# POZZOLANICITY ASSESSMENT OF SUDANESE GROUNDNUT SHELL ASH

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**مُسْتَخْلَص**

تهدف هذه الورقة الي تقييم الخواص البوزولانية لرماد قشرة الفول السوداني , وذلك بدراسة خواصه الكيميائية , الفيزيائية, و المعدنية ومدي تفاعله مع الجير والاسمنت بالاضافة لمعرفة مقاومة الانضغاط للمونة الاسمنتية المحتوية علي نسب مختلفة من هذا الرماد لفترات انضاج 7, 28, و91 يوم .كما تم استخدام تقنية اشعة الحيود السينية لتحديد درجة الحرارة المثلي للحرق.
اظهرت نتائج التحليل الكيميائي ان مجموع اكاسيد السليكا والالمونيا والحديد 76.3 % مقابل 70% ، كحد ادني تشترطها المواصفات. كما اكدت نتائج الاختبارات المعملية بان درجة الفاعلية البوزولانية مع الجير والاسمنت هي 3.7 ميقاباسكال و75% علي التوالي بينما تشترط المواصفات العالمية 4 ميقاباسكال و75% علي التوالي كحد ادني . كما اظهرت نتائج الاختبارات الفيزيائية بان درجة الحرارة المثلي للحرق للحصول علي سليكا نشطة هي 650 درجة مئوية لمدة ساعتين وان نسبة الاحلال للاسمنت يجب ان لا تزيد عن 15% كما تشير نتائج الاختبارات الميكانيكية . وعلية , فان رماد قشرة الفول السوداني يمتلك درجة فاعلية بوزولانية اقل رغم مطابقته كيميائيا وفيزيائيا لمواصفات المواد الوزولانية .

## ABSTRACT

This paper focused on the evaluation of the Pozzolanic characteristics of the Sudanese Groundnut Shell Ash (GSA). The study investigated the chemical, physical, and mineralogical characteristics of the GSA and its reactivity toward lime and cement, in addition, the compressive strengths of blended mortar containing GSA in percentage addition were tested at 7, 28, and 91 days. XRD technique was used to achieve an optimal calcining temperature for the shell. The results of the chemical analysis showed that the sum of Silica, Alumina, and Iron oxide was 83.75%. The strength reactivity with lime was 3.7MPa, against 4 MPa required by ASTM C-618 and IS: 1344. The strength activity index was found to be 73% against 75% and 80% required by ASTM C-618 and IS: 1344, respectively. These results indicated that the GSA possesses low Pozzolanic activity and the optimum pyroprocessing temperature is 650 $^0$C with heating time 2 hours , and the recommended substitution level is 15%.

***Keywords***: - *Blended cements, Groundnut Shell Ash, pozzolanicity, strength activity index,*

## 1. Introduction

Recently there has been a growing trend towards the use of pozzolanic materials, whether natural, waste or by-products, in the production of blended cements (BC) because of ecological, economical, and technical reasons. One of the major options adopted for economic reason is to utilize local resources that would provide cost effectiveness and also a potential utilization of hazardous waste which would otherwise causes environmental pollution.

Pozzolana is defined as an essentially silicious material which while in itself possessing little or no cementitious properties will, in finely divided form and in the presence of water, react with calcium hydroxide at ambient temperature to form compounds possessing cementitious properties, [1] and [2]. The pozzolanas are classified into Natural and Artificial: - The Natural Pozzolans (NP) are products of volcanogenic activities such as volcanic ash, volcanic tuff, pumice, shells, and diatomaceous. Natural pozzolanas requiring no energy inputs, apart from transportation, prior to utilization [2] and [3], while the Artificial Pozzolanas are residues of waste industrial and agricultural products such as fly ash and rice husk.

Blended cements (Portland Pozzolona Cement) are produced by mixing Ordinary Portland Cement (OPC) with a low-cost cementitious material, notably any of the popularly adopted pozzolanas and lime. The principle behind blended cements is to obtain a binder which is nearly equal in strength to Portland cement but, at the same time, is cheap. Examples of blended cements are Portland-pozzolana and lime-pozzolana cements [4]. Blended cements (Portland Pozzolona Cement) can generally be used wherever Ordinary Portland Cement is usable under normal conditions. It is particularly useful in marine and hydraulic structures and large mass concrete structures.

