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Effect of Rice Straw Ash on Concrete for Using as Nuclear Shields

Yasser R. Zaghloul

Abstract— Both radiation shielding and nuclear waste elimination packages are part of the vital activities of the atomic energy authority in all over the world. That is because of their dangerous to the environment especially of human-beings. As well, gamma radiation has high penetrating power and consequently special shields should be built. Furthermore, the rice straw after harvest is one of the important wastes which cause the environmental pollution in Egypt. Also, the idea of using rice straw ash either as partial replacement of cement or as additive in concrete became prevalent for producing high strength concrete. The main goal of this study is to investigate the possibility of using rice straw ash in concrete for radiation shielding and for safe storage of radioactive waste packages. Rice straw ash (RSA) has been utilized with 5%, 10% and 15% percentages as a partially replacement of cement and as an additive to concrete. Results obtained showed that 10% of RSA as cement replacement has found to be the optimum replacement both for radiation shielding and in improving the physical and the mechanical properties of concrete.

Index Terms— Rice straw ash, Density, Porosity, Water absorption, Compressive strength, Splitting tensile strength, Nuclear shielding of concrete.

1 Introduction

THE inclusion of mineral admixtures in building materials can cause benefits such as amelioration of mechanical properties and durability. For example, the utilization of rice husk ash as a good reacting pozzolanic material in the manufacture of building materials has been studied for decades [1]. The utilization of rice husk ash as a supplemental cementitious material in construction is very attractive to many developing countries where Portland cement is scarce but rice production is abundant [2]. Generally, many researchers concluded that using different agriculture leftover ashes obtain construction materials of standard quality as well as improving the durability [3-7]. Rice straw is one of agriculture leftover and studied by a few researchers. It is a rice plant stem that is released during rice harvest and is considered as agricultural waste. In Egypt, farmers burnet it every year to clean the field for the new crop that led to tremendous environment pollution.

On the other hand, both radioactive materials and nuclear radiation are dangerous to the environment particularly of the health of human beings. Therefore, concrete beside it is the most commonly used building material; it is an excellent and versatile material, which is used as radiation shielding and is suitable for safe storage of packaging for radioactive waste.

Kartini et al (2012) [8], have found that cement replacement by high rate of rice husk ash (RHA) caused a decrease in compressive strength of investigated concrete. Hence, 10% replacement with RHA leads to the objective compressive strength rather than cement and also durability presented in conventional concrete. **Nour Eldin et al** (2013) [9], have observed the effect of rice straw ash (RSA) addition and cement replacement to produce high performance concrete. They reported that, slump consistency was reduced thus superplasticizer in the mixes should increase to acquire the same consistency of conventional concrete. Also, the greater compressive strength observed after 28 days at 10% replacement with RSA. **Munshi and Sharma** (2016) [10], concluded that the concrete produced with 10% cement replacement with RSA show higher compressive strength and lower permeability than normal concrete. **El-Sayed et al** (2017) [11], have studied three types of ashes in concrete; wheat straw, rice straw and rice husk. Results showed that, 15% cement replacement with all investigated ashes showed better density, sorptivity and strength.

The aim of this work is to investigate the effect of rice straw ash (RSA) as an additive and a partial substitute for cement on concrete properties. Furthermore, investigate its impact on the performance of concrete used in several nuclear applications, such as radiation shielding and for radioactive disposal packages.

2 Materials and Method

This section describes the experimental work performed through this study.

2.1 Properties of the Used Materials

The materials used properties of the in this work which are; Cement, Fine aggregate, Coarse aggregate, RSA and Superplasticizer are given below. All materials used are locally produced. Ordinary Portland cement (CEM I-42.5) has been used. Sand with a specific gravity of 2.60 is used as fine aggregate in concrete samples. It is clean and deleterious organic matter. Analysis of sand grading is shown in Table (1). Dolomite is often used as a coarse aggregate because it provides the required dimensions, ease

• *Yasser R. Zaghloul, Higher Institute of Engineering, Shorouk City, Cairo, Egypt, E-mail: y.zaghloul@sha.edu.eg*

of use, and satisfying results. Dolomite with a specific gravity of 2.54 is used and sieve analysis is shown in Table (2). The grading of dolomite is based on ACI 211.1-91 [12].

