Compressive Strength Characteristics of Pigeon Pea Pod Ash Concrete

Okala, E.D., Maxwell, S.S., Zakka, P.W and Job, O.F

Abstract

The increasing cost and scarcity of Ordinary Portland Cement (OPC) has impacted negatively on the delivery of affordable housing and infrastructural development in developing countries like Nigeria. This has led to researches in search of alternative supplementary cementitious materials that can replace and/or substitute cement in concrete production without affecting the structural integrity of the concrete. Therefore, this study investigated the suitability of Pigeon Pea Pod Ash as a partial substitute for Portland cement in the production of Concrete. Mix proportion of 1:2:4 and at water cement ratio of 0.6 for the production of concrete. Seventy-five cubes were cast. Results from the chemical analysis of Pigeon Pea Pod Ash showed the combined percentages of Silicon Oxide, Aluminum Oxide and Iron Oxide (SiO₂ + Al₂O₃ + Fe₂O₃) as 85.2% which confirms Pigeon Pea Pod Ash as a Pozzolana. Concrete of different mixes were prepared using Pigeon Pea Pod Ash to replace 10%, 20%, 30% and 40% of Portland Cement by mass namely CPA 10, CPA 20, CPA 30 and CPA 40 while CPA 0 serves as control. The Compressive Strengths of the cast concrete cubes were determined at 7, 14 and 28 days of curing in water The results show an increase in strength from 10% replacement to 20% replacement of cement with the pigeon pea pod ash however the strength decreased with increase in percentage replacement of pigeon pea pod ash more than 20% (30% and 40% replacement levels). From the study, the blend CPA 20 exhibits the maximum compressive strength of 20.0N/mm² at 28 days of hydration which was close to the control cubes CPA 0 with Fcu of 22.80N/mm² and the target strength of Fcu 21.0N/mm². The study concludes that Pigeon Pea Pod Ash is a pozzolana and that it use up to 20% replacement of OPC in concrete production to attain adequate strength. Furthermore, the study concludes that inclusion of PPPA into concrete production does not affect the structural integrity of concrete in terms of strength as the compressive strength continued to increase with age of curing in water. The study therefore recommends concrete with optimum Pigeon Pea Pod Ash (PPPA) of 20% as suitable for structural elements while concrete blend of Pigeon Pea Pod Ash (PPPA) greater than 20% replacement of cement are considered not suitable for use in structural elements due to low strength exhibited.

Key words: Compressive strength, Pigeon Pea, Pigeon Pea Pod Ash, Pozzolana, Structural Elements

1. 3 Department of Building, University of Jos – Nigeria
2. Department of Building, Moddibo Adama University of Technology, Yola – Nigeria
3. Professor of Building, Department of Building, University of Jos – Nigeria

