Fused Laterite Powder Substitution for Cement in Concrete Production

*Adinkrah-Appiah, Kwadwo¹ and Obour, Gyau David²

¹Civil engineering Department, Sunyani Polytechnic and ²Building Technology Departments, Sunyani Polytechnic, Jojoappiah2001@yahoo.co.uk, 0205862167/0244389790.

Abstract

The high cost of cement affects the cost of concrete and hence reduces housing delivery. Research has established that the use of supplementary cementitious materials can improve the strength and reduce the cost of concrete. Fused laterite, a hard-pan formed from lateritic materials contains high silica and lime contents. Silica is known to prolong the setting time and hence, increase the strength of concrete. Fused laterite abounds in Ghana and its use can reduce the cost of concrete. This study purposed to find the compressive strength of concrete from partial replacement of cement with fused laterite powder (FLP). Lumps of fused laterite were ground to fine powder. Two concrete cubes were produced from five batches of concrete with FLP replacements of 0%, 10%, 20%, 30% and 40% using 1:2:4 mix ratio and water/cement ratio of 0.55. The average 28-day compressive strength for the various replacements were 21.74 N/mm², 22.46 N/mm², 18.49 N/mm², 16.02 N/mm² and 14.10 N/mm² for 0%, 10%, 20%, 30% and 40% respectively. It was concluded that FLP replacement of 10% produced the optimum compressive strength that was 3% higher than the strength of the cement-only control sample, and hence should be adopted for structural concrete production.

Keywords: Fused Laterite Powder (FLP); Compressive strength; Pozzolan; Partial replacement; Ordinary Portland cement; Silica content

Introduction

The high cost of building materials, especially cement, in Ghana has made building construction quite expensive and difficult for the average income earner to build and own houses. This has created a housing deficit of over one million (Daily Graphic, 2009) to which the government and other stakeholders are trying to find solution. The problem could be attributed to limited resources and lack of awareness of availability of local construction materials that could be utilized to make cost of housing construction reasonable and affordable for the average person.

The construction industry in Ghana has over-depended on cement-based products for the delivery of housing and other infrastructural facilities. Andam (2005) reports that sandcrete block-walls constitute about 90% of urban housing construction in Ghana as compared to other walling materials. The over-reliance on cement and many other factors have resulted in the high cost of housing delivery that has led to the high housing deficit.
It is reported that Ghana’s consumption of Portland cement has risen over the past decade from 2.5 million tons in 2005 to 4.5 million tons in 2009 (Ofiri-Atuahene, 2008). This has caused the price of cement and other cement-based products to increase at an alarming rate in recent times. A bag of cement (50kg) leaped from GH¢ 1.50 in 1992 to GH¢ 30 in 2010 and about GH¢ 33.00 in recent times, representing over 2000% increase only in 24 years. This can be attributed to the high cost of clinker, the major input material for cement manufacture, which is imported at a very high foreign exchange rate (Adinkrah-Appiah, 2012).

In view of environmental and sustainability concerns associated with the production of cement, the use of pozzolans to replace some percentage of cement is receiving a lot of attention. Replacing Portland clinker either partially or entirely is also being investigated as an alternative to curb carbon dioxide emissions associated with cement manufacture and use. Up to 70% of cement can be replaced by using materials such as fly ash, slag, silica fume, natural pozzolans, rice-husk ash, wood ash, and agricultural products ash. Artificial pozzolans used in modern commercial cement are derived from fly ash produced by coal burning plants and incineration of municipal solid waste.

Pozzolanic materials do not possess any cementing properties on their own, but they contain silica and alumina in reactive form that can react with cement to increase its bonding power. Ancient Romans produced exceptional cement by mixing pozzolanic materials with lime to build structures, some of which are still standing till date. Pozzolanic materials chemically react with calcium hydroxide in the presence of water to form compounds possessing cementitious properties. The pozzolanic reactions are silica reactions in the presence of calcium hydroxide and water to produce calcium silicate hydrates (C-S-H) (Metha et al, 1992; ASTM C618, 1993).

Lateritic soils are formed in the tropics through weathering processes that favour the formation of iron, aluminum, manganese and titanium oxides. These processes break down silicate minerals into clay minerals such as kaolinite and illite. Iron and aluminum oxides are prominent in lateritic soils, and with the seasonal fluctuation of the water table, these oxides result in the reddish-brown colour that is seen in lateritic soils. Fused laterite is formed when lateritic soils are subjected to intense heat and pressure over a long period of time, and may possess some pozzolanic properties when in powdered form.