## 2. Background

Artificial pozzolanas can be obtained from agricultural wastes such as sunflower, bamboo leave, bagasse, rice straw, wheat, and groundnut shell; those are widely available in Sudan. The problem to use which one is associated with the percent of silica and ash content in each waste. Sudan is one of the largest producers and exporters of groundnuts worldwide, and is considered as the fifth country in the world producing peanut. The utilization of groundnut shell will promote waste management at little cost, reduce pollution by these wastes and increase the economic base of farmers when the waste is sold thereby encouraging more production.

## 3. Materials and Methods

### 3.1 Materials

The materials used in the study are sand, cement, groundnut shell ash, marble, and water.

#### 3.1.1 Cement and Sand

Ordinary Portland cement (OPC) procured from Atbara Cement Company was used. River sand procured from Wadi Nyala, was used in present study. The sand was washed, dried, and sieved into different fractions, it was standardized to three grades - fine (90 μm to 500 μm), medium (500 μm- 1mm) and coarse (smaller than 2mm- and greater than 1 mm) fractions [5].

#### 3.1.2 Sudanese Groundnut Shell (GSA)

The Groundnut shell was obtained from the oil mill in Nyala city after threshing/separating the shell from the nut using the threshing machine. In order to obtain optimal burning parameters, the ash was subjected to thermal treatment at different heating temperatures 450 $^0$C, 550 $^o$C, and 650 $^0$C for 2 hours using XRD techniques. Then the ash burned at temperature 650 $^O$C for 2 hours was used. The burnt ash was passed through an IS sieve (63 microns). The portion passing through the sieve 0.063 mm was the parts that have been utilized in this study.

#### 3.1. 3 Lime

Lime used in this study is hydrated lime (CH). The raw material was burned at 975 $^0$C for 3 hours, the produced quick lime (CaO) was slacked and ground to pass 90-micron sieve.

#### 3.1.4 Water

Drinking water was used for the production and the curing of the mortar cubes.

### 3.2 Methods

#### 3.2.1 Testing of GSA reactivity

In this investigation, the pozzolanic reactivity of GSA with lime and Portland cement was examined in the term of compressive strength following the procedures described in IS:1727 (1967) [6]. For determining the reactivity of the pozzolanic material with hydrated lime, the standard mortar cubes of 50 mm was prepared, cured, and tested accordingly. The mix of CH: GSA: standard sand in proportion (1: 2M: 9) by weight was used, where M: is the ratio of Specific gravity of pozzolana to Specific gravity of lime.

For the pozzolanic activity with OPC, A control mix was prepared in 50 mm cubes moulds. The control mix was produced using OPC only as binder, while in other mix, GSA : OPC: standard sand in proportion( 1: 2N: 9) by weight were casted, cured, and tested at 7, and 28days, where N is the ratio of Specific gravity of pozzolana to Specific gravity of cement. The details of mix proportions are shown in Table 1.

#### 3.2.2 Preparation of blended cement mortar

A control mix was prepared in 70.7 mm cube moulds (area of face 50 cm$^2$) composed of one part of cement, three parts of standard sand by mass, and (P/4 + 3.0) percent (of combined mass of cement and sand) water, (where P is the standard consistency), and prepared, stored and tested in the manner described in IS 4031 (Part 6): 1988 [7]

The ground GSA was used to replace 10%, 20%, and 30% of the mass of OPC in the control mix. Compressive strength of all the mixes was measured at 7, 28, and 91days. The details of mix proportions are shown in Table 2.

**Table 1: Mix proportions for pozzolanic reactivity with CH and OPC following IS: 1727 (1967) [6]**

| Control Mix | | Pozzolana-cement mix | | Lime – pozzolana mix | |
|---|---|---|---|---|---|
| Component | Amount (g) | Component | Amount (g) | Component | Amount (g) |
| OPC | 450 | OPC | 400 | Lime – $Ca(OH)_2$ | 75 |
| GSA | 0 | GSA | 88 | GSA | 145.5 |
| Standard sand | 1350 | Standard sand | 1350 | Standard sand | 1350 |
| flow | 105 + 5 | flow | 105 + 5 | flow | 70 + 5 |

**Table 2: Mix proportions of blended mortar**

| **Mortar Code** | Blending ratios (by weight %) | |
|---|---|---|
| | CEMENT | GSA |
| **CTR** | 100 | 0 |
| **GSA3 10** | 90 | 10 |
| **GSA3 20** | 80 | 20 |
| **GSA3 30** | 70 | 30 |

