A COMPARATIVE EVALUATION OF THE APPLICATION OF AGRO-WASTE AS CONSTRUCTION MATERIAL

Akhionbare, W.N.
Department of Project Management, Federal University of Technology, Owerri, Nigeria
E-mail: wnakhionbare@gmail.com; Telephone: +234 703 793 6066

ABSTRACT
This study evaluates the application of agro-waste as partial replacements for cement in construction activities. The properties of seven selected agro-wastes namely bambara ground shell ash (BGSA), acha husk ash (AHA), rice husk ash (RHA), groundnut husk ash (GHA), wood ash (WA), palm oil shell ash (POSA) and bone powder ash (BPA). The chemical ash analysis was done with the Bogue’s model. A linear program calculates the equations governing the model for ease of complex computations. Results obtained revealed that bone ash (BA) has the most compressive strength and C3S composition while rice husk is most economically viable. Local rice mills use firewood as source of heat and as such 100% of the rice husk from the mill is wasted. This reiterates the availability and abundance of rice husk ash. A concerted effort by stakeholders is needed to explore agro waste streams as durable raw materials in engineering works.

KEYWORDS: Agro-based, partial replacement, construction, chemical analysis, engineering work etc.

INTRODUCTION
Aggregates for concrete works are required to possess certain physical quality characteristics which include the ability to develop at the full strength of the cementing matrix (Concrete Engineering Handbook, 2010). Cement is a binder which sets and hardens and can bind other materials together. Portland cement is manufactured by heating calcium carbonate and clay or shale in a kiln at a temperature of 1300 – 1500 degrees Celsius. This process yields lime and dicalcium silicate (C3S) and other inorganic oxides. The lime reacts with C3S to form tricalcium silicate (C3S) which undergoes phase transition (Barron, 2009). C3S and C3S are two important compounds responsible for strength. Together they constitute 70 to 80% of cement (Neville and Brooks, 2003). Cement production consumes huge quantities of energy and emits large amounts of CO2 which is a major cause of global warming. The use of concrete in road construction is associated with such environmental problems as gaseous emissions, visual pollution, traffic congestion, noise pollution, adverse health effects and water pollution (Bremner, 2001). Concrete generates about 7% of the total CO2 generated worldwide hence contributing significantly to global green house gas problem. With increasing demand for raw materials for production, the non-renewable resources are dwindling by the day. Environmentally friendly construction materials are encouraged to rescue this situation.

In the third world, the most common and readily available materials that can be used to partially replace cement without huge economic implications are agro-based wastes. They are bambara ground shell ash (BGSA), acha husk ash (AHA), rice husk ash (RHA), groundnut husk ash (GHA), wood ash (WA), palm oil shell ash (POSA) bone powder ash (BPA), periwinkle shell ash, etc. Advantages derived from the use of agro-wastes as partial replacements for cement in construction are low capital cost per tonne production when compared with cement, promotion of waste management at little cost, reduced pollution by these waste and increased economic base of peasant farmers when such wastes are sold, thereby encouraging more production, conservation of limestone deposits and a reduction in CO2 emission (Joel, 2010).