TABLE 1. GRADING OF SAND

Sieve size (mm)	4.76	2.40	1.20	0.60	0.30	0.15
Sand (Passing %)	95.90	90.25	76.40	18.50	4.10	0

TABLE 2. GRADING OF COARSE AGGREGATE

Sieve size (mm)	38	19	9.5	4.75	2.36
Dolomite (Passing %)	100	96.6	52.4	16.9	0

However, the rice straw was locally available and was burnet under controlled temperature. It has a specific gravity 2.2 and dark gray in color. Finally, to adjust workability of fresh concrete with small water to cement ratio a commercial superplasticizer was used.

2.2 Mix Proportions

In the current study seven concrete mixtures were optimized and used. The mixes proportions are presented in Table (3), as presented (S1) is the control specimen. The samples of standard cubes (15 cm x15 cm x15 cm), special cubes for radiation shielding measurements (10 cm x10 cm x10 cm) and standard cylinders of (15 cm Diameter x30 cm height) have been casted. All experiments have been conducted on three samples and the average of the outcomes was considered. All investigated specimens were cured in water at room temperature.

2.3 Testing Procedures

The slump test was carried out for fresh concrete according to ASTM C 143M-03 [13]. For hardened concrete the density of all investigated specimens are determined. Percentage of water absorption capacity, W_a% and porosity percentage, n% are calculated. In this case, the prepared cube is dried after 28 days at 105 ° C in the oven for 1 day until the weight is constant, then cooled in a desiccator. Dry samples were weighed (W_d) and then immersed in water. The sample weight is checked every 24 hours until a constant weight (W_w) is recorded. Also for mechanical measurements, a hydraulic testing machine is used to determine the compressive strength of cubic samples. On the other hand, cylindrical samples are used to determine splitting tensile strength with respect to ASTM C 496M-04 [14].

TABLE 3. MIX PROPORTIONS OF THE CONCRETE MIXTURES

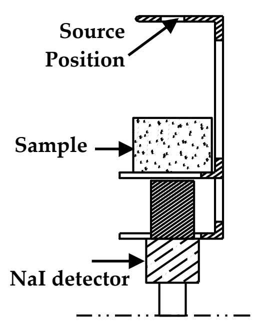
No.	RSA/cement %	RSA Kg/m³	Cement Kg/m³	w/c ratio	Fine Agg. Kg/m³	Coarse Agg. Kg/m³
S1	0	0	400	0.35	646	1290
S2	5	12.5	396	0.35	646	1290
S3	10	25	388	0.35	646	1290
S4	15	37.5	380	0.35	646	1290
S5	5	25.2	400	0.35	614	1290
S6	10	50.4	400	0.35	581	1290
S7	15	75.5	400	0.35	549	1290

Super plasticizer was added to adjust workability

The radiation shielding properties of the mixed special cubes are examined by gamma rays photo peak energies emitted by Cs-137 (662 keV) and Co-60 (1173 keV and 1332 keV). The intensity of the transmitted gamma ray (γ) was measured using a gamma ray spectrometer with NaI detector. The source-sample holder is required to fix the sources and samples at a defined position and distance from the detector, as shown in Fig. (1-a). It is made of cast iron and is located inside the shield house; Fig. (1-b). In the beginning, the two sources are placed in the source position at the source-sample holder, and the intensity of γ-radiations transmitted through the air is detected for each γ ray photo-peak energy; initial intensity (I_o). Then the concrete sample is placed in its position at the holder and the γ-radiations are pass through it. The intensity of the transmitted γ-radiations for each concrete sample is detected; I_x. By using the measurement values of Io and I_x in the attenuation coefficient equation (Eq. 1), the linear attenuation coefficient (μ) of the each concrete sample is determined [15],

$$I_x = I_o\, e^{-\mu x} \quad (1)$$

Where, x is the thickness of the concrete block.



