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Studies on the Effect of Rice Straw Ash as Admixture of Ordinary Portland Cement Mortar

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ABSTRACT

Compressive strength tests were carried out on six mortar cubes with cement replaced by rice straw ash (RSA) at five levels (0, 2, 4, 6, 8 and 10%) by weight of cement. The result of the compressive strengths test at 2% replacement with RSA at the curing age of 2, 7 and 28 days was found to be 15.77, 34.73, and 48.53 N/mm^2 and increased with age of curing but decreased at 10% replacement for 7days (18.06 N/mm^2) and 28days (27.23 N/mm^2) with increase in RSA content for all mixes. The chemical analysis of RSA revealed high amount of silica (61.60%), calcium oxide (15.45%), alumina (4.67%) and iron oxide (3.08%) responsible for strength, soundness and setting of the concrete. It also contained high amount of magnesia (1.89%) which is responsible for the unsoundness. This result, therefore, indicated that RSA can be used as cement substitute at 2% and 4% and 6% replacement and 2 and 28 day curing age.

Key words: Rice straw, setting time, soundness and admixture.

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INTRODUCTION

Cement is a mixture of argillaceous and calcareous materials mixed with gypsum, sintered and pulverized into fine particles [1]. It has a cohesive and adhesive properties when mixed with water, which makes it capable of bonding material fragment into a compact whole [2]..

Cements are classified calcium silicate and calcium aluminate. Calcium silicate is further classified into Portland and slag, while calcium aluminate is classified into high aluminate and pozzolona cement [3]].

For the improvement of the properties of cement mortar and cement concrete, admixtures are added with the cement mix and these are either naturally occurring compounds or chemicals produced in industrial process. Most of the admixtures are pozzolans. Pozzolan is a powdered material, which when added to the cement in the mix reacts with lime, released by the hydration of the cement, to create compounds which improve the strength or other properties of the concrete or mortar [4].

Many countries have the problem of shortage of conventional cementing materials. Recently there are considerable efforts worldwide of utilizing indigenous and waste materials in concrete. One of such materials is the rice stalk which under controlled burning, and if sufficiently ground, the ash that is produced can be used as a cement replacement material in concrete [5].

Rice stalk and husk are composed of both organic and inorganic matter. Organic matter consists of cellulose, lignin, hemi cellulose, some proteins and vitamins while the major component of inorganic minerals is silica. The actual composition of rice stalk and husk varies with the type of paddy, inclusion of brand and broken rice in the husk, geographical factors, crop season, samples preparation and relative humidity [6], this is a bio waste from the rice plant. The silica is absorbed from the ground and gathered in the straw where it makes a structure and is filled with cellulose. When cellulose is burned, only silica is left which is grinded to fine powder which is used as pozzolana [7].

Rice straw over the years has been considered a waste product of rice cultivation, for this reason it is mostly left unattended and constitutes a source of significant environmental concern. The use of rice stalk ash as additive in cement will considerably reduce; if not entirely resolved the environmental concern associated with the rice straw.

The aim of this research project is to study the effect of rice straw ash (RSA) as admixture of Ordinary Portland Cement (OPC) mortar.

2.0 MATERIALS AND METHOD

2.1 MATERIALS

The materials used in this research are rice stalk ash (RSA) and Ordinary Portland Cement (OPC) (42.5)

2.2 SAMPLING

Locally available rice straw used for this work was obtained from Kwalkwalawa, Wamakko Local Government, Sokoto, North-western Nigeria. The sample was allowed to dry under the sun for two weeks until it is moisture free, it was then pounded and sieved to obtain finely powdered particles. The dried straw was ashed in a carbolite furnace for two hours at 1100^0C to obtain a finely divided ash, which was kept aside for analysis [8].

Cement is partially replaced by RSA at a different percentage of 0, 2, 6, and 10% by weight of cementitious materials. The rice straw ash and cement were thoroughly mixed so as to obtain a uniform mixture Fine aggregates were added together and a definite proportions of cement-RSA were obtained, which were used for the formation mortar cubes.

METHOD

PHYSICAL TESTS

Various physical tests were carried out; including compressive strength test, setting time, and soundness expansion using standard procedures [10].

Compressive strength Test

The compressive strength test of the block samples was determined in accordance with the standard procedure for precast concrete blocks. The weight of the block samples were always taken before the compressive strength test. The sample blocks were each crushed at 2, 7 and 28 days after casting at different replacement levels using the compressive testing machine as explained in the CCNN manual [11]

Chemical Tests

The chemical analyses of the rice straw ash (RSA) was carried out for the determination of CaO, MgO, Al_2O_3, Fe_2O_3, K_2O, Na_2O, SO_3, Free Lime and Loss of Ignition and Insoluble residue using the CCNN procedure [11].