## 4. Results and Discussion

### 4.1 Chemical Properties

The chemical analysis results of Sudanese groundnut shell, OPC, sand, and CH are presented in Table 3 and table 4. The ash SGS1 was first analyzed as a raw (before burning) using XRF technique, and then chemically analyzed after burning the ash (GSA2 and GSA3) using XRF and AAS techniques respectively. The results showed that the principal oxides of Silicon ($SiO_2$), aluminum ($Al_2O_3$) and Iron ($Fe_2O_3$) are substantially present in the samples investigated with the sum oxides of 58.66% with high $K_2O$ content 20.21% and CaO 9.78%. After burning the results have shown that the principal oxides present are ($SiO_2$), ($AI_2O_3$) and ($Fe_2O_3$) are substantially present in the samples investigated with the sum oxides of 76.33% and 90.11%, for GSA2 and GSA3 respectively. It is evidence that the percentages of $K_2O$, $Fe_2O_3$, and CaO contents have been reduced by 62%, 85%, and 76% for GSA2 and 90%, 86%, and 80% for GSA3 respectively. The analyses also showed the increase in $SiO_2$ percentages after burning. It is noteworthy that the raw shell is amorphous by nature as deduced from the XRD analysis in figure 1. It has high content of alkali in the form of $K_2O$, while the burning temperature decrease the alkali and increase the crystalline state of the silicon dioxide ($SiO_2$).

### 4.2 XRD Analysis Results of (GSA)

To obtain optimal pyroprocessing parameters, the ash was subjected to thermal treatment at different heating temperatures 450 $^0$C , 550 $^o$C, and 650 $^0$C for 2 hours , the XRD patterns of starting and burned ash were compared in Figure 2. It is evident from figure 1, that the raw ash is amorphous by the nature. Major mineral constituents of the burned ash are quartz and albite. The results of combined XRD measurements of the ashes selected on the base of the burning temperature, are given in Figure 2. After thermal treatment of ashes at temperature 650 °C and heating time 120 min, the most characteristic peaks for Albite disappear, while peaks assigned to quartz ($2\theta$ 21.22 and 27.45°) remains unchanged. These results indicated that 650 $^0$C has produced well amorphous state of ash to be burned.

**Table 3: Chemical composition of Sudanese groundnut shell ash**

| Material | Chemical Composition (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $Na_2O$ | $K_2O$ | LOI |
| **SGS1*** | 40.84 | 7.42 | 10.4 | 9.788 | 2.433 | 3.123 | 0.637 | 20.217 | - |
| **SGSA2** | 69.64 | 5.123 | 1.57 | 2.29 | 1.62 | - | 3.6 | 7.7 | - |
| **SGSA3** | 78.92 | 9.71 | 1.48 | 2.03 | 0.6 | | 0.97 | 1.93 | 3.07 |

***Raw shell**

**Table 4: Chemical properties of Atbara OPC, Marble, and wadi Nyala sand**

| Material | Chemical Composition (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $Na_2O$ | $K_2O$ | LOI |
| **OPC** | 20.82 | 4.41 | 2.63 | 63.38 | 0.07 | 2.83 | 1.26 | 1.2 | 2.4 |
| **SAND** | 82.5 | 0.72 | 0.26 | 8.75 | 0.76 | | 0.1 | 0.06 | 6.4 |
| **MARBLE** | 0.07 | 0.023 | 0.022 | 45.45 | 1.68 | | 0.69 | 0.014 | 43.8 |

