Effect of amorphous silica ash used as a partial replacement for cement on the compressive and flexural strengths cement mortar.

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Abstract. This research is aimed at investigating the effect of using amorphous silica ash (ASA) obtained from rice husk as a partial replacement of ordinary Portland cement (OPC) on the compressive and flexural strength of mortar. ASA was used in partial replacement of ordinary Portland cement in the following percentages: 2.5 percent, 5 percent, 7.5 percent and 10 percent. These partial replacements were used to produce Cement-ASA mortar. ASA was found to contain all major chemical compounds found in cement with the exception of alumina, which are SiO\textsubscript{2} (91.5\%), CaO (2.84\%), Fe\textsubscript{2}O\textsubscript{3} (1.96\%), and loss on ignition (LOI) was found to be 9.18\%. It also contains other minor oxides found in cement. The test on hardened mortar were destructive in nature which include flexural strength test on prismatic beam (40mm x 40mm x 160mm) and compressive strength test on the cube size (40mm x 40mm, by using the auxiliary steel plates) at 2, 7, 14 and 28 days curing. The Cement-ASA mortar flexural and compressive strengths were found to be increasing with curing time and decreases with cement replacement by ASA. It was observed that 5 percent replacement of cement with ASA attained the highest strength for all the curing ages and all the percentage replacements attained the targeted compressive strength of 6N/mm\textsuperscript{2} for 28 days for the cement mortar.

1. Introduction

The use of supplementary cementitious materials in cement-based materials has grown in recent years. When a suitable amount is used as a partial replacement for cement, the performance of cement-based materials can be improved through changes in the fresh and hardened states, the modifications in physical, mechanical and chemical properties, as well as micro structural properties and hydration. Dry rice husk ash (RHA) obtained from different locations contains more than 70\% silica [1]. The total worldwide production of rice stands at over 580 million tons per year and 20\% of the husk is rice husk ash (RHA) [2]. This amounts to 29 million tons of RHA per year worldwide. The disposal of this husk constituted a challenge to scientists for a long time. Burning of the husk constitute an environmental problem, necessitating the need to find use for this waste material as a secondary resource material. Rice husk is burnt in controlled temperatures which are between 500°C-700°C, the ash generated is amorphous in nature. The highest amount of amorphous silica occurs in samples burnt in the range of 500°C - 700°C [3]. In another research it was reported that a highly reactive ash can be produced by maintaining the combustion temperature at about 500°C [4]. It was also stated that ash prepared at a temperature of about 500°C to 600°C consist of amorphous silica [5]. In addition, the amorphous state can be achieved under oxidizing conditions at relatively prolonged period or up to 680°C provided that the high temperature exposure was less than one minute.
2. Literature Review

2.1 Cement
Cement is a material with adhesive and cohesive properties which makes it capable of bonding mineral substances into a compact whole. Adhesiveness are those properties which enable the cement to bond to other materials (e.g. bonding to aggregate), whereas cohesiveness allows it to become homogeneous and strong within itself [6]. It is necessary to understand the chemistry of cement before understanding the role of complementary cementitious materials. To be used in construction cement must have certain qualities in order to play its part effectively in structures. When these properties lie within a certain specified range of standard values, the engineer is confident that in most of the cases the cement performance will be satisfactory [7]. There are several brands of OPC available in the market, but their

Table 1. Composition of major constituents of some Nigerian and imported ordinary portland cement.

| Test Samples | CaO (%) | SiO₂ (%) | Al₂O₃ (%) | Fe₂O₃ (%) |
|--------------|---------|----------|-----------|-----------|
| Ashaka       | 60.00±0.58 | 20.65±1.33 | 3.83±1.17 | 2.20±0.12 |
| Elephant     | 58.83±2.09 | 17.33±1.76 | 5.07±1.48 | 2.50±0.29 |
| Burham       | 56.17±1.01 | 19.07±0.88 | 5.30±0.45 | 3.15±0.60 |
| Dangote      | 51.67±3.84 | 18.02±0.66 | 1.25±0.25 | 10.5±0.76 |

2.2 Cement Replacement Materials
Cement replacement materials are those which are used as substitute for some part of the Portland cement in a concrete; partial cement replacement is therefore a more accurate but less convenient name [8]. There are also a number of other names for this group of materials, including supplementary cementitious materials, cement extenders, mineral admixtures, mineral additives, latent hydraulic materials or, simply cementitious materials. [9] Stated that naming the materials as supplementary cementitious materials is not perfect, but it does give a better indication of why the various materials are added to concrete mixtures.

2.3 Pozzolanic Materials
Pozzolana are materials containing reactive silica and/or alumina which on their own have little or no binding property but when mixed with lime in the presence of water, will set and harden like cement. They are an important ingredient in the production of alternative cementing materials to Portland cement [7]. Pozzolana is defined as siliceous or siliceous and aluminous materials, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties [10].

