%, b) adding HCl to the filtered solution, c) centrifuge equipment, d) the formed silica gel, and e) the collected silica gel

2.3 Mix proportions

The mix proportions of the concrete mixes for phase II and phase III are listed in Tables 1 and 2, respectively.

2.4 Preparation of concrete test specimens

To prepare the concrete mixes, first coarse and fine aggregates, cement and RSA, RHA or RS are dry mixed for about one minute until a homogenous color is observed, then the water is added while hand mixing continues for two minutes. Concrete is cast in molds and cured for the hardened concrete tests, as in Fig. 5.

Table 1 Mix proportions for 1 m^3 concrete of phase II, El-Sayed et al. [8].

Mix ID	RSA or RHA %	RSA or RHA (kg/m^3)	cement (kg/m^3)	coarse aggr. (kg/m^3)	fine aggr. (kg/m^3)	water (kg/m^3)
C	0%	0	400	1075	725	200
RSA-5, RHA-5	5%	20	380			
RSA-10, RHA-10	10%	40	360			
RSA-15, RHA-15	15%	60	340			
RSA-20, RHA-20	20%	80	320			

Table 2: Mix proportions for 1 m3 concrete of phase III.

Mix ID	RS %	RS (kg/m^3)	cement (kg/m^3)	Super plasticizer %	coarse aggreg. (kg/m^3)	fine aggreg. (kg/m^3)	water (kg/m^3)
C-0	0%	0	350	0%	1150	575	140
RS-1	1%	3.5	346.5	0%			
RS-3	3%	10.5	339.5	2%			
RS-5	5%	17.5	332.5	2%			

Fig. 5: Specimens prepared from concrete mixes for hardened concrete tests.

2.5 Testing procedures for fresh and hardened concrete

Slump test was made for the fresh concrete of all mixes of phases II and III in accordance with ASTM C143 [9], as shown in Fig. 6(a). The density is evaluated according to BS1881: 114 [10], based on the oven dry weight and volume as average of three specimens. Compressive strength of concrete is determined according to Standard of BS1881:1983 Part 108-111 [11] for all concrete mixes. Cubes with dimensions 100x100x100 mm are tested in ELE automatic compression testing machine of capacity 2000 kN, as shown in Fig. 6(b), the load is increased gradually until failure to determine the maximum compression load, the compressive strength is calculated as the average values of three cubes. Splitting tensile strength test is carried for cylindrical specimens 100 mm diameter and 200 mm height of phase I mixes only, according to ASTM C 496-96 [12], in a hydraulic compression machine as shown in Fig. 6(c). The test is carried out at ages 7 and 28 days. The splitting tensile strength was calculated average of three specimens.

The sorptivity test is carried out to determine the amount of water absorbed by capillary action using a plastic container with 18 mm diameter steel bars resting on the bottom. Cubes of the different mixes were left in an oven at 105°C for 24 hours then the test is carried out: water is added to a height of 20 mm, just above the top surface of the steel bars, as shown in Fig. 6(d), the specimens are weighed at several intervals and the sorptivity of the tested specimens is calculated using the equation. $S = i/\sqrt{t}$

Where: S: sorptivity in $cm/s^{1/2}$, i: increase in mass in g/cm^2, and t: time in seconds at which the weight is determined.

(a) (b)

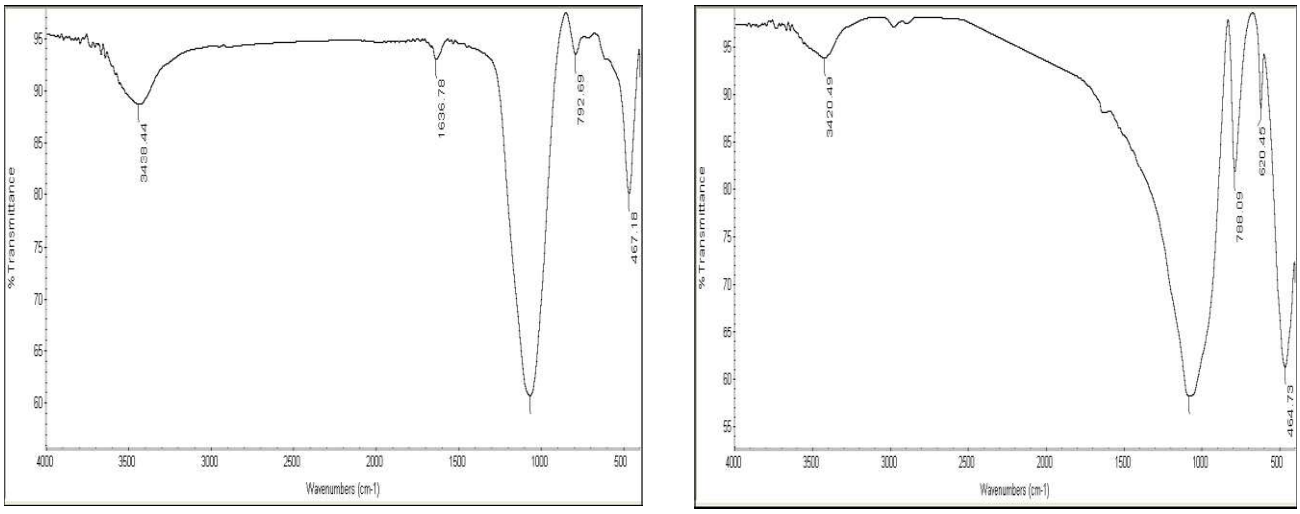
(c) (d)