Experiences have shown that POSA posseses good pozzolanic property and can be used as supplementary cementing material for the production of durable concrete (Safiuddin et al., 2010). It produces high strength and shows good resistance to expansion due to sulphate attack and alkali silica reaction. RHA is rich in silica, highly porous and light weight, with a very high external surface area. It has absorbant and insulating properties (Ozeh, 2010); is a good super-pozzolan usable in making concrete mixes for production of high strength. In steel production, RHA, which possesses low thermal conductivity, high melting point, low bulk density and high porosity, make it an excellent insulator that can prevent rapid cooling in flat sheet production for automobile body panels (SCM, 2004). BGSA’s use in concrete production has been recorded (Alabadan, 2005). Due to the variability of bone sources, there is inconsistency in the chemical composition of BPA (Aribisala and Bamisaye, 2006). WA contains calcium carbonate as its major component and could also be used as a major pozzolan in concrete (Rosenfeld and Henry, 2001). GHA, AHA and PSA could also be used as replacements for cement in construction activities. The properties of the selected agro-wastes with natural resources. The environmental gains are discussed as well as the socio-economic benefits.
MATERIALS AND METHODS
Materials used include ordinary Portland cement (OPC), groundnut husk ash (BGSA), wood ash (WA), palm oil shell ash (POSA) bone powder ash (BPA), groundnut husk ash (GHA), conventional fine and coarse aggregates (sand and gravel) and water. RHA was obtained from the combustion of rice husk at 438°C. The product was ground and sieved through 212 micron BS sieve (Oyetola and Abdullahi, 2006). AHA was obtained by incineration between 650 and 700°C to avoid formation of crystalline ash which is less reactive to lime. The resulting ash was ground in a ball mill to the required degree of fineness of cement (Dashan and Kamang, 1999). BGSA was obtained from burnt bambara groundnut shell at 500°C in a furnace after threshing out the shell from the nut. The ash residue was sieved through 75 microm sieve after grinding (Joel, 2010). BPA was obtained from incineration of cattle bones in a furnace at a temperature of more than 900°C. The residue was ground in a hammer mill to fine powder (Aribisala and Bamisaye, 2006). POSA was obtained by oven drying palm oil fuel ash in the oven at 110°C to remove moisture. Ground ash was sieved through 45micron sieve and stored in airtight container and kept free from atmospheric humidity (Abdullahi et al., 2006 as cited by Ozeh, 2010). WA was powdered and sieved through 75 microns sieve. The various samples were tested for 28 days compressive strength in accordance with BS1881:108:1983 (method for making test cubes from concrete) and BS1881:116:1984 (method for the determination of compressive strength of concrete cubes). Each specimen was placed with the cast faces in contact with the platens of the testing machine. The load was applied at a constant rate of stress within the range of 0.2 to 0.4 MPa/s, and the crushing strength reported to the nearest 0.5 MPa.

RESULTS AND DISCUSSION
The results of analyses are presented in Tables 1-4 and figures 1-4.

Variation in Compressive Strength

TABLE 1: Compressive Strength (KN/mm²) of Concrete with Varying Percentages of Agro-waste Ash

<table>
<thead>
<tr>
<th>Replacement ashes</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHA</td>
<td>3.89</td>
<td>2.3</td>
<td>1.95</td>
<td>2.74</td>
<td>2.43</td>
<td>2.34</td>
</tr>
<tr>
<td>WA</td>
<td>23.96</td>
<td>13.09</td>
<td>14.13</td>
<td>9.02</td>
<td>8.59</td>
<td>0.0</td>
</tr>
<tr>
<td>POSA</td>
<td>7.70</td>
<td>6.10</td>
<td>5.84</td>
<td>3.81</td>
<td>1.95</td>
<td>0.96</td>
</tr>
<tr>
<td>GHA</td>
<td>21.78</td>
<td>18.4</td>
<td>14.67</td>
<td>11.40</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>BPA</td>
<td>28</td>
<td>30</td>
<td>25</td>
<td>19</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>AHA</td>
<td>26.10</td>
<td>25.60</td>
<td>27.60</td>
<td>20.90</td>
<td>19.40</td>
<td>0.0</td>
</tr>
<tr>
<td>BGSA</td>
<td>31</td>
<td>20</td>
<td>11</td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

The optimum compressive strength of the replacement materials was achieved when cement was replaced with 10% BPA. The use of AHA at 20% led to the attainment of OCS. The use of BGSA to partially replace cement in concrete production exhibited a decrease in compressive strength with increase in BGSA content. Also compressive strength with GHA decreased with increase in GHA content. Also RHA and WA exhibited similar trends. Thus BPA exhibited the greatest appreciation in strength and is thus most suitable.