(a) (b)

Fig. 1. (a) Schematic diagram of the source-sample holder, (b) source–sample holder inside the shield house

3 Results and Discussions

3.1 Physical Properties

The results of the slump, the water absorption rate and the porosity percentage for all investigated samples are shown in Table (4). Due to the high specific surface area of RSA, slump values seem to decrease with increase of RSA percentage either as cement replacement or as additive to concrete mixture, but these values are controlled by superplasticizer. Table (4) shows that the replacing or adding RSA to concrete leads to lower water absorption and porosity than that of conventional concrete. This may be due to the pozzolanic influence, which consolidate silica elements in RSA with the lime elements in cement such as calcium oxide and calcium hydroxide to increase the bonding strength and solid volume.

Table 4. Slump, water absorption and porosity for all concrete mixtures

No.	Slump (cm)	Water Absorption (%)	Porosity (%)
S1	6.9	5.90	14.8
S2	6.4	4.95	12.1
S3	5.9	4.20	9.5
S4	5.3	3.75	8.8
S5	6.2	5.05	12.4
S6	5.4	4.35	9.9
S7	4.8	3.90	9.1

Figure (2) shows the results of the density for mixtures of replacing cement by RSA and of adding RSA to concrete mixtures. It is clear from Fig.(2) that the density of the samples with different ratios replacement of RSA increases than that of conventional concrete until 10%. Further, the density decreased slightly with the increase of the RSA ratio. Likewise, the density of the samples with different ratios of adding RSA increases until 5% and goes to decrease slightly after that. Accordingly, RSA results denser concrete than the conventional concrete. These results have a favorable effect in ameliorating both radiation shielding and leaching properties for the investigated samples which are significant in the nuclear shields and in the nuclear waste elimination packages.

3.2 Mechanical Properties

In general, silica has a strong influence on the compressive strength of concrete at the age of 7 and 28 days. The relationship between various RSA replacement percentages (S2 – S4) and the corresponding compressive strength is shown in Figs.(3a & 3b) and it has the same trend of the density. Figure (3b) shows that, the compressive strength increases with an increase in the percentage of RSA until 10% replacement. This was followed by a slight decrease with an increase in RSA percentage until 15%. The high pozzolanic nature of rice straw is responsible for increase in the compressive strength. Also, Figs.(3a & 3b) show the relationship between different RSA additive percentages (S5 – S7) and the corresponding compressive strength. As noticed the compressive strength increases with an increase in the percentage of RSA until 5% additive and then followed by slight decrease until 15%. All these compressive strength results are consistent with the results obtained by Nour Eldin et al.

