

Physical and Chemical Properties of Rice Straw Ash and Its Effect on the Cement Paste Produced from Different Cement Types

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Abstract. This research was conducted to study the effect of partial replacing of three different types of cement (ordinary Portland cement, high-slag cement, sulphate resistance cement) with Rice Straw Ash (RSA) on the properties of produced cement pastes. Further, the study focused on incinerations and milling method, physical and chemical properties and pozzolanic activity of RSA. The effect of using RSA on water/cement ratio of the standard consistency paste as well as initial and final setting times of cement paste were investigated. The results show that both initial and final setting times increase with increasing the rice straw ash replacement percent.

Introduction

Rice straws are a residue produced in significant quantities on a global basis. While they are utilized in some regions, in others they are a waste causing pollution and problems with disposal. When burnt, the rice straw ash is highly pozzolanic and suitable for use in lime-pozzolana mixes and Portland cement replacement [1, 2].

Rice straw ash is pozzolanic and satisfies the minimum requirements of ASTM class N, F and C pozzolana and is suitable for use in Portland cement replacement. Also, Ranasinghe [2] reported that rice straw ash (RSA) is also a good partial substitute for cement. It was found that the compressive strength of RSA concrete is slightly higher than ordinary Portland cement (OPC) and rice husk ash (RHA) concrete. Table 1 shows the ash and silica content of some plants [2]. It can be seen that rice straw have about 15% ash after burn, thus for every 1000 kg of rice straw burnt 150 kg ash are produced, and about 82% silica content.

Table 1. Ash and silica content of some plants [2]

Plant	Part of plant	Ash%	Silica%
Sorghum	Leaf sheath epidermis	12.25	88.75
Wheat	Leaf sheath	10.48	90.56
Corn	Leaf sheath	12.15	64.32
Bamboo	Nodes(inner portion)	1.44	57.40
Bagasse	-----	14.71	73.00
Lantana	Leaf and stem	11.24	23.38
Sunflower	Leaf and stem	11.53	25.32
Rice husk	-----	22.15	93.00
Rice straw	-----	14.65	82.00
Bread fruit tree	Stem	8.64	81.80

The chemical composition of rice straw ash is similar to that of many common organic fibers, containing [3]:

- Cellulose ($C_5H_{10}O_5$), a polymer of glucose, and bonded with B-1.4,
- Lignin ($C_7H_{10}O_3$), polymer of phenol,
- Hemi cellulose, a polymer of xylenes bonded with B-1.4 and its composition is like xylem ($C_5H_8O_4$), and
- SiO_2 , the primary component of ash.

The salient features in the production of cements based on RSA are the conversion of the straw to ash and grinding of the ash to a suitable practical size. This aspect is common to all processes currently in operation. In the conversion of rice straw to ash, the combustion process removes the organic matter and leave silica-rich residue. However, such thermal treatment of silica in straw results in structure transformation that influence both the pozzolanic activity of the ash and its grinding. Pichai Nimityongskull and Telesforo U. Daladar [4] reported that the amorphous ash is much easier to grind than the crystalline ash.

The technologies of ash production vary from open-heap burning to specially designed incinerations. Because of high temperature gradient produce formation of higher crystalline siliceous structure [5], open-heap burning is associated with pozzolanas of low reactivity index.

Experimental Work

Incinerator and milling method

In this research, a special incinerator was used for one hour at $550^\circ C$ to obtain the maximum pozzolanic activity and minimum percentage of carbon. The obtained rice straw ash grounded in Los Anglos rotary machine, with 16 kg RSA capacity, rolling for 20000 turns. Nevertheless, the RSA not pass smoothly through sieve No. 200, therefore RSA toasted in an oven with $150^\circ C$ until the difference in weight dwindles. After that,

RSA was mechanically sieved through sieve No. 200. Then RSA was absolutely isolated from humidity by packing until use. The relevant characteristics of RSA are discussed below.

Physical properties of rice straw ash

a) Specific gravity and fineness

Table 2 gives the specific gravity and specific surface area (fineness) of RSA. From the data of Table 2, it is clear that specific gravity of ash is 2.25 which is about 2/3 of the specific gravity value of ordinary cement.

Table 2. Physical properties of used RSA

Specific gravity	2.25
SP. Surface area(cm ² /g)	18460
Color	Gray

b) Particle size distribution

After finishing the grinding process, laser diffraction analysis was carried out on the ash to define the particle size distribution of RSA. Figures 1 and 2 show the results of laser diffraction analysis.