Ash Analysis
Table 3 shows the oxide composition of replacement ashes. The oxides (Fe₂O₃, SiO₂, Al₂O₃, CaO, SO₃) are the elemental constituents of a typical clinker and forms the bedrock of the Bogue’s Model, which is an important analytical tool.
Table 3 shows that only GHA and RHA satisfied pozzolanic material requirement with the sum of SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ being greater than 70%. POSA, WA, AHA and BGSA had values lower than 70% and can be considered non-pozzolanic materials. Although BPA is non-pozzolanic, its moderate CaO composition and low SiO$_2$ components make it a valuable agro-waste.

**Bogue’s Model**

The Bogue’s equations provide a simple and convenient method to find out the final composition of a clinker. It is used to calculate the approximate proportions of the four main minerals in Portland cement clinker. These minerals are C$_3$S, C$_2$S, C$_3$A and C$_4$AF. The Bogue’s equations for potential composition are given as:

\[
\begin{align*}
C_3S &= 4.07(CaO) - 7.60(SiO_2) - 6.72(Al_2O_3) - 1.43(Fe_2O_3) - 2.85(SO_3) \\
C_2S &= 2.87(SiO_2) - 0.753(C_3S) \\
C_3A &= 2.65(Al_2O_3) - 1.69(Fe_2O_3) \\
C_4AF &= 3.04(Fe_2O_3)
\end{align*}
\]

Cement clinker is a combination of lime and silica and also lime with alumina and iron. Although Bogue’s equation is limited in application, it is useful in the cement industry. The clinker analysis as extracted from Table 3 gives the following:

**TABLE 4: Clinker Analysis**

<table>
<thead>
<tr>
<th>Oxides</th>
<th>AHA</th>
<th>BGSA</th>
<th>BPA</th>
<th>GHA</th>
<th>POSA</th>
<th>RHA</th>
<th>WA</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe$_2$O$_3$</td>
<td>2.40</td>
<td>2.16</td>
<td>1.33</td>
<td>4.35</td>
<td>5.44</td>
<td>0.95</td>
<td>2.55</td>
<td>2.50</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>40.46</td>
<td>33.36</td>
<td>3.16</td>
<td>54.03</td>
<td>55.20</td>
<td>67.30</td>
<td>3.38</td>
<td>20.70</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>5.50</td>
<td>1.75</td>
<td>6.39</td>
<td>39.81</td>
<td>4.48</td>
<td>4.90</td>
<td>28.00</td>
<td>5.75</td>
</tr>
<tr>
<td>CaO</td>
<td>0.84</td>
<td>10.91</td>
<td>28.68</td>
<td>1.70</td>
<td>4.12</td>
<td>1.36</td>
<td>10.53</td>
<td>2.75</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>0.0</td>
<td>6.40</td>
<td>0.0</td>
<td>0.09</td>
<td>2.25</td>
<td>2.80</td>
<td>0.0</td>
<td>2.75</td>
</tr>
<tr>
<td>Loss on ignition (LOI)</td>
<td>43.57</td>
<td>43.57</td>
<td>11.32</td>
<td>4.00</td>
<td>13.86</td>
<td>17.78</td>
<td>27.00</td>
<td>1.30</td>
</tr>
</tbody>
</table>

* C: chemical composition of the control OPC (clinker)

The optimum compressive strength for RHA is obtained at 30% replacement level (Table 2), i.e. 70%C + 30%RHA. Thus the elemental oxides are computed thus:

\[
\begin{align*}
SiO_2, 70\%C &= 70H 20.7 \\
&= 14.49 \\
&= 30H 20.7 \\
30\%RHA &= 30H 67.30 \\
&= 20.19 \\
Adding up &= 34.68 \\
Al_2O_3, 70\%C &= 70H 5.75 \\
&= 4.025 \\
&= 30H 4.90 \\
&= 1.47 \\
Adding up &= 5.49 \\
Fe_2O_3, 70\%C &= 70H 2.5 \\
&= 1.75 \\
&= 30H 0.95 \\
&= 0.29 \\
Adding up &= 2.04 \\
CaO, 70\%C &= 70H 64 \\
&= 44.80
\end{align*}
\]

Replacing these values in Bogue’s equations yields (for RHA):

\[
\begin{align*}
C_3S &= 127.37 \\
C_2S &= 195.57 \\
C_3A &= 11.11 \\
C_4AF &= 6.20
\end{align*}
\]

Hence applying the analysis to other samples yields Table 5 which shows that only the replacement with BPA has calculated C$_3$S value greater than 50.7 recorded for OPC. The other ashes exhibited increased values in C$_3$S particularly RHA. C$_3$S and C$_2$S composition in cement play very crucial roles in strength gain by concrete (Neville and Brooks, 2003).