Introduction

Cement or some form of binding agent is a vital element in almost all types of construction and in recent years the cement market has been dominated by one product, Ordinary Portland Cement (OPC) (Li, 2011). In many countries, particularly Nigeria, OPC is an expensive and sometimes scarce commodity and this has severely limited the construction of affordable housing (Dadu, 2011). Consequently, alternative cements provide an excellent technical option to OPC at a much lower cost and have the potential to make a significant contribution towards the provision of low-cost building materials and, consequently, affordable shelter (Tsado, Yewa, Yaman and Yewa, 2014: Dadu, 2011). According to Neville and Brooks (2008), Pozzolans had been used as a partial substitute to cement in concrete. Pozzolans are materials with an amorphous siliceous or siliceous and aluminous content that react with calcium hydroxide in the presence of water to form cementitious hydration products (calcium silicate hydrates and calcium silicate aluminate hydrates). With the development of the construction industry, more and more by-products or waste has been generated, causing serious environmental pollution problem. To solve the problem, people have to find away to consume such wastes. It has been found by several researches that many industrial wastes can be recycled as a substitute (replacement) for cement or aggregate, such as fly ash, slag, ground granulated blast-furnaces (GGBFS) slag), waste glass, and ground vehicle tires in concrete (Walker and Pavia, 2011). Production of concrete with the incorporation of industrial waste not only provides an effective way to protect our environment, but also leads to better performance of a concrete structure (Dadu, 2011 and Girard, 2011). Due to the large amount of concrete produced annually, it is possible to...
completely consume most of industrial waste in the world, provided that suitable techniques for individual waste incorporation are available (Li, 2011). The addition of pozzolanas in either a lime or OPC-based product has two major advantages. Firstly, the properties of the cement will be improved, and secondly, as the costs of a pozzolana are usually low and certainly well below that of lime or OPC, overall cost will be significantly reduced assuming the pozzolana does not have to be transported too far (Osei and Jackson, 2012). Industrialization in developing countries has resulted in an increase in agricultural output and consequently accumulation of unmanageable agro waste pollution arising from such waste is a cause of concern for many nations like Nigeria (Emefiene, Salaudeen and Yaroson, 2013). Recycling such waste material into a new construction material might be a viable solution to the problems of high cost of construction materials in the developing nation (Dadu, 2011 and Tsado, et al., 2014). This, coupled with the pollution associated with cement production has necessitated a search for an alternative binder which can be used solely or in partial replacement of cement in concrete production (Suresh, 2012). More so, disposal of agricultural waste materials is an environmental challenge hence the need to convert them into useful materials to minimize their negative effect on the environment (Tsado, et al., 2014). The pigeon pea (Cajanus cajan), whose cultivation can be traced back more than 3,500 years, is known by a variety of names: Congo pea, Angola pea, red grain (Amarteifo, et al., 2002). It spread from eastern India to Africa and the Middle East. In Barbados, it was used to feed pigeons (Spurrier, 2013). Pigeon pea is mostly cultivated in the north central zone of Nigeria (Benue and Kogi State) and also in Enugu State. (Emefiene, et al., 2013) but the hard-to-cook phenomenon and disposal problems have limited its utilization. The challenges of low cost housing and cheap building materials have stopped many prospective house owners from acquiring their personal houses (Okala, 2015). This situation has necessitated the research into new building materials that will perform at a level close to the conventional building materials. Similarly, as reported by Tsado, et al (2014), concrete that contains pozzolana contains reactive silica which consumes the lime liberated during initial hydration and forms a cementitious compound instead of leaching on the concrete surface and this helps in reducing void space and also blocks capillary channels and subsequently reduces permeability of concrete. A problem however is the indiscriminate disposal of pigeon pea pod or having to burn the pod husk and the stem in an open area, this process leads to release of CO₂ into the atmosphere (Okala, 2015). It is therefore on this basis that investigation of the suitability of pigeon pea pod ash (PPPA) as pozzolana to partially replace OPC in production of concrete was carried out in this research with a view of further helping out in the disposal of the agricultural waste if found useful in constructions. Therefore, the study evaluates the compressive strength characteristics of concrete produced using pigeon pea pod ash (PPPA) as partial replacement for OPC. The objectives of the study are; to ascertain the suitability of pigeon pea pod ash (PPPA) as a pozzolan and also to determine the optimum percentage replacement that produces concrete of the target strength.

MATERIALS AND METHODS

Cement and Aggregates

The Dangote brand of Ordinary Portland Cement (OPC) manufactured by Dangote Cement Company Plc in Yandev near Gboko in Benue State which conforms to BS 12 (1996) and ASTM C 150 (1994) was used throughout the test. The fine aggregate used for this research was natural quartzite dredge from river and free from deleterious materials. It was obtained from Jos, Plateau State. It has a specific gravity of 2.60 and bulk density of 1622kg/m³. The coarse aggregate used was a normal weight aggregate (machine crushed gravel) with maximum size of 16mm and obtained from PW Nigeria Plc. Quarry in Jos, Plateau State. It has a specific gravity and bulk density of 2.68 and 1600kg/m³ respectively.

Pigeon Pea Pod Ash (PPPA)

The Pigeon Pea Pod used for this research was sourced from Abejukolo in Omala LGA of Kogi State. Table 1 shows the physical properties of the pigeon pea pod. Sample of the Pigeon Pea Pod was burnt under controlled conditions at National Metallurgical Development Centre (NMDC) laboratory, Zaria road, Jos, into ashes at a temperature of 750°C. The pulverized ash was sieved using 212um sieve.