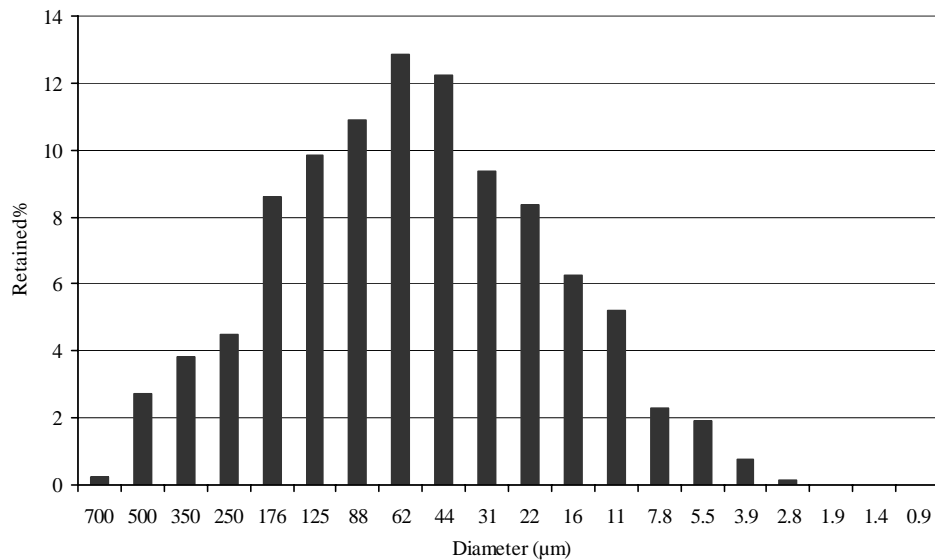


Fig. 1. Particle size distribution of used RSA.

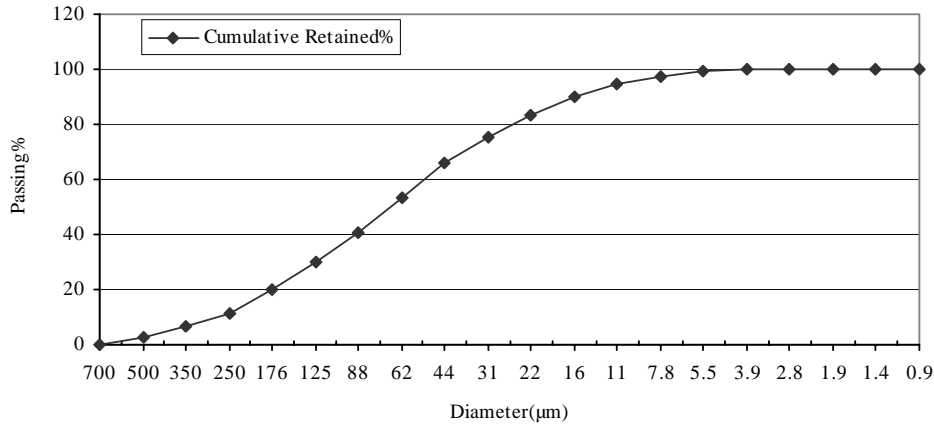


Fig. 2. Cumulative retained % of RSA used.

Chemical composition of rice straw ash

The chemical reactivity of the ash is related to the form of silica in the ash and carbon content. Mehta [6] proposed the silica activity index (SAI) as a measure of degree of amorphousness of silica in the ash. The index is determined by calculating the percentage of available silica that dissolves in an excess of boiling 0.5 N Sodium hydroxide in a three-minute extraction in a stainless steel beaker on a -325 mesh sample. The higher the amount dissolved, the more amorphous the silica. Table 3 shows the chemical composition and (SAI) of RSA used.

Table 3. Chemical composition of RSA

Constituents	RSA
Silica dioxide, SiO ₂ *	65.92
Aluminum oxide, Al ₂ O ₃	1.78
Ferric oxide, Fe ₂ O ₃	0.2
Calcium Oxide, CaO	2.4
Magnesium Oxide, MgO	3.11
Sulfur trioxide, SO ₃	0.69
Loss on ignition	9.71

- Silica Activity Index (SAI) = 70.3%

Physical and chemical properties of used cements

The selection of the cement is one of the most important steps in the production of concrete. Variation in the chemical composition and physical properties of the cement affect the compressive strength more than the variation in any other single material [7].