**TABLE 5: Percentage Bogue Compound Composition of Main Compounds in the Various Cement replacement Materials**

<table>
<thead>
<tr>
<th>Oxides</th>
<th>RHA</th>
<th>POSA</th>
<th>WA</th>
<th>GHA</th>
<th>BPA</th>
<th>AHA</th>
<th>BGSA</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30%</td>
<td>10%</td>
<td>20%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>C$_3$S</td>
<td>-127.37</td>
<td>3.08</td>
<td>-35.86</td>
<td>-19.97</td>
<td>53.35</td>
<td>-26.23</td>
<td>23.90</td>
<td>50.70</td>
</tr>
<tr>
<td>C$_2$S</td>
<td>195.57</td>
<td>33.20</td>
<td>92.87</td>
<td>84.02</td>
<td>14.93</td>
<td>90.47</td>
<td>45.68</td>
<td>22.50</td>
</tr>
<tr>
<td>C$_3$A</td>
<td>11.11</td>
<td>8.10</td>
<td>22.86</td>
<td>19.73</td>
<td>11.37</td>
<td>10.91</td>
<td>10.02</td>
<td>8.60</td>
</tr>
<tr>
<td>C$_4$AF</td>
<td>6.20</td>
<td>10.18</td>
<td>7.50</td>
<td>8.18</td>
<td>7.24</td>
<td>7.54</td>
<td>7.50</td>
<td>9.40</td>
</tr>
</tbody>
</table>

**Cost Analysis**

Due to high demand for concrete in the construction industry, the use of conventional raw materials like aggregates and limestone has drastically depleted natural deposits thereby causing ecological degradation necessitating the exploration of suitable alternatives. The current cost of one 50kg bag of OPC is N1750, hence the calculated price of OPC utilized per tone of binder is shown in Table 6.
TABLE 6: Price of OPC Utilized per Tonne of Binder Material (Agro-waste Ash)

<table>
<thead>
<tr>
<th>Replacement Material</th>
<th>% Replacement Material</th>
<th>% Cement Used</th>
<th>Price Equivalent of Cement per Tonne in Naira</th>
</tr>
</thead>
<tbody>
<tr>
<td>POFA</td>
<td>10</td>
<td>90</td>
<td>32,004</td>
</tr>
<tr>
<td>RHA</td>
<td>30</td>
<td>70</td>
<td>24,892</td>
</tr>
<tr>
<td>AHA</td>
<td>20</td>
<td>80</td>
<td>28,448</td>
</tr>
<tr>
<td>BGSA</td>
<td>10</td>
<td>90</td>
<td>32,004</td>
</tr>
<tr>
<td>GHA</td>
<td>10</td>
<td>90</td>
<td>32,004</td>
</tr>
<tr>
<td>BPA</td>
<td>10</td>
<td>90</td>
<td>32,004</td>
</tr>
<tr>
<td>WA</td>
<td>20</td>
<td>80</td>
<td>28,448</td>
</tr>
</tbody>
</table>

RHA best satisfies the cost requirement. Rice is a staple food in Nigeria and is grown locally also, rice husk is readily available as it is generated by various mills. RHA is therefore economically viable compared with other agro-wastes.

CONCLUSION
The partial replacement for cement in concrete with agro-waste is aimed at the pursuance of Clean development Mechanism, conservation of resources as well as combating the environmental degradation associated with mining of silica and limestone. The study has shown that bone ash has the highest compressive strength and C3S while rice husk is the most economically viable. Proper utilization of agro-wastes should be given due attention in Nigerian economy.

REFERENCES