Chemical Analysis of OPC and PPPA

Samples of Pigeon Pea Pod Husk and cement were taken and analyzed chemically in the laboratory of Nigerian Mining Development Corporation (NMDC) Jos, Plateau State through chemical Energy Dispersion X- RAY fluorescent analysis (ED XRF Test).

Experimental Procedures

The materials were mixed manually and were well vibrated for five minutes. Four mixes containing PPPA were produced with identity CPA 10, CPA 20, CPA 30 and CPA 40 with replacement percentages of
10%, 20%, 30% and 40% by mass (weight) of cement. Mix ratio 1:2:4 and 0.6 W/C ratios were adopted for this work with a target strength of 21 N/mm². Cubes of dimension 100mm x 100mm x 100mm were produced. A total of 75 cubes were cast with each mix proportion CPA 0, CPA 10, CPA 20, CPA 30 and CPA 40 having 15 cubes each. The absolute volume method was adopted for the computation of the various quantities of materials required. The hardened concrete cubes were then tested for compressive strength at 7 days, 14 days and 28 days hydration period using the compressive strength crushing machine.

RESULTS AND DISCUSSIONS

Chemical Analysis of OPC/PPPA

Table 2 shows the result of chemical composition of Dangote Ordinary Portland cement (OPC) and the Pigeon Pea Pod Ash (PPPA) used in this research. The combined percentage of Silicon Oxide, Aluminum Oxide and Iron Oxide (SiO₂ + Al₂O₃ + Fe₂O₃) of the pigeon pea pod ash was 85.2%. This meets the specification for Pozzolans as provided in ASTM C618-84 (70% minimum requirement). The oxide with the highest percentage is SiO₂ (82.2%); this is greater than the range in OPC (17-25%). While the percentage of the calcium oxide (CaO) content is far lower in PPCA (3.67%), this value is less than that present in OPC (73.96%). This Calcium Oxide which is a major constituent of OPC is responsible for the high rate of hydration, this explains maybe the reason for the slow rate of hydration and strength gain in pozzolana cement and also, the increase in the setting time of cement paste mixed with Pigeon Pea Pod Ash (PPPA) (Okala, 2015).

The absence of SO₃ (Sulphur IV Oxide) in the pigeon pea pod ash indicated that there will be reduction or no likelihood of Sulphate attack on concrete reinforcements; as sulphur dioxide according Neville (2006) corrodes reinforcement. From the chemical analysis, Sodium Oxide (Na₂O) is absent in both OPC and PPPA. The Pigeon Pea Pod Ash (PPPA) has MgO (2.73%), according to Alp et al (2009), Natural pozzolans with a high content of SiO₂ + Al₂O₃ (≥80%) but a low content of MgO and SO₃ generally exhibit a high pozzolanic activity. The chemical analysis confirms pigeon pea pod ash as a good pozzolana.

Table 1 Physical Properties of Pigeon Pea Pod

<table>
<thead>
<tr>
<th>Property Measured</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent specific gravity</td>
<td>2.20</td>
</tr>
<tr>
<td>Loose bulk density</td>
<td>905kg/m³</td>
</tr>
<tr>
<td>Compacted bulk density</td>
<td>1038kg/m³</td>
</tr>
</tbody>
</table>
Table 3 Quantities of material per Metre cube for cast concrete cubes

<table>
<thead>
<tr>
<th>Batch No /Code</th>
<th>Cement (kg)</th>
<th>PPPA (kg)</th>
<th>Sand (kg)</th>
<th>Gravel (kg)</th>
<th>Water (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPA 0</td>
<td>3.1</td>
<td>-</td>
<td>7.19</td>
<td>14.19</td>
<td>1.92</td>
</tr>
<tr>
<td>CPA 10</td>
<td>2.79</td>
<td>0.31</td>
<td>7.19</td>
<td>14.19</td>
<td>1.92</td>
</tr>
<tr>
<td>CPA 20</td>
<td>2.48</td>
<td>0.62</td>
<td>7.19</td>
<td>14.19</td>
<td>1.92</td>
</tr>
<tr>
<td>CPA 30</td>
<td>2.17</td>
<td>0.93</td>
<td>7.19</td>
<td>14.19</td>
<td>1.92</td>
</tr>
<tr>
<td>CPA 40</td>
<td>1.86</td>
<td>1.24</td>
<td>7.19</td>
<td>14.19</td>
<td>1.92</td>
</tr>
</tbody>
</table>