For this reason, and to make a complete comparison, three types of cement (Ordinary Portland Cement, Blast Furnace Slag Cement and Sulfate Resistance Cement) were used with RSA. Physical and chemical properties of used cements are given in Tables 4 and 5.

Table 4. Physical properties of used cements

Specific gravity (g/cm ³)		OPC 3.13		BFSC 3.15		SRC 3.16	
Fineness	Surface area (cm ² /g)	3000		2800		3140	
Setting time	W/C ratio (standard)	0.283		0.28		0.291	
	Initial (h:min)	(2:10)		(2:30)		(2:15)	
	Final (h:min)	(3:55)		(4:15)		(4:45)	
Strength (kg/cm ²)	Compressive	3 days	213	3 days	141	3 days	291
		7 days	229	7 days	198	7 days	323
		21days	312	21days	245	21days	354

Table 5. Chemical composition of used cements

Constituents	OPC	BFSC	SRC
	Percentage by weight (%)	Percentage by weight (%)	Percentage by weight (%)
Ignition loss	1.36	2.1	2.6
SiO ₂	19.49	26.1	21.0
Al ₂ O ₃	7.36	8.5	5.3
Fe ₂ O ₃	2.68	1.9	5.4
CaO	62.51	54.6	60.1
MgO	3.7	3.5	1.95
SO ₃	2.4	2.5	1.1
Mineralogical	Components (%)	Components (%)	Components (%)
C ₃ S	37.17	----	38.53
C ₂ S	33.65	----	31.22
C ₃ A	11.73	----	4.52
C ₃ AF	8.15	----	16.4

Cement Paste Properties

Standard consistency

The Vicat needles were used to determine the rate at which cement pastes harden. Paste specimens were prepared under standard conditions and cured at constant temperature and humidity. Figures 3, 4 and 5 show the obtained results of the water-cementitious material ratio of the standard consistency pastes. From the results, it is clear that the water-cementitious material ratio increases with the increasing of the RSA replacement ratios. This is attributed to the difference in the specific surface area of RSA (18460 cm²/g) and that is used in these cements.

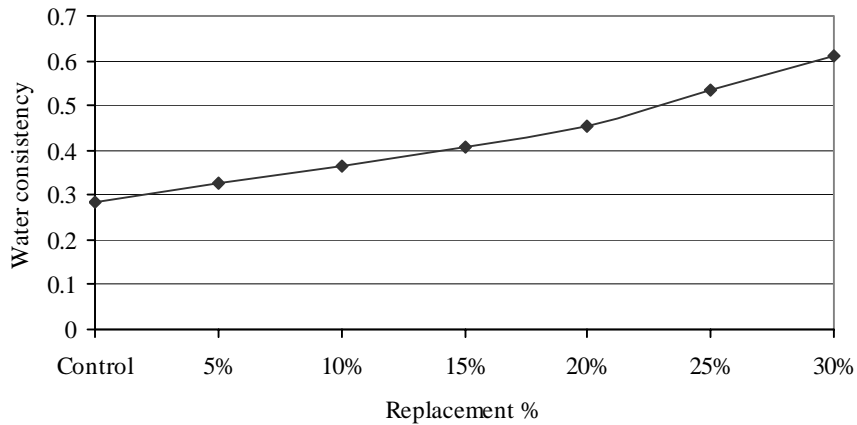


Fig. 3. Relation between the replacement ratios and water consistency (OPC).