Fig. 6: Performed tests on concrete: a) slump test, b) compression test, c) splitting tensile test, and d) sorpitivity test

3. Results of Phase I Characterization Tests

3.1 FT-IR test results

Fourier Transform Infrared Spectroscopy (FT-IR) spectra of chemically and heat treated samples are shown in Fig. 7(a) and 7(b), respectively. The absorption bands around 465 cm^{-1} in both figures are corresponding to vibration band of (Si–O) bond. The absorption peaks at 1080 cm^{-1} is assigned to the stretching vibrations of (Si–O) bond, at 1620 cm^{-1} assigned to water physically adsorbed on the SiO_2 surface, and 3430 cm^{-1} is corresponding to the O-H bond of the absorbed water. Ghorbani et al. [13] made a study on silica extraction from rice husk by acid treatment and performed EDX test; they reported that vibration signals around 1075, 780 and 665 cm^{-1} are typical of Si–O–Si bands attributed to the asymmetric stretching [13].

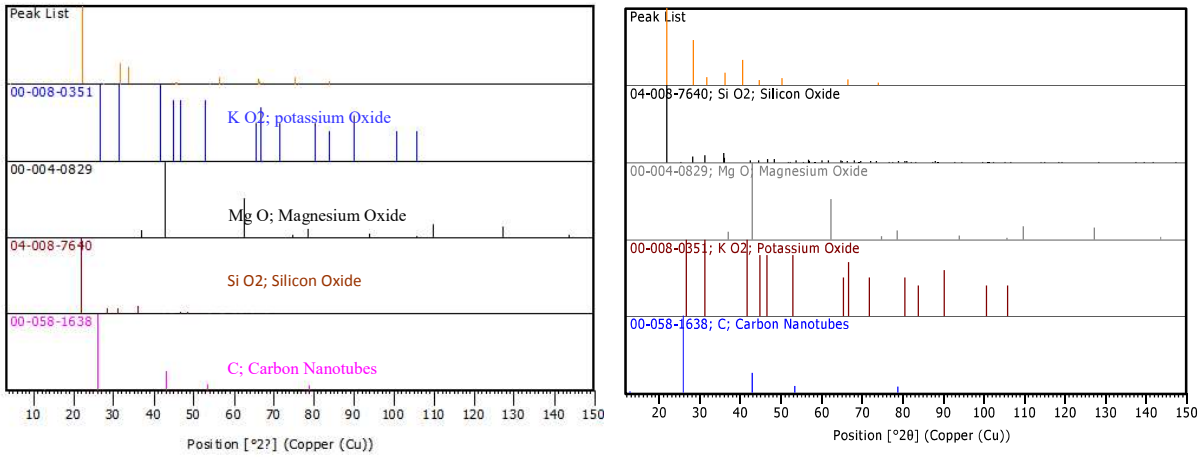


(a) (b)

Fig. 7: FT-IR results for silica extracted by: a) chemical treatment and b) burning

3.2 XRD test results

The X-ray diffraction (XRD) analysis of chemically and heat treated samples are presented in Fig. 8. Matching is observed in Fig. 8(a) between SiO_2 pattern and the sample peaks pattern for chemically treated sample, also the sample contains KO_2 molecules and there are no peaks indicating presence of carbon. In Fig. 8(b) the heat treated sample is observed to contain more unwanted impurities like KO_2, MgO and C beside silica than chemically treated samples. Real et al. [14] found similar results and showed that treating of rice husk with a solution of HCl before combustion at 600˚C could result in relatively pure silica of approximately 99.5% X-ray diffraction pattern.

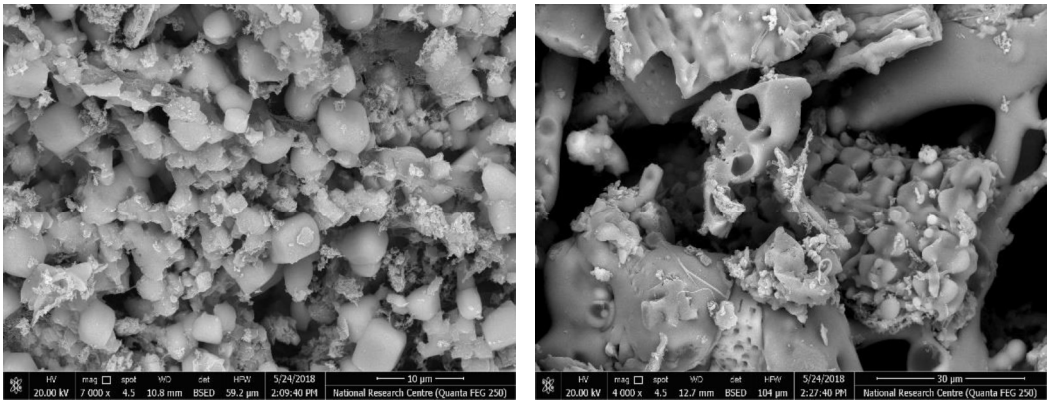


(a) (b)

Fig. 8: XRD results for silica extracted by: a) chemical treatment and b) burning

3.3 Scanning Electron Microscopy (SEM) results

The morphology and microstructure of samples was examined via SEM, and the obtained data are presented in Fig. 9. It is observed that the chemically treated sample (Fig. 9(a)) has homogeneous distribution particles that are uniform and spherical shape more than the heat treated sample, which enhances the dispersion of the particles and increases its surface area. In contrast, Fig. 9(b) shows that the heat treated sample has large particles with no homogenous distribution, has a lot of flocculation with sharp particles and a lot of pores between molecules. Ghorbani et al [13] reported that SNPs produced out of this silica extract by slow gelation technique exhibited a spherical shape with an average particle size of 200 ± 20 nm and purity of 97%.