CPA = Pigeon Pea Pod Ash Concrete

Table 4 Variation of Compressive Strength with PPPA replacement (N/mm²) Percentage Replacement (%) Age of curing (days)

<table>
<thead>
<tr>
<th>Age of curing (days)</th>
<th>CPA 0</th>
<th>CPA 10</th>
<th>CPA 20</th>
<th>CPA 30</th>
<th>CPA 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>16.30</td>
<td>6.80</td>
<td>10.00</td>
<td>5.00</td>
<td>4.00</td>
</tr>
<tr>
<td>14</td>
<td>17.50</td>
<td>7.25</td>
<td>15.80</td>
<td>6.25</td>
<td>5.50</td>
</tr>
<tr>
<td>28</td>
<td>22.30</td>
<td>7.80</td>
<td>20.0</td>
<td>5.50</td>
<td>3.50</td>
</tr>
</tbody>
</table>

Compressive Strengths Test Results

Table 4 shows the compressive strength of crushed concrete cubes with different percentage replacement of cement with pigeon pea pod. The compressive strength increases with curing age but the values were initially low with the cubes containing the pigeon pea pod ash blend. Results shows that the compressive strength increased from 10% to 20% PPPA content replacement but later decreased above 20% replacement of cement with PPPA. Figure 1 shows gradual increase in strength as curing age progressed this confirms report by Practical Action (2009), that early strength gain is slightly slower with pozzolana blended cements. Cubes CPA 20 exhibited a high compressive strength when compared with that of the control mix. Therefore, maximum compressive Strength was achieved at 20% replacement of Cement with Pigeon Pea Pod Ash at 28 days. The results at 28 days shows specimen CPA 20 attained a compressive strength of 20N/mm² which were close to the specimen without the pozzolanas with compressive strength of 22.30N/mm² and also in the range of the target strength of 21N/mm². The lower values of the compressive strength of the blended mixture at early stage of hydration constitute a greater percentage ranging 24.5% to 61% in the mixture; this may be due to the reduction in cement content and the slow dissolution of silica as reported by Tsado, et al. (2014) and Suresh (2012) leading to lower pozzolanic activity at the early days of curing. However, the compressive strength at 28 days of hydration is quite comparable with that of the control. This may be due to more of silica going into solution which forms additional amount of calcium silicate hydrate (CSH) that leads to strength enhancement in
the longer time as reported by (Osei and Jackson, 2012). Also, at 28 days hydration the strength development (\(F_c\)) ratio (28/7) of CPA 20 was obtained as 1.27 which is higher than the desirable ratio of 1.25 (Neville, et al., 1987). The high ratio may be attributed to the formation of more Calcium – Silicate – Hydrate (CSH) between 7 and 28 days curing age as reported by Walker and Pavia (2011).

CONCLUSION

The investigation into the use of Pigeon Pea Pod Ash as pozzolana to partially replace OPC in concrete concludes that: Pigeon Pea Pod Ash (PPPA) meets the minimum requirement of ASTM C 618. Pigeon Pea Pod Ash can therefore be said to be a pozzolana. From the study, the optimum percentage replacement of OPC with Pigeon Pea Pod Ash (PPPA) that produced maximum strength was CPA 20. Though, all the replacement proportions CPA 10, CPA 20, CPA 30 and CPA 40 shows good qualities in terms of increased in compressive strength with increased in curing days in water. Therefore, the study concludes that Pigeon Pea Pod Ash has promising properties for partial replacement of Ordinary Portland cement in production of concrete with increased strength.

RECOMMENDATION

From the result of findings, the following recommendations were drawn:

1. CPA 20 concrete containing 20% Pigeon Pea Pod Ash (PPPA) having achieved Fcu of 20.0N/mm² at 28 days is recommended for use in the production of structural elements.

2. CPA Concretes with percentage replacement above 20% are not recommended for use in structural elements due to the low strength exhibited.

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