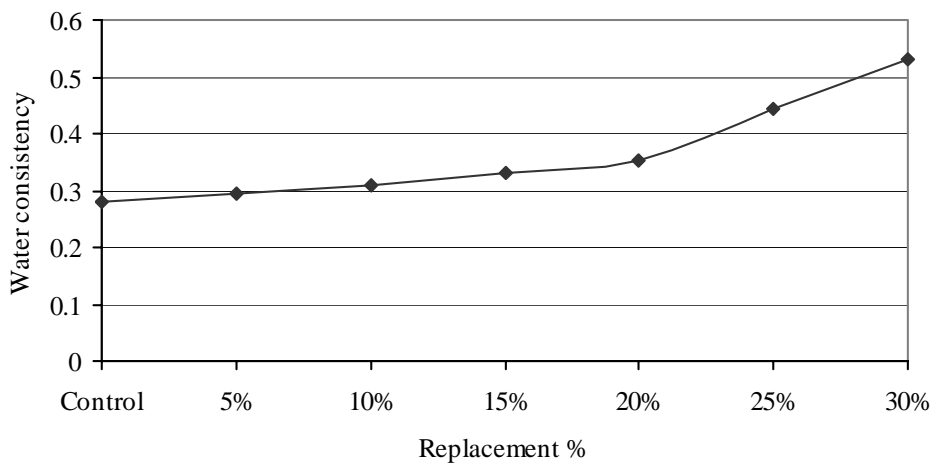


Fig. 4. Relation between the replacement ratios and water consistency (BFSC).

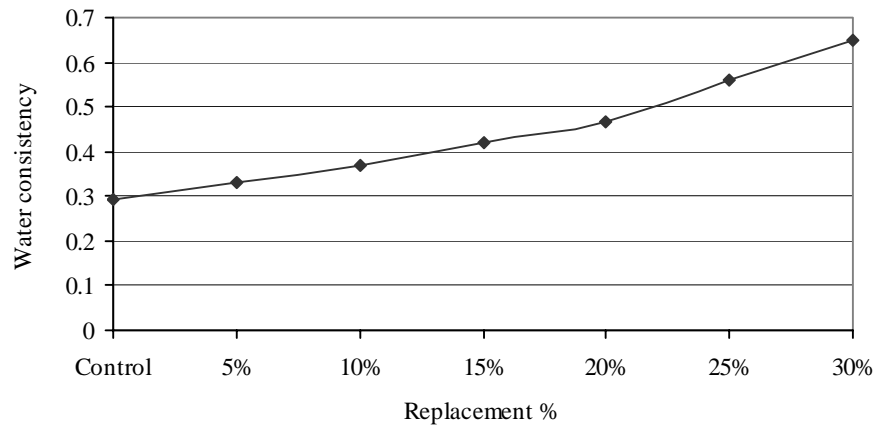


Fig. 5. Relation between the replacement ratios and water consistency (SRC).

Initial and final setting times

Initial and final setting times tests were performed on plain cement paste and pastes having rice straw ash. The contents of RSA were 5, 10, 15, 20 and 25% by the weight of cement. The results of initial and final setting times of RSA with different replacement percentages are presented in Figs. 6, 7 and 8. RSA pastes show increases in initial and final setting times pastes over those of other studied cement pastes. The results also show that the setting times increased with the increasing content of RSA in pastes. This may be due to the slower pace of heat-induced evaporation of water from the RSA paste due to its lower cement content. Moreover, this phenomenon is due to the inert nature of RSA in early ages and it acts as a filler, and for this reason it does not contribute to the initial and final setting times.

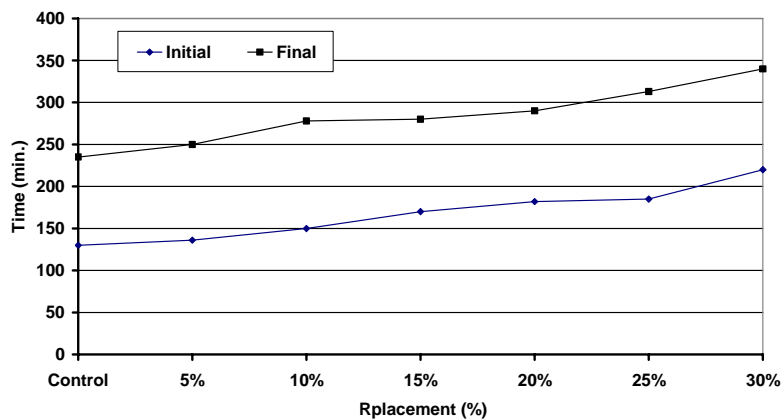


Fig. 6. Initial and final setting times of ordinary Portland cement with different replacement ratios of RSA.