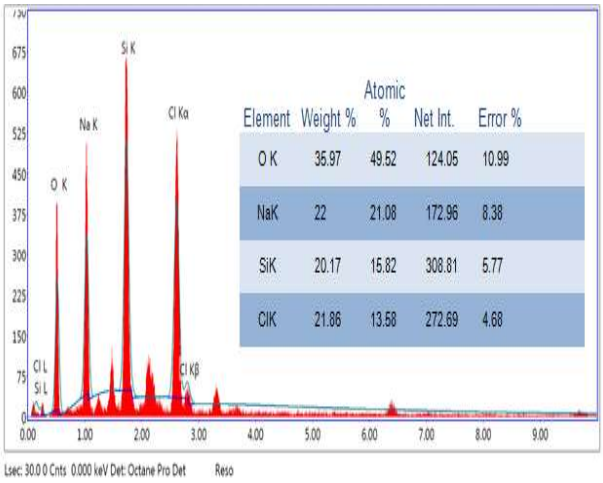


(a) (b)

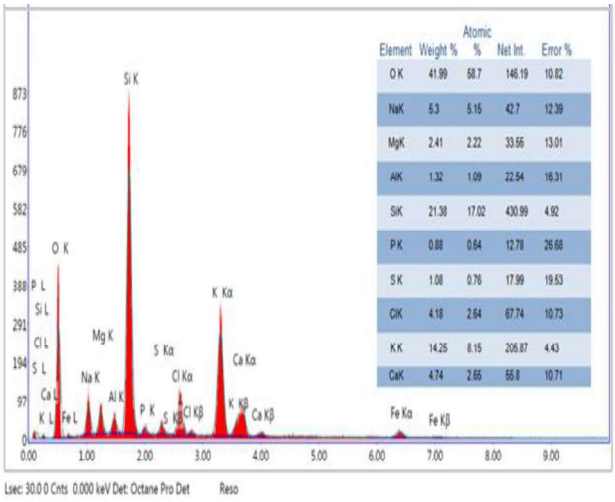
Fig. 9: SEM results for silica extracted by: a) chemical treatment and b) burning

3.4 EDX test results

Elemental analysis with Energy Dispersive X-ray (EDX) consists of spectra showing peaks corresponding to the elements and the true composition of the sample being analyzed, shown in Fig. 10. From the composition of the chemically treated sample, shown in Fig. 10(a), only four elements are noticed: sodium, chloride, silicon and oxygen. The expected components from those materials are silica SiO_2 and sodium chloride NaCl that is obtained from adding NaOH as an activating reagent. No presence of carbon molecules or any other unwanted impurities is observed in the sample. Whereas, the sample treated by burning has less purity and contains many unwanted components like KO_2, MgO, AlO_3 as shown in Fig. 10(b). Similarly, Ghorbani et al [13] concluded that application of hydrochloric acid was remarkably effective in reducing the content of alkali metal oxides (Na_2O and K_2O) in the sedge ash.



(a)



(b)

Fig. 10: EDX results for silica extracted by: a) chemical treatment and b) burning

4. Fresh and Hardened Concrete Tests Results and Discussion

4.1. Slump

The test results for the slump of the different mixes of phases II and III are plotted in Fig. 11. The experimental results of phase II mixtures show that increasing the ashes content leads to a stiff mix that is near to zero slump. Slump of control mix with no ashes is 72 mm then decreased gradually to reach 31mm for RSA-20 and 41 mm for RHA-20. In general, slump of RSA mixes is less than that of RHA mixes. This means that the concrete mixes containing RSA and RHA are less workable than the control mix. This result agrees with the experimental findings of El-Sayed et al. [8] and Bui et al. [14] who concluded that slump decreases with the increase of RHA content for same level of superplasticizer. This can be explained by the high specific area of RHA and RSA; the higher the surface area of RHA, the greater the demand for water. For phase III mixes, the results show that the slump is 140 mm for the mix without RS and 1% RS content; then it decreases to reach 120mm and 110 mm for 3% and 5% RS content, respectively.