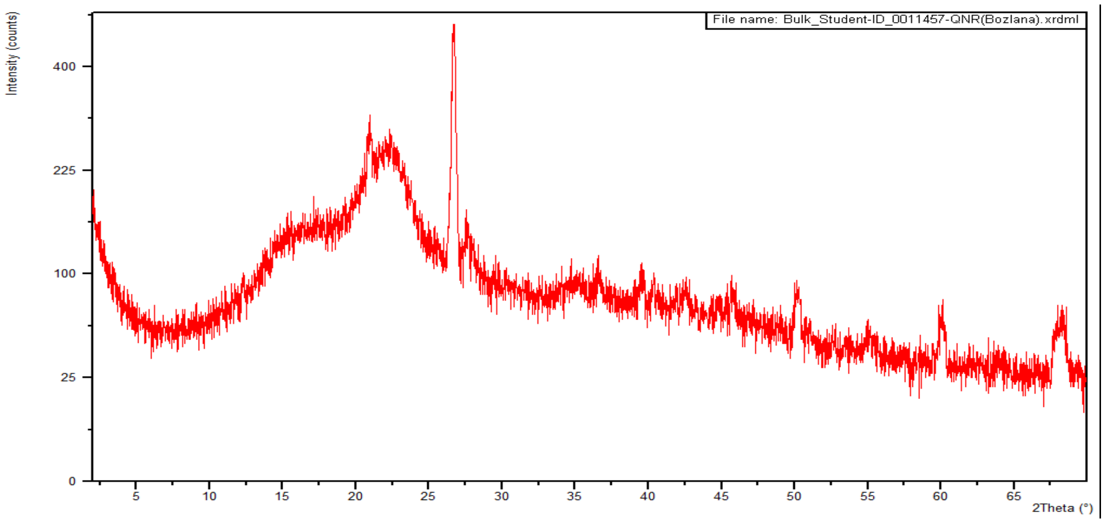


**Figure 1: XRD Pattern of Raw GSA**

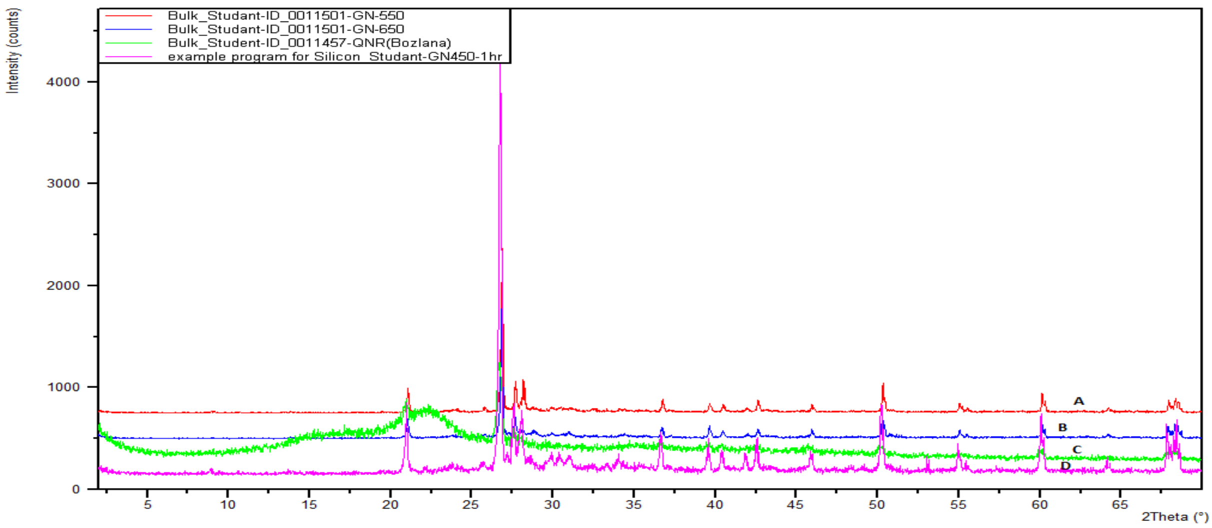


**Figure 2: Combined XRD pattern of GSA at, A) 550 $^{o}$C, B) 650 $^{0}$C, C) raw ash, and D) 450 $^{0}$C**

**4.3 Physical properties of blended mortars**

Standard consistency, initial and final setting times were determined for each blend in Table 5.

**4.3.1 Water Consistencies and Setting Time Limits**

The results presented in Table 7, indicated that addition of GSA retarded the setting; however this retardation was negligible and was within limits as specified in IS: 4031: Part 4: (1988) [8]. It could have been caused due to the adsorption of water at the surface of GSA with higher surface area. The higher the proportion of GSA, the higher was the adsorption of water and hence higher amount of water retarded the setting time. Most pozzolanas tend to increase the water requirement in the normal consistency test as a result of their micro-porous character and high surface area [9].

**4.4 Mechanical properties results**

**4.4.1 Reactivity Test Results**

The pozzolanic reactivity with lime and OPC is measured through the compressive strength of standard mortar tests according to IS: 1727-(1967) [7]. The result of the GSA reactivity with lime is 3.7 MPa, at age of 8 days, IS-1344 (1981) [10] required a minimum of 4.0 MPa., while the compressive strength with OPC were, 23 MPa , at 7 days, 31 MPa. at 28 day respectively, against 37.67, and 43.34 MPa, for the reference mortar at 7, and 28 days respectively. The strength activity indices of GSA at 28 days are therefore 72%. IS-1344 (1981) [10] required a minimum of 80% of the strength of corresponding reference mortar. It can be seen from the reactivity results, the low pozzolanicity of GSA.