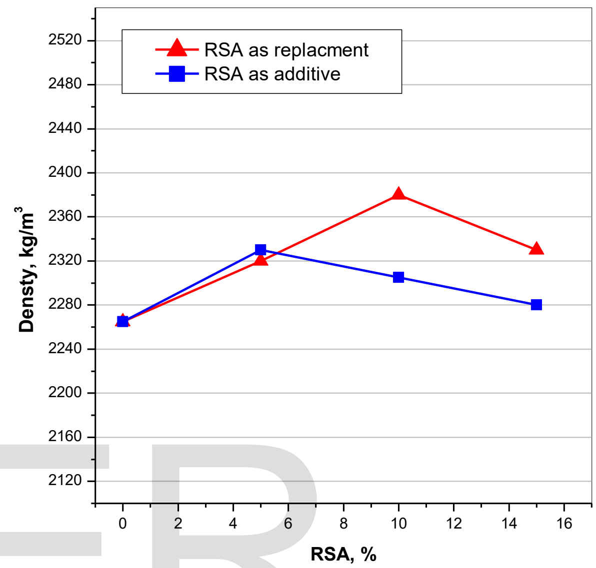


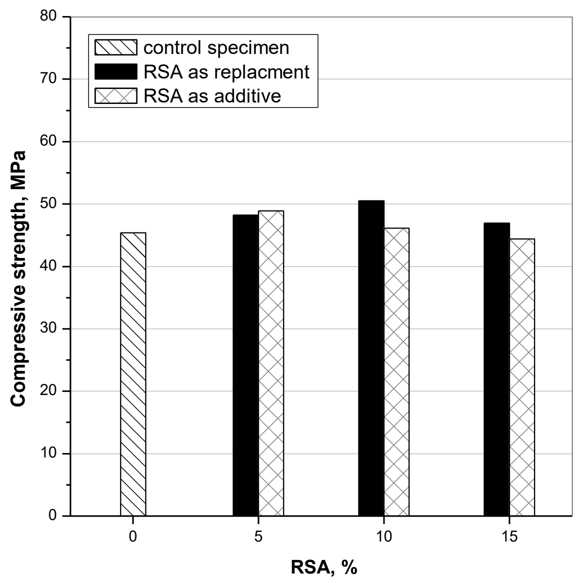
Fig. 2. Density of all concrete mixtures

Results of the splitting tensile strength for all mixtures are studied and shown in Fig.(4). The results of RSA replacement do not have any effect on splitting tensile strength. While results of RSA additive have slight decrease in splitting tensile strength than conventional concrete. These results are harmonic with El-Sayed et al results.

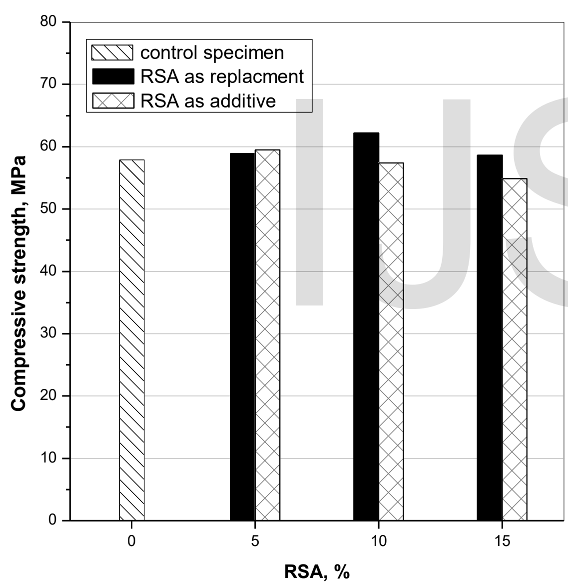
It is worth to correlate the obtained compressive strength and tensile strength of the investigated mixtures to provide the engineers a sense of the benefits of using RSA in concrete. Empirical relations have evolved from experimental data and will be verified with newly obtained experimental data for two new RSA percentages (7% and 12%). The relation between the compressive strength after 28 days and RSA percentage as cement replacement up to 15% can be expressed by Eq.2. Also, the variation in the splitting tensile strength by different percentages of RSA as cement replacement was found to follow the polynomial equation (Eq.3);

$$y = 58.25 + \frac{35.666}{4(x-10)^2+7.123} \tag{2}$$

$$y = 6.495 - 0.011\,x - 0.001\,x^2 \tag{3}$$



(a) After 7 days



(b) After 28 days

Fig. 3. Compressive strength of all concrete mixtures

Applying the same approach, same mechanical properties for RSA as additive to concrete with different percentages are analyzed mathematically. The relation between the compressive strength after 28 days and RSA percentage up to 15% can be expressed by Eq.4. Also, the splitting tensile strength up to 15% RSA as additive was found to follow (Eq.5);