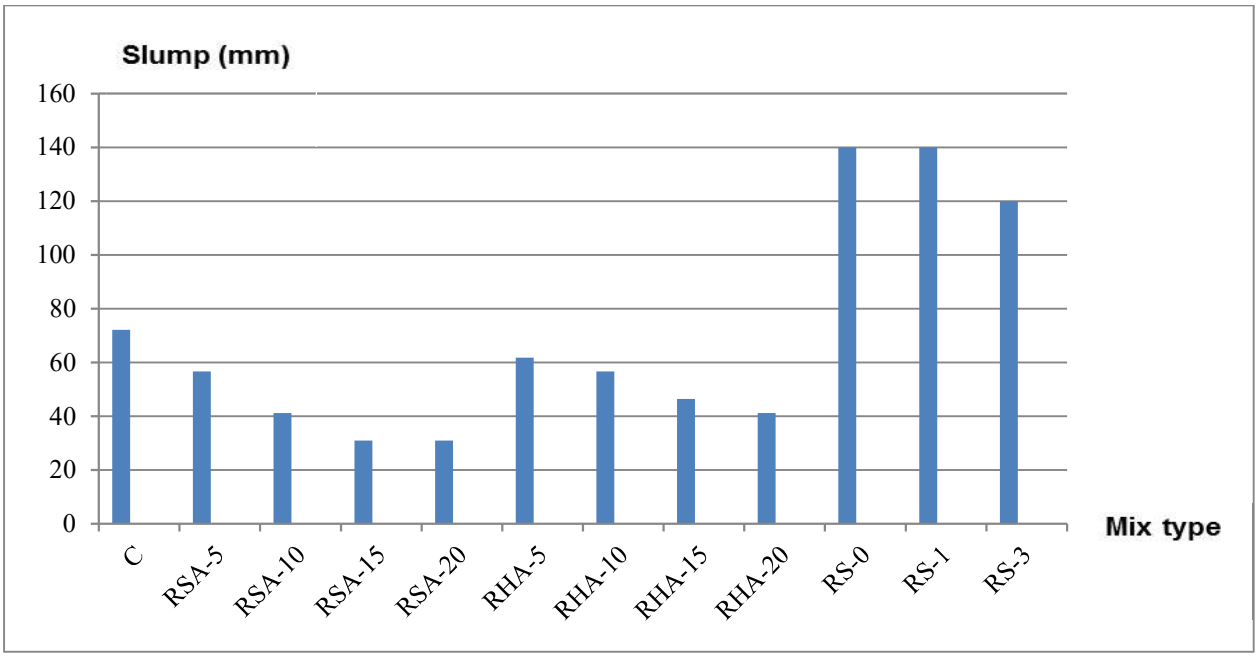


Fig. 11: Slump test results for all concrete mixes

4.2. Density

For phase II, the experimental results given in Table 3 and Fig. 12 show that the dry density of RSA and RHA mixes increase with increasing the ash ratio in the mix, this is due to pozzolanic reaction that releases CH and generates denser components that fill up the voids and produce denser concrete. The experimental results of phase III mixes are plotted in Fig. 13 and show that before burning, the control mix is the densest mix; adding RS reduces density gradually. El-Sayed et al. [8] and Bahnsawy et al [15] reported that cement replacement with RS decreases density due to the low density of rice straw. It can be observed from Fig. 13 that after heating to 300°C for 1 or 2 hours the RS-1 and RS-3 mixes show higher density than RS-0, also heating to 500°C for 1 hour. This can be explained that high temperature transforms crystalline silica to amorphous silica which forms silica gel and consequently produces denser concrete.

Table 3: Density, compressive strength and tensile strength of RSA and RHA mixes (phase II)

Mix ID	Density (kg/cm^3)	Avg. compressive strength		Avg. tensile strength	
		MPa	Relative %	MPa	Relative %
C	2352.52	38.88	100.00%	2.62	100.00%
RSA-5	2385.48	31.42	80.81%	2.32	88.54
RSA-10	2419.47	33.37	85.82	2.63	100.38
RSA-15	2456.55	38.63	99.35	2.85	108.77
RSA-20	2438.01	34.35	88.34	1.93	73.66
RHA-5	2341.19	36.36	93.51	2.24	85.49
RHA-10	2379.30	37.80	97.22	2.66	101.53
RHA-15	2390.63	42.80	110.08	2.90	110.69
RHA-20	2380.33	38.47	99.94	1.98	75.57