2.4 OPC-Pozzolana
In OPC-based concretes, pozzolanas are used to replace up to 30% of OPC for use in structural applications and up to 50% for non-structural purposes. As OPC is an expensive and sometimes scarce commodity, this can represent a significant cost saving [11]. In addition Portland-pozzolana blended cement has a number of significant technical advantages over plain OPC. These according to [11] include:
- Improved workability
- Improved water retention/reduced bleeding
- Improved sulphate resistance
- Improved resistance to alkali aggregate reaction
- Lower heat of hydration and
- Enhanced long-term strength

The only disadvantage of these blended cements is that their early strength gain is slightly slower. This might mean that the dismantling of formwork on structural concrete may need to be delayed by a day or so, but this disadvantage is far outweighed by the advantages [11].

2.5 Rice Husk Ash
Rice Husk Ash (RHA) is produced from rice husks, which are the shells produced during the dehusking operation of rice. Rice husks are approximately 50% cellulose, 30% lignin and 20% silica. To reduce the amount of waste materials, rice husks are incinerated by controlled combustion to remove the lignin and cellulose, leaving behind an ash composed mostly of silica [12]. [13] has shown that RHA, produced by controlled incineration under oxidizing conditions at relatively low combustion temperatures and short holding time, is highly pozzolanic with high surface area (50 to 100 m$^2$/g by nitrogen adsorption), and consists mainly of amorphous silica. By varying the temperature, RHA can be produced with a range of colors from nearly white to black. The chemical analysis of fully burnt RHA shows that it ranges between 90 and 96%. It is a highly active pozzolana, suitable for making high-quality cement and concrete products.

3. Materials
The materials used for this work were first tested according to the relevant specifications to determine their suitability before use for pastes and mortars. The materials used in this research work were Dangote brand of Ordinary Portland Cement, river sand (fine aggregate), rice husk ash (RHA) and water.

3.1 Cement
3.1.1 Dangote brand of Ordinary Portland Cement
The result of chemical composition analysis of Dangote brand of Ordinary Portland cement (OPC) using XRF is compared with [14] requirements as shown in the Table 2 below

| Element Oxide | OPC Composition (%) | BS EN197-1(2000) Requirement |
|---------------|---------------------|-----------------------------|
| SiO$_2$       | 28.57               | Max. 35.5%                  |
| Al$_2$O$_3$   | 2.8                 | Max. 6.3%                   |
| CaO           | 79.12               | Limit not specified         |
| Fe$_2$O$_3$   | 4.28                | Max. 6.5%                   |
| K$_2$O        | 0.24                | Less than 0.6               |
| MnO           | 0.01                | Limit not specified         |
| SO$_3$        | 1.6                 | Max. 3.5%                   |
| TiO$_2$       | 0.16                | Limit not specified         |
It could be seen that the values of the oxides composition are all within the recommended range prescribed by the code of practice. Thus, the Dangote brand of OPC can be said to be of sound quality in terms of chemical composition and has satisfied the standard requirement. Also, the results obtained from the physical properties of the cement were compared with [14] requirement as shown in Table 3 below.

| Parameters Tested | BS EN197-1(2000) requirement | Current study |
|-------------------|------------------------------|--------------|
| 1 Specific Gravity | 3.15                         | 3.12         |
| 2 Standard Consistency | 26%-33%                     | 30.33%       |
| 3 Setting Time (minutes) | ≥ 45mins                     | 93mins       |
| 4 Soundness       | ≤ 10mm                       | 0.5mm        |

3.2 Fine Aggregate
Locally available river sand was used as fine aggregate. Prior to using it, sieve analysis in accordance with [15] was done to determine its grading.

3.3 Water
According to [16] water for concrete should be of portable quality (pH -6.8 to 8.0). The University water supply, which is fit for drinking, was used in preparing all mixes of pastes, mortars and curing in this investigation.

3.4 Methods
3.4.1 Preparation of Mortar Prismatic Specimens
Mortar is usually a mixture of a binder material and sand. The mortar used herein is one part binder material to three parts of sand (1:3) as specified in [17]. The various percentages of cement and RHA mixture were prepared as in a dry powdered form. This was used as a binder and mixed in a ratio of one part binder to three parts sand, using a water/cement ratio of 0.5 as specified in [17]. The mortars were labeled in such a way that M0 represent one part of binder containing cement and 0 percent RHA (control) mixed with three parts sand. While M2.5 represent one part of binder containing cement partially replaced with 2.5 percent RHA mixed with three parts sand. M5 represents one part of binder containing cement partially replaced with 5 percent RHA mixed with three parts sand. M8 represents one part binder containing cement partially replaced with 8 percent RHA mixed with three parts sand. And M10 represents one part binder containing cement partially replaced with 10 percent RHA mixed with three parts sand.
4. Analysis and Discussion of Results

4.1 Effect of ASA on the Flexural Strength of Mortar

The flexural test results on (40x40x160) mm rectangular prisms were presented in Table 4. Each value of the result is an average of three tests, where $x_i$ is the ith independent factor coded value, $X_i$, $X_o$ is the actual values of the center point where $\Delta X$ refers to step change for the ith variable.