$$y = 57.945 + 0.379\,x - 0.039\,x^2 \tag{4}$$

$$y = 6.495 - 0.081\,x - 0.001\,x^2 \tag{5}$$

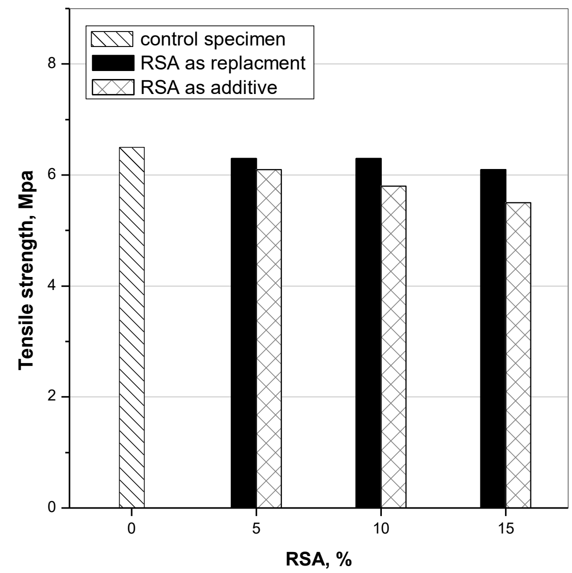


Fig. 4. Splitting tensile strength of all concrete mixtures

To test the validity of the empirical equations both compressive strength and splitting tensile strength were determined experimentally at 7% and 12% RSA as cement replacement and as additive. The experimental results are tabulated together with the mathematical calculated values, table (5). From this table it is clear that, the calculated values are almost the same as experimental data, which justifies the validity of the all empirical equations.

TABLE 5. EXPERIMENTAL AND CALCULATED DATA FOR VERIFY EMPIRICAL EQUATIONS

RSA %		Compressive strength (Mpa)		Tensile strength (Mpa)	
		Experimental	Calculated	Experimental	Calculated
Replacement	7	59.22	59.08	6.40	6.37
	12	59.94	59.79	6.25	6.22
Additive	7	58.74	58.69	6.01	5.98
	12	56.93	56.88	5.71	5.67

3.3 Nuclear Shielding Properties

The intensity of the transmitted gamma rays, I_x, was measured for all investigated concrete mixtures. Therefore, the linear attenuation coefficient (μ) is calculated for all mixtures using equation (1). The thickness of the concrete mixture, where I_o decreases to half its value is called; the half value thickness ($X_{1/2}$) which calculated using equation (6);

$$\frac{I_x}{I_O} = \frac{1}{2} = e^{-\mu x_{1/2}} \tag{6}$$

Mathematical calculations yield that, $X_{1/2} = 0.693/\mu$. Table (6) shows the calculated values of the linear

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attenuation coefficient (μ) and the half value thickness ($X_{1/2}$) for the all investigated mixtures for each gamma ray photo peak energy.

TABLE 6. ATTENUATION OF γ-RADIATION OF ALL CONCRETE MIXTURES

No.	Source type	γ-Ray Energy (keV)	μ (cm^{-1})	HVT $X_{1/2}$ (cm)
S1	Cs-137	662	0.169	4.10
	Co-60	1173	0.138	5.02
		1332	0.132	5.25
S2	Cs-137	662	0.180	3.85
	Co-60	1173	0.148	4.68
		1332	0.140	4.95
S3	Cs-137	662	0.215	3.22
	Co-60	1173	0.162	4.28
		1332	0.155	4.47
S4	Cs-137	662	0.189	3.67
	Co-60	1173	0.154	4.50
		1332	0.146	4.75
S5	Cs-137	662	0.185	3.75
	Co-60	1173	0.152	4.56
		1332	0.144	4.81
S6	Cs-137	662	0.171	4.05
	Co-60	1173	0.141	4.91
		1332	0.133	5.21
S7	Cs-137	662	0.163	4.25
	Co-60	1173	0.132	5.25
		1332	0.125	5.54

Table (6) shows that, S3 has the lowest $X_{1/2}$ for all the energy ranges tested, while S7 has the highest values. This implies that S3 has the best shielding properties in all tested mixes, while S7 has the worst shielding properties. Changing conduct of shielding properties has the same tendency with compressive strength. The shielding properties are improved by the 10% percentage of RSA as cement replacement and afterward diminish, likewise the shielding properties of 5% of RSA as additive is still superior to conventional concrete shielding properties. This can be attributed to an increase in density therefore in compressive strength and decrease of pores thus, increasing in linear attenuation coefficient and diminishing in $X_{1/2}$.