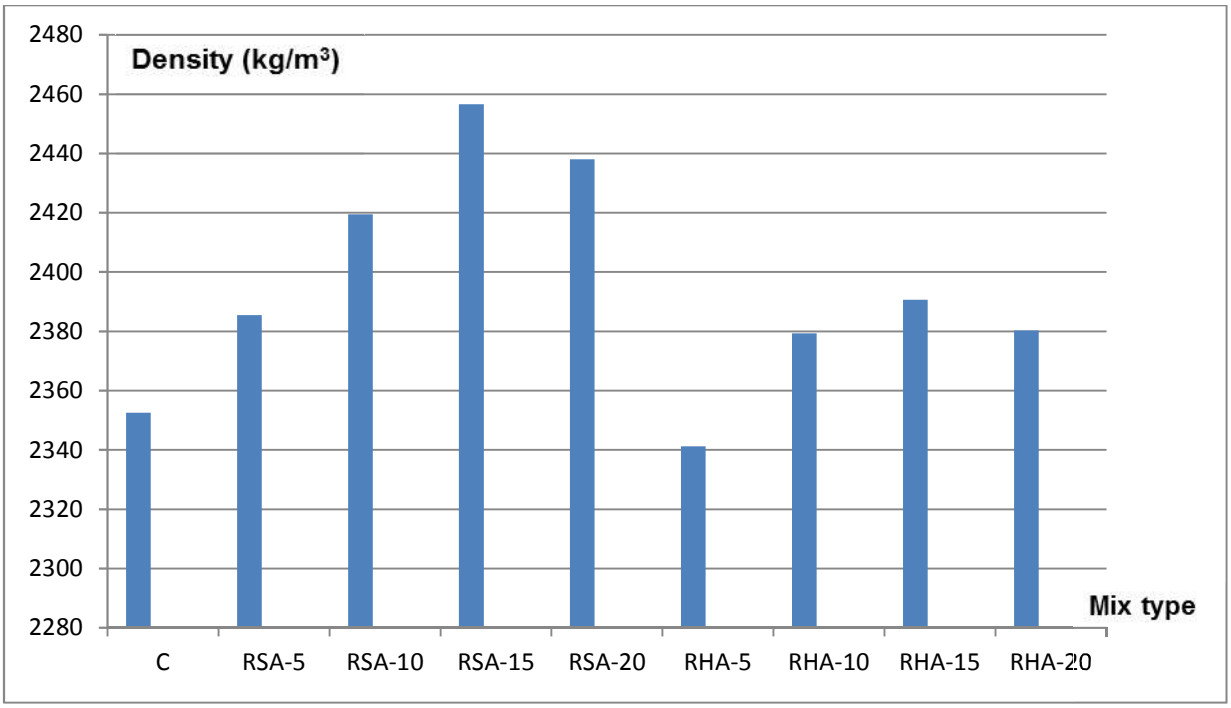


Fig. 12: Dry density of all concrete mixes of phases II and III

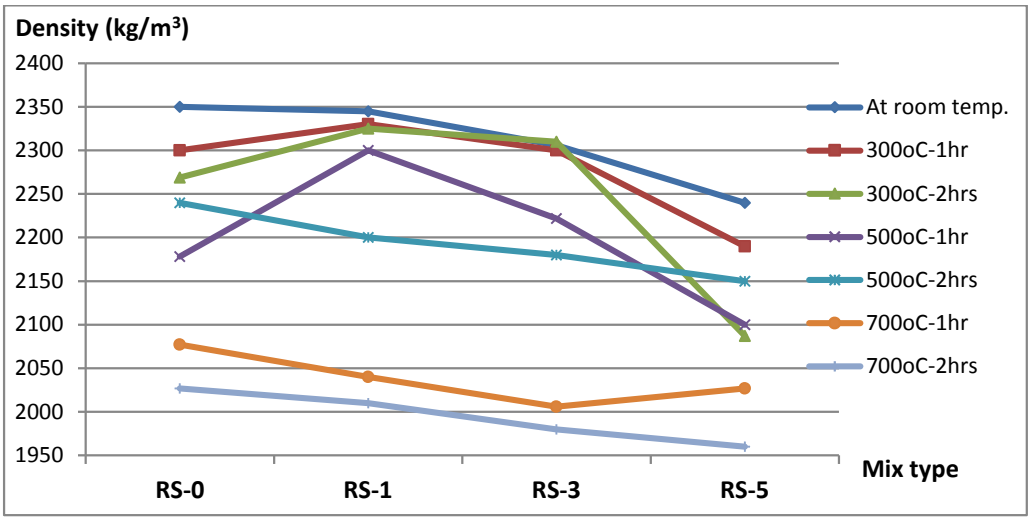


Fig. 13: Dry density of concrete mixes before and after burning (phase III)

3.3 Compressive strength

The experimental results for 28 days compressive strength of concrete mixes of phase II are listed in Table 3 and plotted in Fig. 14, it is shown that using RSA slightly decreases the compressive strength; the best RSA content was 15% with compressive strength 99.35% of the control sample. The compressive strength of RHA-5, RHA-10 and RHA-20 are very close to the control sample result (93.51, 97.22 and 98.94%, respectively), while RHA-15% is higher than control sample with a ratio of 110.08%. The increase in compressive strength of RSA and RHA mixes is due to the fact that the pozzolanic reaction of RHA increase the reaction with $Ca(OH)_2$ to produce more calcium silicate hydrates (C-S-H) responsible for high compressive strength. El-Sayed et al. [8], Mahmud et al. [17] and Ganesan et al [18] reported that the optimum replacement level of cement by RHA is 15% which achieves maximum compressive strength.

For phase III, the experimental results of compressive strength at 28 days are given in Table 4 and Fig. 15. It is observed that the average compressive strength of unburnt

cubes slightly increased from 28.733 Mpa to 28.833 Mpa by adding 1% RS, while it decreased to 26.00 and 20.91 Mpa with increasing RS content to 3% and 5%, respectively. Allam and Garas [19] reported that RS used as aggregate replacement to produce rice straw-cement bricks, decreased the compressive strength. This may be due to conversion of crystalline silica inside test specimen to amorphous silica that have stronger bond with each other and due to removal of organic materials and any unwanted impurities by high temperature effect.

Table 4: Compressive strength of concrete exposed to high temperature (phase III)

	Compressive strength (MPa)						
Temp. ºC	20 ºC	300 °C		500 °C		700 °C	
Duration (hr)	-	1hr	2hrs	1hr	2hrs	1hr	2hrs
RS-0	28.733	28.733	24.200	23.333	18.967	10.933	8.063
RS-1	28.833	26.900	24.033	22.633	18.367	17.030	13.277
RS-3	26.033	25.033	23.100	21.700	18.133	13.600	11.083
RS-5	20.910	20.060	18.813	18.600	14.030	11.183	10.557