| No | Sample No. | Flexural Strength $R_f$ (N/mm$^2$) |
|----|------------|-----------------------------------|
|    |            | 2 days    | 7 days    | 14 days   | 28 days   |
| 1  | FS0        | 5.20      | 5.07      | 7.16      | 7.99      |
| 2  | FS2.5      | 5.04      | 4.70      | 7.10      | 6.94      |
| 3  | FS5        | 4.80      | 4.95      | 7.05      | 6.80      |
| 4  | FS7.5      | 5.16      | 5.05      | 5.88      | 6.73      |
| 5  | FS10       | 4.95      | 4.77      | 5.34      | 6.63      |

(Note that FS0 represent 0% modified Flexural Strength sample and so on)

The results of the tests conducted at 2, 7, 14 and 28 days curing ages to ascertain the effect of cement replacement with RHA amorphous silica on mortar flexural strength is presented in Figure 1.

![Figure 1](image-url)

**Figure 1.** Flexural Strength of Cement-RHA mortar with increased curing ages

It could be observed from the above Figure that the flexural strength of Cement-RHA mortar increased with curing time and decreased with increase in percent of RHA content. Also, it could be inferred from the Figure 1, the RHA is participating in the hydration process gradually, as the rate of change of flexural strength due to varying percentage replacements of RHA is gradually reducing with age.
4.2 Effect of ASA on Mortar Compressive Strength

The results of Cement-RHA mortar compressive strength were presented here in the Table 5, each value of the result is an average of three tests.

Table 5. Results of the compressive strength for 2, 7, 14 and 28 days of curing

| No | Sample No. | 2 days | 7 days | 14 days | 28 days |
|----|------------|--------|--------|---------|---------|
| 1  | CS0        | 7.4    | 8.04   | 8.65    | 8.81    |
| 2  | CS2.5      | 5.75   | 5.89   | 7.84    | 7.97    |
| 3  | CS5        | 6.18   | 6.51   | 7.76    | 8.25    |
| 4  | CS7.5      | 6.06   | 6.20   | 6.88    | 7.56    |
| 5  | CS10       | 6.15   | 6.32   | 6.51    | 7.56    |

(Note that CS0 represent 0% modified Compressive Strength sample and so on)

![Compressive Strength of Cement-RHA mortar with increased curing ages](image)

**Figure 2.** Compressive Strength of Cement-RHA mortar with increased curing ages

The compressive strength of Cement-RHA mortar increased with curing time and decreased with cement replacement with RHA as could be seen in the Figure 2 above. The rate of decrease in compressive strength with increase in percentage of RHA differs for 2, 7, 14 and 28 days, the higher the curing age the lower the percentage reduction in compressive strength. In general, the compressive strength of Cement-RHA mortar was less than the compressive strength of Ordinary Portland Cement mortar used in all cases, and with increase in the percent of RHA replacement in the mix, it resulted in decrease in the compressive strength (Table 6).
5. Conclusion, Recommendation and Contribution to Knowledge

5.1 Conclusion
Based on the experimental results and discussions, the following conclusions could be drawn:

- Chemical analysis of rice husk ash amorphous silica using XRF indicates the presence of major oxides such as SiO$_2$ (91.5%), CaO (2.84%), Fe$_2$O$_3$ (1.96%); minor oxides such as MnO (0.247%), TiO$_2$ (0.11%), V$_2$O$_5$ (0.004%) etc and Loss on Ignition was found to be 9.18%.
- The chemical analysis using XRF and physical properties of Dangote brand of OPC indicates that is sound and is Ordinary Portland cement.
- The compressive and flexural strengths of RHA-Mortar decreased with increase in RHA content.

5.2 Recommendations
(i) Based on the result of the findings from this work, an optimal of 5% RHA replacement of Dangote brand of OPC is recommended for use as partial replacement of cement. The replacement will aid in waste disposal and utilization of Rice husk.

(ii) It is also recommended that the Cement-RHA mortar be used as a general purpose mortar.

5.3 Contribution to Knowledge
The RHA used was of high reactivity, with a combined SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ content of 93.46 % which indicated that it satisfied the minimum value of 70% ASTM C618 (2008) for a good pozzolana therefore, it can be used as a retarder, suitable for use in hot weather concreting, as well as in mass concreting and long haulage of ready mix concrete.

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Table 6. Comparison of 28 days mortar compressive strength with BS 5628-1(1991)

| S.No | Sample No | Compressive Strength (N/mm$^2$) | BS 5628-(1990) (N/mm$^2$) |
|------|-----------|-------------------------------|--------------------------|
| 1    | CS0       | 8.81                          |                          |
| 2    | CS2.5     | 7.97                          |                          |
| 3    | CS5       | 8.25                          | >6.00                    |
| 4    | CS7.5     | 7.56                          |                          |
| 5    | CS10      | 7.56                          |                          |
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