RESULTS AND DISCUSSION

The results of the physical and the chemical analysis of the rice straw ash is presented in Table 1 -4 below

Table 1: The Compressive Strength Test Parameters

S/N	RSA (%)	Amount of cement (g)	Amount of RSA (g)	2 Days strength (N/mm^2)	7 Days strength (N/mm^2)	28 Days strength (N/mm^2)
1	0	450	0	15.77	34.73	48.53
2	2	441	9	16.97	31.03	43.82
3	4	432	18	18.93	29.47	41.83
4	6	423	27	19.20	27.64	39.33
5	8	414	36	20.04	26.78	38.15
6	10	405	45	22.72	18.06	27.23

RSA= rice stalk ash

The strength of hardened cement is its most important property. The rate of hardening of cement depends on the chemical and physical properties of the cement, the curing conditions and the water/cement ratio. The most important property of a Portland cement is its strength development characteristics. This property is dependent on several factors including mix proportion, temperature, curing conditions, age, size and shape of test specimens [12]. The results of the compressive strength tests are showed in Table 1. The compressive strength tests carried out on the six mortar cubes showed that the strength of the blocks for all the mix at 2% replacement of RSA were 16.97, 31.03 and 43.82 N/mm^2 , which showed increase with increase in the age of curing and increase in the concentration of the RSA.

However, a decline in the compressive strength was observed as the amount of RSA increases at 10% replacement there is age at curing and decreases at 10% replacement were 22.72, 18.06 and 27.23 N/mm^2 as the RSA content increases. It is believed that the compressive strength of concrete is influenced by the curing conditions, mix proportions, mode of testing, age at testing and temperature [2].

Table 2: initial and final setting times of cement paste

Cement (g)	RSA (g)	Initial Setting Time (mins)	Final Setting Time (mins)
400	0	148	211
392	8	151	217
384	16	165	235
376	24	196	256
368	32	198	258
360	40	222	284

RSA= Rice Stalk ash

Setting refers to stiffening of a cement paste, which changes in character from a plastic of flowing mass into a rigid material [13]. The setting time is dependent on several factors including temperature, water-to-cement ratio and characteristics of the cement. A generally accepted standard method for assessing the setting time of cement is the vicat needle method [11]

In Table 2, the initial and final setting times of the entire cubes were considered using cement at different percentages of RSA. The initial and final setting times increases with increase in RSA content. The reaction between cement and water is exothermic. The liberation of heat and evaporation of moisture causes the stiffening of the paste and slower heat induced evaporation of water from the cement paste due to its lower cement content [14], and therefore an accelerated increase in the initial setting time of the mixture was observed. Thus, an increase in the setting time was noticeable from 151 minutes (at 2% RSA) to 165 minutes (at 4% RSA) and the setting time continued to increase until the last proportion as the percentages of rice stalk ash increased to 10% (222 minutes). Similarly, the final setting time also increases from 217 (at 2% RSA) to 235 (at 4% RSA) as the percentages of RSA increases thereby retarding the hydration process.

The main and the most important mineral content of Portland cement are the calcium silicates, C_3S and C_2S. These silicates hydrate as follows:

$$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3CH$$

$$2C_2S + 4H \longrightarrow C_3S_2H_3 + CH$$

$$2C_3S + 2C_2S + 10H \longrightarrow 2C_3S_2H_3 + 4CH$$

In the presence of RSA that contains 61.6% SiO_2, the silica will combine with the released $Ca(OH)_2$

$$2SiO_2 + 3CH \longrightarrow C_3S_2H_3$$

This means that the $Ca(OH)_2$ is being depleted from the system. It is very essential that the hydrated cement should have a pH of 13±1 otherwise the hydrated silicates and aluminates will be destabilized thereby causing the weakening of the cement structure which explains the reduction of the compressive strength with the increase in concentration of RSA. When water is added to cement, the hydration starts typically. In the presence of RSA there is competition for the added water between the SiO_2 and other cement material. Since the SiO_2 is finer it absorbs the water first before the commencement of the hydration of the other cement materials. This, therefore, explains the retardation effect of the RSA on the setting time [8].