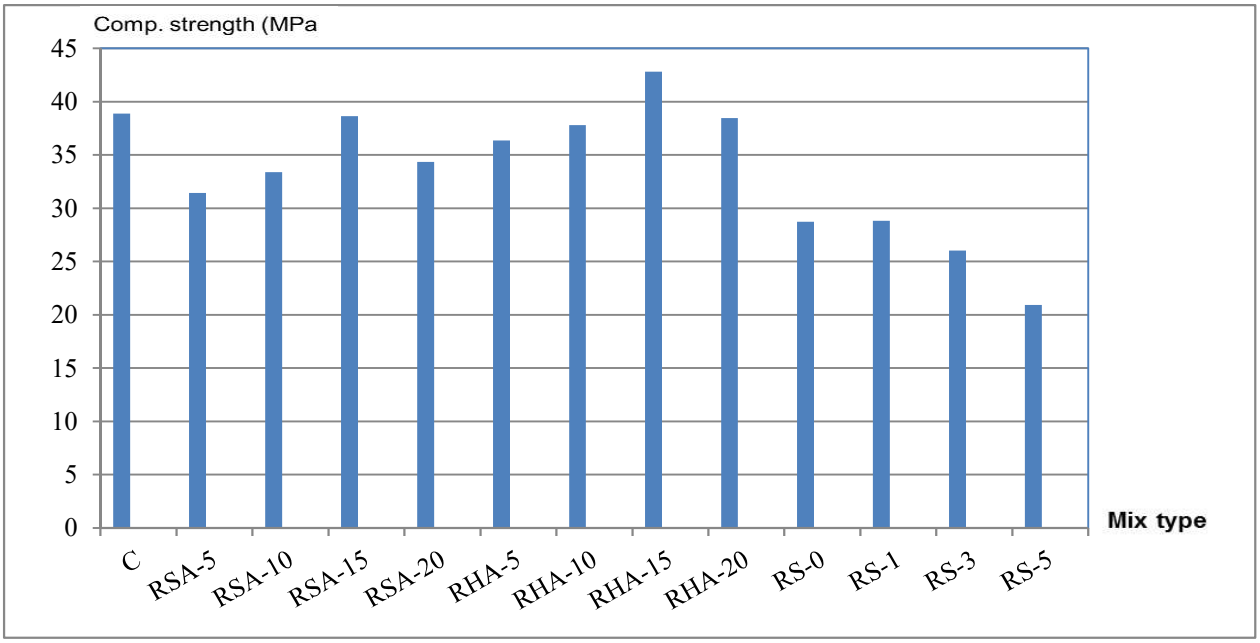


Fig. 14: Average compressive strength at 28 days for all concrete mixes

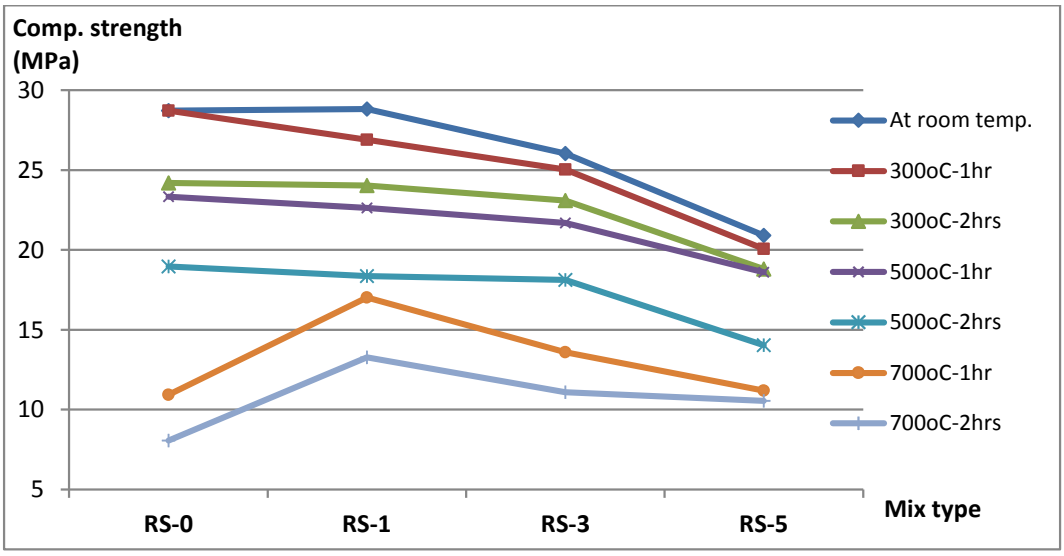


Fig. 15: Average compressive strength at 28 days for all concrete mixes

3.4 Tensile strength

The experimental results are given in Table 3 and plotted in Fig. 16, show that the 28 days tensile strength of 0% ash mix was 2.62 MPa, higher tensile strengths were 108.77% and 110.69% of the control mix tensile strength obtained for RSA-15 and RHA-15 mixes, respectively. It is observed that increasing RHA content in concrete mixes enhance splitting tensile strength. This result agrees with El-Sayed et al. [8] and Sakr results [20], that addition of RHA results in significant increase of the tensile strength.