According to Obour (2015), a raw material of fused laterite (Laterite rock) can be found in many parts of Ghana and can react with cement in the presence of water to increase the strength of concrete and hence, act as a pozzolan in a finely divided form. The objective of the study therefore was to investigate the pozzolanic action of fused laterite powder by substituting cement with fused laterite powder at different percentages.

**Materials and Methods**

Different materials were employed for different processes during the study. Diamond cement of Class 42.5 N (Ordinary Portland Cement) was used for the casting of concrete cubes for testing.

Granite coarse aggregates of maximum size 20mm and washed river sand were used as coarse and fine aggregates respectively.

**Fused laterite powder**

Boulders of fused laterite samples were collected from a building construction site at Sunyani Berlintop area and were first broken into smaller sizes after which they were ground into fine powder and sieved through BS 75micron sieve. The powder so produced was added to the concrete mixes by replacing portions of the cement in the different concrete batches.
Concrete mix proportions

A mix ratio of 1:2:4 was used to prepare concrete cubes which satisfy nominal mix design for the production of concrete with characteristic compressive strength of 25 N/mm² at 28 days. Five different concrete batches were prepared by replacing portions of the cement with fused laterite powder in replacement ratios of 0%, 10%, 20%, 30% and 40%. Table 1 shows details of the various compositions of material requirements for the concrete samples. Two concrete cubes were cast for each sample batch using water/cement ratio of 0.55. The samples were cured for 28 days after which they were subjected to crushing tests to determine their compressive strength.

Table 1: Composition of materials for concrete samples

<table>
<thead>
<tr>
<th>Type of Material</th>
<th>Fused Laterite Powder percentage in concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>FLP</td>
<td>0.00</td>
</tr>
<tr>
<td>Cement</td>
<td>2.73</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>10.95</td>
</tr>
<tr>
<td>Sand</td>
<td>5.78</td>
</tr>
<tr>
<td>Water</td>
<td>1.51</td>
</tr>
</tbody>
</table>

Findings

The 28 days average compressive strength for the various mixes (replacements) recorded values of 21.74 N/mm², 22.46 N/mm², 18.49 N/mm², 16.02 N/mm² and 14.10 N/mm² for 0%, 10%, 20%, 30% and 40% respectively (Table 2). The replacement with 10% FLP recorded the highest 28-day compressive strength of 22.46 N/mm². This was followed by the samples with 0% replacement, that is, Ordinary Portland cement only, which recorded a compressive strength value of 21.74 N/mm². This was followed by the 20% FLP replacement which also recorded a value of 18.49 N/mm².

Discussions

The average compressive strength of 22.46 N/mm² produced for the 10% FLP replacement, compared to the strength recorded for the 0%, replacement which was 21.74 N/mm², implies that the 10% FLP replacement was 3% higher in strength than the Ordinary Portland cement only concrete. This proves that the FLP contains some pozzolanic properties which reacted with the cement to cause the strength of the resulting concrete to be higher than the control specimen.

Table 2: 28 Days compressive strength test results for concrete cubes

<table>
<thead>
<tr>
<th>FLP (%)</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Weight (g)</td>
<td>8,199.5</td>
<td>8,355.0</td>
<td>7,857.0</td>
<td>8,137.0</td>
<td>8,181.0</td>
</tr>
<tr>
<td>Average Density (Kg/m³)</td>
<td>2429.5</td>
<td>2475.6</td>
<td>2328.0</td>
<td>2411.0</td>
<td>2424.0</td>
</tr>
<tr>
<td>Average Compressive Strength (N/mm²)</td>
<td>21.74</td>
<td>22.46</td>
<td>18.49</td>
<td>16.02</td>
<td>14.10</td>
</tr>
</tbody>
</table>
According to Rodriguez et al. (2006), concrete produced from a blend of Ordinary Portland Cement and Rice Husk Ash (RHA) pozzolan has higher compressive strength at 91 days (i.e. longer periods) in comparison to that without pozzolan. The increase in compressive strength of concrete with residual RHA, according to the study, may be justified by the filler (physical) effect. Thus, replacement of cement with pozzolans becomes more effective at longer days beyond 28 days. However, the concrete batch with 10% replaced produced a higher strength at 28 days than the OPC only sample. This suggests that, the strength of the concrete with FLP replacement of 10% may produce very high strength concretes at longer periods than cement-only concretes.