Table 3: Initial and final expansion test parameters

RSA (%)	**Cement (g)**	**RSA (g)**	**Initial expansion (mm)**	**Final expansion (mm)**
0	200	0	9	10
2	196	4	10	11
4	192	8	8	9
6	188	12	10	11
8	184	16	16	17
10	180	20	15	16

RSA= rice stalk ash

Soundness of cement implies freedom from excessive expansion during hydration of pastes, mortar or concrete. Excessive expansion can cause cracks and consequently reduce strength and durability [12]. The unsoundness of cement is not apparent until after some months or years, therefore soundness test is required to detect the possible excessive expansion that can cause cracks and consequently reduce strength and durability of cement [15]. Table 3.3 showed the initial and final expansion after addition of different percentages of rice straw ash. in accordance with the British standard institution [13], which stipulated that the standard the expansion of cement should not be more than 10mm .

Table 4: Chemical Analysis of RSA and Cement

Constituent	RSA (%)	Cement
SiO_2	61.5	19.22
CaO	15.45	60.04
Al_2O_3	4.67	5.39
Fe_2O_3	3.08	3.51
MgO	1.89	2.26
K_2O	1.07	0.21
SO_3	2.18	1.67
LOI	9.79	5.69
Free lime	0.30	1.50

The result of the chemical analyses of the rice straw ash (RSA) for the determination of CaO, MgO, Al_2O_3, Fe_2O_3, K_2O, Na_2O, SO_3, Free Lime and Loss of Ignition and Insoluble residue was presented in Table 4.

The silica (SiO_2) content is one of the most important constituent of cement; it or imparts strength to the cement due to the formation of dicalcium and tricalcium silicates. If silica is present in excess quantity, the strength of cement increases while the is prolonged. The silica content was found to be 61.60%, which indicate a higher silica content in RSA compared to cement (19.22%). The workability of cement mortar (mixture of cement, sand and water) decreases by increasing the amount of silica content, as long as the inserted silicon dioxide can be interactive with calcium hydroxide resulting from the hydration process of cement with water [16]. However, the compressive and flexural strength of the cement is proportional to the amount of silica that is increase in amount of silica lead to increase in strength of cement mortar with age at curing [17].

Alumina imparts quick setting property on the cement and lowers the clinkering temperature. However excess alumina weakens the cement. Alumina content on the other hand was higher in cement (5.39%) than in the RSA (4.67%). Higher alumina in cement in form of C_3A will led to widespread construction problems, due to its faster hardening properties [18]. However the alumina content in the RSA falls within the range (2.4-6.3%) which was in accordance with the Nigerian Industrial Standard and ASTM specifications [19].

Calcium oxide is responsible for the formation of C_3S (3CaO.SiO2) and C_2S (2CaO.SiO2) in cement and all other clinker minerals, responsible for the strength in the late or early part of the concrete [20]. The percentage calcium oxide in RSA (53.45%) was lower than that in cement (60.04%). Calcium oxides dominate all other oxides because of its the abundance in an ordinary portland cement and is the most important component in cement [21].

Magnesia, if present in small amount, imparts hardness and color to cement. A high content of magnesia makes the cement unsound. Table 3.4 showed low magnesia content in the RSA (1.89%) was lower than that of cement (2.26%). High magnesia content is not required in cement because it reduces the strength of cement [20].Low iron content obtained in RSA (3.08%) was lower than that of cement which was (3.51%). The results obtained in both RSA and cement is in agreement with the BSI standard range off 0-6.1%. [13].

Potassium oxide (K_2O) are the main alkalis associated with cement. There was high percentage of potassium oxide in the RSA (1.07%) than in cement (0.21%). Higher alkali in cement is undesirable as it causes damage to kiln and attack reinforced concrete [20].

High sulphite (SO_3) obtained in RSA (2.18%) was lower than that of cement which was (1.67%). High sulphate content in cement could be from gypsum which is one of the raw materials in cement and is used control the early stiffening of cement but it also has a remarked influence on strength development [22].

Free lime content is the excess uncombined lime in cement. Higher amount of free lime is undesirable as it is the main cause of unsoundness in hydrated cement, thus, responsible for cracking of concrete; a value of 1.0 or above indicate that belite will be present at equilibrium at a clinkering temperature and thus liable to persist in the products while value less than 1.0

has an effect which is easier burnability, low cement strength and low heat consumption [19]. Free lime content was found to be (2.01%) in cement and was absent in the RSA.

Conclusion

Based on the experimental results of this study, the following conclusions were drawn.

i. The chemical analysis done on rice stalk ash indicated high amount of silica (61.60%) and high amount of calcium oxide (53.45%) which are very good for workability.
ii. The initial and the final setting time increased with increased percentage of RSA replacement.
iii. Rice stalk ash which contains high amount of silica, and calcium oxide as in cement, and are important as a minor cement substitute, if there is addition of other raw materials containing iron and alumina.
iv. The use of RSA significantly improves the mortar strength and can be use as pozzolanic material in cement mortar.

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