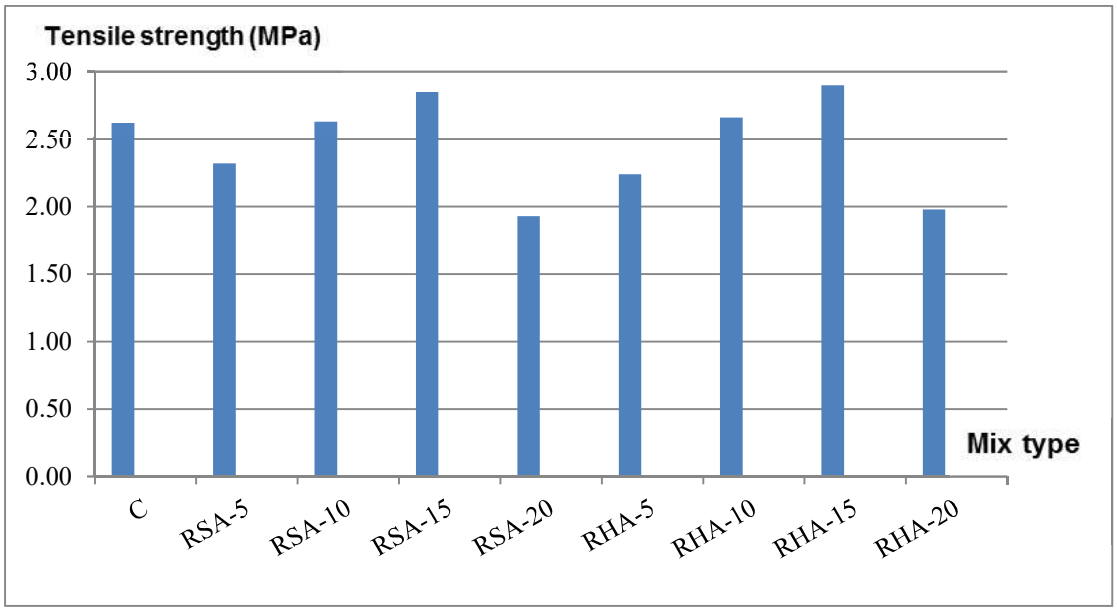


Fig. 16: Average tensile strength at 28 days for concrete mixes containing RSA and RHA

4.5 Sorptivity results

The sorptivity test results of RSA and RHA mixes after 28 days are given in Table 5 and Fig. 17. The sorptivity value is given at different times 10, 20, 30, 60, and 120 minutes. For phase II mixes, the highest sorptivity obtained is for mix C for all time intervals, while the least sorptivity is for RSA 10% as it equals zero for 10, 20, and 30 minutes. The results indicate that RSA mixes have lower permeability than control mix. Sorptivity decreases with increasing RHA content from 5 to 15%, and then it increases at 20% RHA. All obtained results show acceptable permeability of RSA and RHA mixes compared to control mix. The results agree with El-Sayed et al. [8] and Saraswathy and Ha-Won [21] observations that water absorption for rice husk ash concrete at all levels was less than control concrete. This occurred due to perfection on the interfacial

transition zones among the cement matrix and aggregate [22].

The experimental results of phase III mixes as in Table 6 showed that before burning the control sample has the highest initial sorptivity of all mixes, there is no clear difference among other mixes before burning to 300°C for 1 and 2 hours, then after burning to very high temperature 700°C for 1 and 2 hours, the lowest initial sorptivity is obtained from RS-1 and RS-5 mixes [23]. Bahnsawy et al [16] demonstrated that the minimum value of absorption and porosity is obtained for concrete mix without rice straw. They found that as the straw content increases, the ability of the composite to absorb water increases, and attributed it to the fact that straw, like other lignocelluloses, is hygroscopic, with relatively high affinity for water.

Table 5: Sorptivity of RHA and RSA mixes of phase II

Mix ID	Sorptivity $*10^{-3}$ $cm.s^{-0.5}$				
	after 10 min.	after 20 min.	after 30 min.	after 60 min.	after 120 min.
C	0.000	3.468	3.120	2.400	1.980
RHA-5	2.448	2.076	1.692	1.392	1.272
RHA-10	0.979	1.039	0.848	0.600	0.425
RHA-15	0.979	0.692	0.565	0.400	0.425
RHA-20	1.140	0.792	0.660	0.540	0.510
RSA-5	1.470	1.039	0.848	0.600	0.425
RSA-10	0.000	0.000	0.000	0.200	0.142
RSA-15	1.601	1.380	1.188	1.140	1.080
RSA-20	1.349	1.224	1.218	1.380	1.560

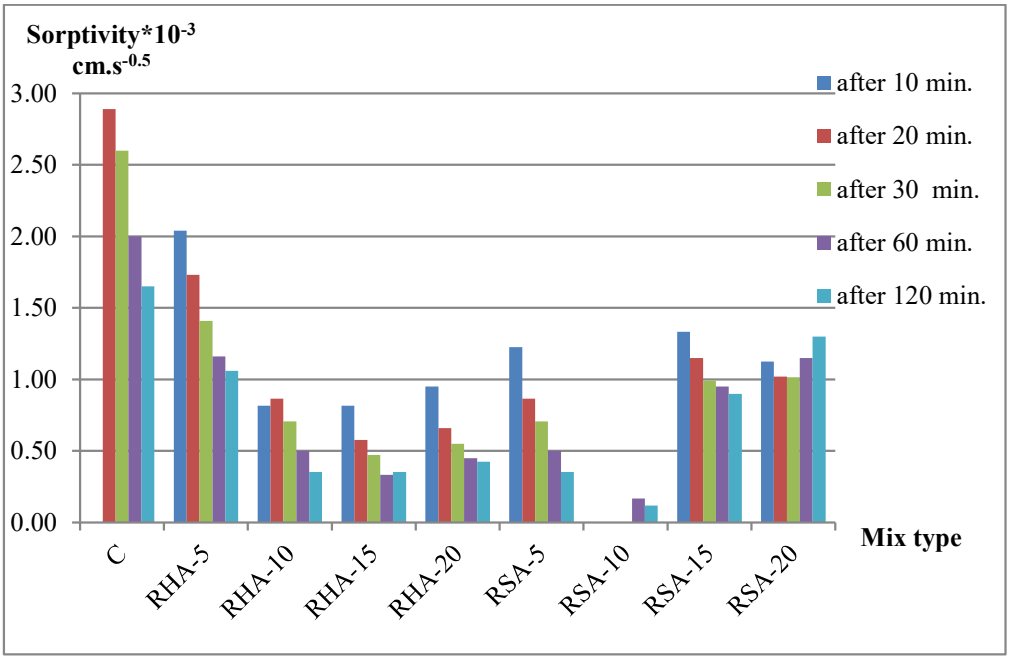


Fig. 17: Sorptivity of concrete mixes containing RSA and RHA (phase II)