Inclusion of Rice Husk Ash(RHA) as partial replacement to cement enhances the compressive strength of concrete, but the optimum replacement level of OPC by RHA to give maximum long term strength enhancement has been reported between 10% up to 30%. All these replacement levels of RHA are in percentage by weight of the total binder material. Ghassan and Mahmud (2010) reported 15% replacement as an optimal level for achieving maximum strength. Zhang and Mohan (1996) suggested that 10% RHA replacement exhibited upper strength than control OPC at all ages. Ganesan et al. (2008) concluded that concrete containing 15% of RHA showed an utmost compressive strength and loss at elevated content beyond 15%. In this study, the optimum strength has been found to be at 10% FLP replacement which produced a strength that was 3% higher than the OPC control sample, which is in conformity with findings of other researchers (Zhang and Mohan (1996); Ganessan, et al 2008; Ghassan and Mahmud 2010).

Other research on Pozzolans conducted by the Building and Road Research Institute (BRRI) (2007) suggests that up to 40% of OPC can be replaced by clay pozzalanic cement material in a concrete mix to produce plain or unreinforced concrete of strength between 15 to 20 N/mm². This conforms to the results of the 20% replacement of FLP which produced an average of 18.49 N/mm²making it suitable for plain concrete production.

Figure 1. indicates that the compressive strength of the concrete samples increased from 21.74 N/mm² at 0% FLP to 22.46 N/mm² at 10% FLP before it started decreasing to 18.49 N/mm², 16.02 N/mm² and 14.10 N/mm² for 20%, 30% and 40% FLP replacements respectively. This shows that, the compressive strength first increased to an optimum strength level at 10% FLP replacement and then began to decrease linearly with increasing amounts of FLP in the concrete beyond the optimum level. This further implies that as FLP is introduced in concrete to replace cement, the resulting concrete gains an increased strength at lower FLP replacement.

![Figure 1: 28-Days compressive strength for different FLP replacements](image-url)
levels, but as the FLP increases beyond 10% the compressive strength of the concrete falls linearly. This suggests that FLP replacement of cement should be at 10% if higher strengths are required. However, replacement up to 30% could be allowed for medium strength concrete with grade not exceeding 15MPa.

Conclusions

From the various tests conducted and the analysis presented, the following conclusions were drawn:

- The compressive strength of the concrete samples increased from 21.74 N/mm² at 0% Fused Laterite Powder (FLP) replacement to 22.46 N/mm² at 10% FLP before it started decreasing to 18.49 N/mm², 16.02 N/mm² and 14.10 N/mm² for 20%, 30% and 40% FLP replacements respectively.

- FLP replacement of 10% produced concrete with compressive strength results of 22N/mm². This implies that FLP replacement of 10% produced the maximum strength in the study that was 3% higher than the strength of the OPC control concrete and, hence should be taken as the ultimate replacement ratio for maximum strength.

- The 20% replacement of FLP produced an average strength of 18.49 N/mm² which makes it suitable for plain concrete production.

- FLP replacement of 30% and 40% produced concretes with compressive strength results of 16 N/mm² and 14 N/mm² respectively conforms to medium grade concrete per the British Standard requirements (BS8110). This means that FLP replacements of up to 40% can be used to produce medium grade concrete for non-structural works such as plain concrete foundation, aprons and oversite concrete floors.

- Fused Laterite Powder is a good pozzolanic material and therefore could be used as a supplement for Ordinary Portland Cement for concrete production to reduce the cost of housing delivery in Ghana.

Recommendations

Based on the conclusions drawn, the following recommendations are proffered:

- Fused Laterite Powder (FLP) production must be undertaken on a large scale to make it available on the market as a supplement for Ordinary Portland Cement for concrete production in Ghana.

- For the production of structural concrete, FLP replacement of 10% is recommended to ensure the achievement of higher concrete strengths.

- Durability tests such as water permeability, resistance to penetration of chloride ions, corrosion of steel reinforcement, and resistance to sulphate attack on FLP pozzolan concrete should be investigated.

- Further research should be carried out in which tests will be conducted at 90 days to establish the potential strength of FLP replaced concrete at longer curing periods.
References

Journal

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Conference Proceedings