**4.4.2 Compressive strength results of GSA /OPC Blends**

The results of the compressive strength tests of GSA (Table 6) indicated that 10, 20, and 30% addition of the GSA provided 37, 30, and 21 MPa respectively compared with 41.33 MPa of the control cubes compressive strengths tested at 28 days curing. The low reactivity of GSA, indicated that the GSA can be considered as a low reactive pozzolana, Based on a general analysis of the results as well as the logical comparison to the acceptable standard, a percentage replacement of 15% is suggested for sustainable construction, especially in mass concrete constructions, plaster, and concrete blocks.

**Table 5: Physical properties of blended mixtures**

| Mortar Code | Consistency % | Initial setting time (min) | Final setting time (Min) |
|---|---|---|---|
| **MCTR** | 32 | 75 | 150 |
| **GSA 10** | 33 | 150 | 210 |
| **GSA 20** | 34.5 | 165 | 220 |
| **GSA 30** | 36 | 170 | 225 |

**Table 6: Compressive Strength of GSA blends at 7, 28, and 91 days (MPa)**

| Mortar Code | Age of specimen (day) | | |
|---|---|---|---|
| | 7 | 28 | 91 |
| **CTR** | .36.67 | 41.33 | 51 |
| **GSA 10** | 31 | 37 | 46 |
| **GSA 20** | 25 | 30 | 38 |
| **GSA 30** | 20 | 21 | 34. |
| **IS: 1489-1981 [11]** | 22 | 33 | |

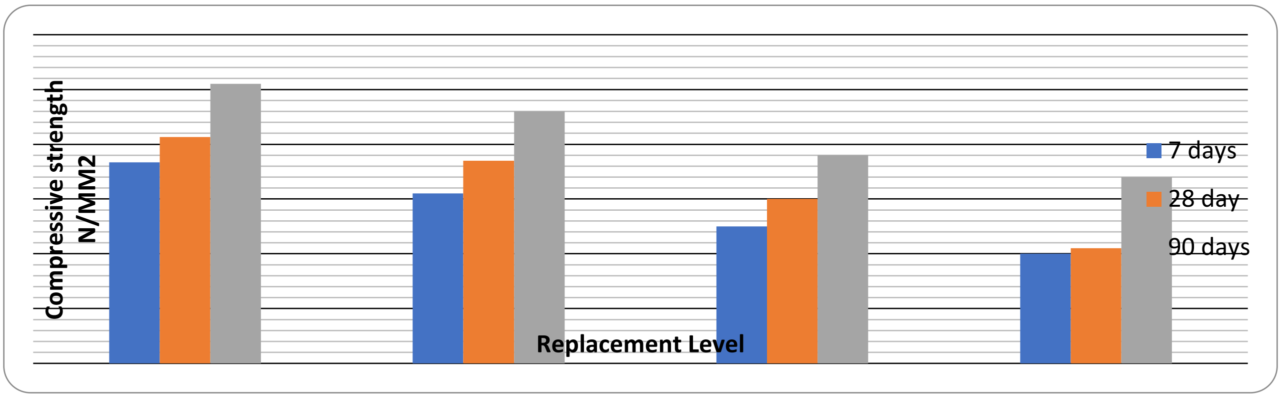


**Figure 3: Compressive Strength of GSA Blended mortar**

### 4.4.3. Summary of findings

1. The oxides of $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ were 69.64, 5.123, and 1.57 % respectively with a sum average of 76.33%.
2. The presence of Alkalis - $Na_2O$ (3.6%) and $K_2O$ (7.7%) was 11.3 %.
3. The strength reactivity of GSA with lime was 3.7 MPa, IS:1344 (1981)[11] specifies a minimum of 4.0 MPa
4. The strength of GSA with OPC at 28 day was 31 MPa, against 43.34 MPa for control mix, with a strength activity index of 72%. IS:1344 (1981)[11] specifies a minimum of 80% of the reference for pozzolana to be used for manufacture of Portland pozzolana cement
5. The compressive strengths at 28 day of mortar containing the GSA materials in 10, 20, and 30 additions were 37, 30, and 21 MPa, respectively against 41.33 MPa of control cubes at 28 days crushing.
6. These findings are congruent with many researches on the GSA, [12], [13], [14], [15], [16]. [17].

## 5. Conclusions

Based on a general analysis of the results as well as the logical comparison to the acceptable standard, It can be seen from the reactivity results that GSA at 20% replacement level of the OPC possesses low pozzolanicity than standard requirements while the 10% fulfilled the requirements. Hence, it may be suggested that the percentage replacement of 15% is suitable for sustainable construction, especially in mass concrete constructions, plaster, and concrete blocks.

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