Table 6: Sorptivity of concrete specimens of phase III before and after burning.

Mix ID	Burning temp °C	Burning duration (hours)	Sorptivity *10^{-3} cm.$s^{-0.5}$				
			after 10 min.	after 20 min.	after 30 min.	after 60 min.	after 120 min.
RS-0	-	-	8.165	11.547	9.428	11.667	10.607
	300 °C	1	16.330	20.785	24.042	18.333	14.142
		2	0.816	0.866	1.179	1.667	0.943
	500 °C	1	5.715	5.774	5.657	5.333	4.125
		2	4.899	5.196	5.893	5.500	4.125
	700 °C	1	31.027	25.403	22.863	18.500	13.789
		2	31.027	25.403	22.863	18.500	13.789
RS-1	-	-	1.225	0.866	0.707	0.500	0.589
	300 °C	1	8.165	14.434	16.499	13.333	12.964
		2	1.633	1.443	1.886	1.833	1.296
	500 °C	1	12.247	17.321	23.570	20.000	15.321
		2	10.614	8.083	7.307	6.167	4.832
	700 °C	1	19.188	16.743	16.263	14.500	11.078
		2	19.188	16.743	16.263	14.500	11.078
RS-3	-	0	0.816	1.443	1.886	1.333	1.296
	300 °C	1	4.082	8.660	11.785	11.667	10.607
		2	0.816	0.866	0.707	0.667	0.471
	500 °C	1	6.532	6.062	5.893	5.667	4.125
		2	15.922	13.568	12.728	9.667	7.189
	700 °C	1	35.518	30.600	28.520	23.833	17.324
		2	35.518	30.600	28.520	23.833	17.324
RS-5	-	-	1.225	1.443	1.179	0.833	0.707
	300 °C	1	2.858	3.464	3.064	2.500	2.003
		2	0.816	0.866	1.414	1.667	1.296
	500 °C	1	1.225	2.021	1.886	1.500	1.414
		2	6.124	12.124	12.964	10.833	9.664
	700 °C	1	20.821	19.053	18.149	15.167	11.314
		2	28.986	24.826	22.863	18.500	13.671

5. Conclusions

From the obtained experimental results, the main conclusions may be pointed out as follows.

- The characterization tests (FT-IR, XRD, SEM and FTIR) proved that the chemical treatment produces pure silica without any carbon traces and with homogeneous distribution with particles spherical and uniform in shape, while samples treated by heating have more impurities like KO_2, MgO and C.
- Increasing RS ratio in concrete mixes decreases the slump value gradually from 140 mm in control mix to 110 mm for mix containing RS 5% of cement weight.
- Adding RSA and RHA to concrete mixes increases its dry density. Adding RHA with ratio 20% increases density from 2352.52 to 2380.33 kg/m^3, while adding RSA 20% increases the density to 2438.01 kg/m^3.
- The density of concrete mix containing RS decreases by increasing the additive proportion at room temperature. However, after heating to 300°C for 1 and 2 hours and to 500°C for 1 hour the 1% RS and 3% RS mixes show higher density than 0% RS.
- The highest compressive strength after 28 days was obtained for mixes with RSA 15% with a ratio of 99.35% of the control sample compressive strength whereas, compressive strength of RHA 15% is higher than that of control sample with a ratio of 110.08%.
- For phase III, before burning the compressive strength increased from 28.73 Mpa to 28.83 Mpa with adding 1%RS to the concrete mix and slightly

decreased to 26.00, 20.91 Mpa with increasing RS content to 3%, 5%, respectively.

- For phase III, by heating to 300°C for 2 hours, the compressive strength of 0% RS samples decreased with a percentage 15.8 %, while for 1%RS, 3%RS and 5%RS it decreased by 16.65, 11.27 and 10.03 %, respectively, compared to the control mix.
- The compressive behavior of the RS concrete is enhanced by heating to 700°C for 1hour and 2 hours compared to the 0% RS concrete. Heating to 700°C for 1hour, the compressive strength of specimens that have no RS content decreased by 61.90% whereas decrease in compressive strength for RS concrete ranged from 40.94% to 47.76%.
- The 28 days tensile strength of concrete containing ash mixes increased more than that with zero ashes mix by 108.77% and 110.69% for RSA15% and RHA15% mixes, respectively.
- Results indicated acceptable permeability of RSA and RHA mixes compared to control sample, especially RHA15% and RSA 10% that have zero sorptivity till 30 minutes.
- Before burning the control sample has the highest permeability of all mixes. After burning to a very high temperature 700°C for 1 and 2 hours, the lowest permeability is obtained from 1% RS and 5% RS mixes.

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