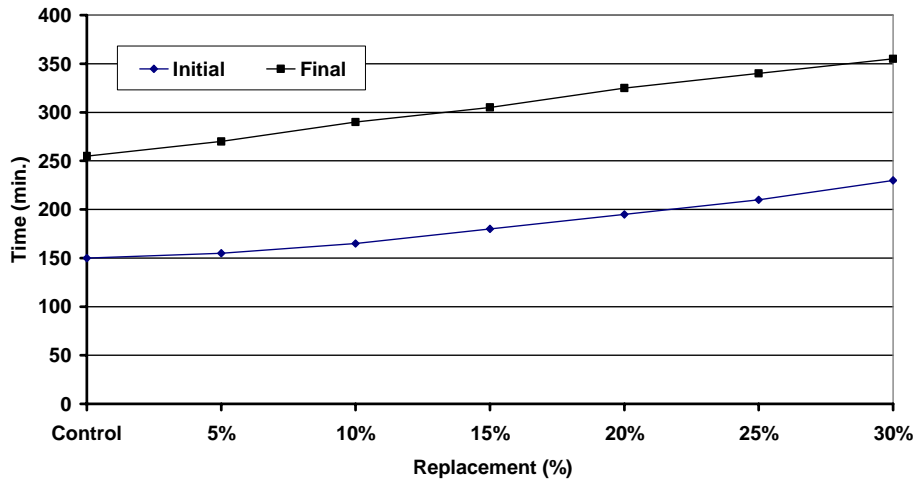


Fig. 7. Initial and final setting times of blast furnace slag cement with different replacement ratios of RSA.

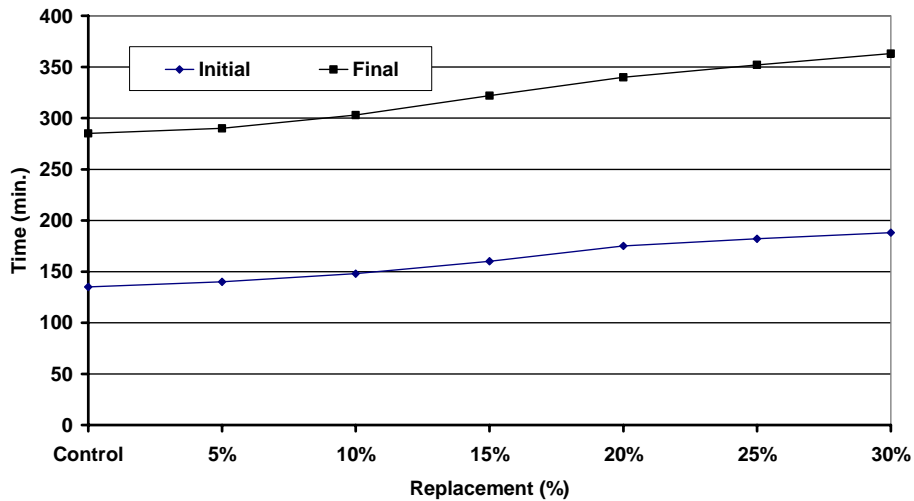


Fig. 8. Initial and final setting times of sulfate resistance cement with different replacement ratios of RSA.

Conclusions

On the basis of the results observed in this study, the following conclusions can be drawn:

- 1) Rice straw ash is pozzolanic and satisfies the requirements of ASTM class N, F and C. Therefore, it can be used as a cement replacement material.
- 2) For the three types of cements used in this test, the experimental results on cement paste showed an increase in the water demand in the standard consistency test as the ratio of RSA replacement increased.
- 3) Both initial and final setting times were found to increase with increasing the percentage of RSA replacement.

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قدّم للنشر في ١٧/٠٤/٢٠٠٤م؛ وقبل للنشر في ١٥/٠٧/٢٠٠٦م

ملخص البحث. يتناول هذا البحث دراسة تأثير استبدال جزء من محتوى الأسمنت برماد قش الأرز على خواص العجينة الأسمنتية. وقد عملت الدراسة باستخدام ثلاثة أنواع من الأسمنت هي الأسمنت البورتولاندي العادي، وأسمنت عالي خبث الحديد، وأسمنت مقاوم للكبريتات. ويتطرق البحث إلى طريقة الحرق والطحن والخواص الطبيعية والكيميائية للرماد المستخدم والفاعلية البوزولانية، هذا بالإضافة إلى تأثير استبدال الأسمنت بالرماد على نسبة الماء/الأسمنت للعجينة القياسية وزمن الشك الابتدائي والنهائي. وأظهرت النتائج زيادة زمن الشك الابتدائي والنهائي بزيادة نسبة الإحلال لجميع أنواع الأسمنت المستخدمة.