For comparison, effect of RSA percentages as a cement replacement and as an additive on the linear attenuation coefficient, μ, and half value thickness, $X_{1/2}$, at 662 keV energy line is presented in Figs.(5) & (6), respectively. The results obtained indicate that 10% cement replacement by RSA in concrete can boost its gamma-ray linear attenuation coefficient to reach 27% of its value for conventional concrete at 662 keV, 17% at 1173 keV and 17% at 1332 keV. Therefore, the use of rice straw ash as replacement of cement in concrete will be an intelligent solution for radiation shielding.

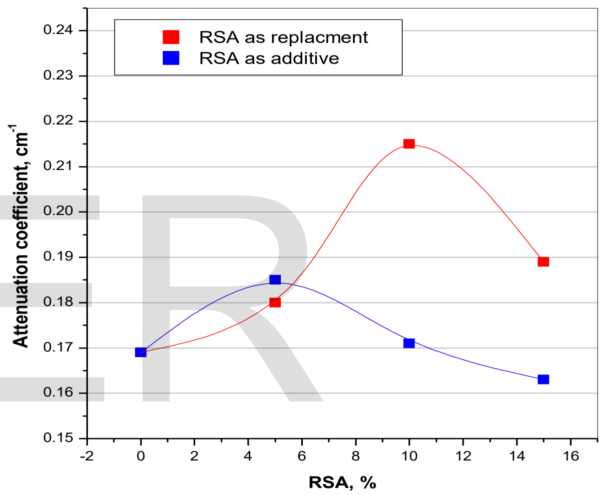

Fig. 5. Effect of RSA percentages on the linear attenuation coefficient at gamma ray of 662 keV energy

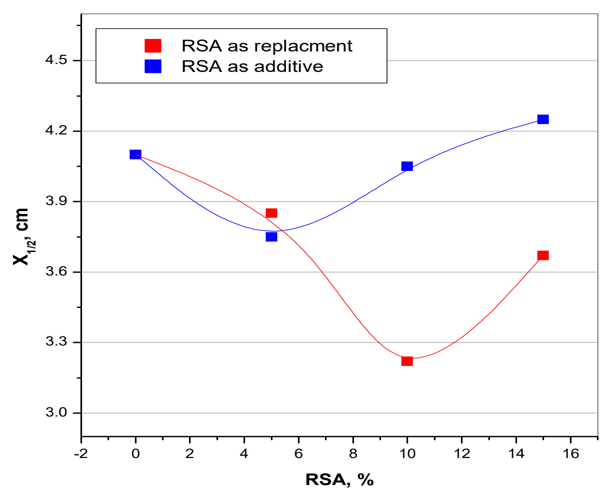

Fig. 6. Effect of RSA percentages on the half value thickness at gamma ray of 662 keV energy

4 Conclusion

The following conclusions will be drawn from the obtained experimental results;

- Rice straw ash is a pozzolanic material and has a good impact as a supplementary cementing material to produce good performance concrete.
- 15% replacement of cement by RSA presented lowest porosity (8.8%) and lowest water absorption ratio (3.75%).
- The maximum increase in compressive strength was obtained for 10% replacement of RSA.
- Using RSA as cement replacement or as additive in concrete has no tremendous effect on the splitting tensile strength.
- Empirical relations developed from the experimental data, within the range used in this investigation, and verified to calculate both compressive strength and splitting tensile strength of concrete with different percentages of RSA either as a cement replacement or as an additive.
- Decrease in porosity and water absorption by replacing RSA in concrete causes a decrease in leachability of the immobilized radioactive materials in the radioactive waste elimination packages.
- Cement replacement by RSA in concrete significantly effects on increasing the attenuation of gamma radiation, thereby reducing the thickness required for the radiation shielding compared to conventional concrete.

Based on this study it can be recommended that RSA in 10% replacement of cement has a positive and desirable effect on concrete to be used in some nuclear activities.

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