Optimum Mix Design for Minimum Concrete Strength Requirement Using Akure Pit-sand as Fine Aggregate

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Abstract
This paper highlights the properties of pit-sand commonly used as fine aggregate and the resulting concrete produced in Akure, South-west of Nigeria. The research into the characteristics and behaviour of locally available aggregates is expected to improve the knowledge of the structural engineers as well as all the civil engineers that make use of concrete. The main aim of this research is to develop optimum proportioning of local aggregate suitable for the customization of BS8110 (1997) in Nigeria. Linear programming technique has been applied to a concrete mix design having least cost while satisfying given water-cement ratio; the specified limits for the range of acceptable workability, expressed in terms of the compacting factor; absolute volume constraint and the specified compressive strength. The objective function, for which a minimum is sought, is the cost of concrete per cubic meter, expressed as the sum of the unit costs of the individual ingredients. The characteristic strength of the concrete at 28 days was found to be 10.44 N/mm² at an optimal mix ratio of 1:2:5 and water-cement ratio of 0.77.

Keywords: pit-sand, concrete, compressive strength, optimization.

INTRODUCTION
Concrete is presently the most common building material in Nigeria, hence careful consideration must be given to factors that affect its strength. To ensure the overall good performance of a reinforced concrete structure, the quality of its constituent materials must be ensured (Afolayan, 1993). Structural collapse of reinforced concrete buildings is usually an outcome of progressive deterioration of the various components forming the structural unit as a result of improper mix ratio or ignorance in the use of locally available fine aggregate containing impurities, which consequently affect the overall mix (Babatunde and Opawole, 2009). Mix ratio can affect the strength and stability of a reinforced concrete structure just as the size, the shape and the grading of the aggregate will do (Alexander and Mindess, 2008). However, the incidence of material failure of concrete in recent years in Nigeria is a clear indication that the professional engineers in the country may not know enough about their concrete. To some extent, the ignorance may cause negligence in the selection of correct ingredients for mixing, to achieve a suitable mix, and obtain a technically sound execution of concrete works (Ayininuola and Olalusi, 2004).

The standard mix of approximately 1:2:4 (ratio of cement to fine and to coarse aggregate) is expected to give a compressive strength of 20 N/mm² at 28 days (Table 5 of BS8110 1997) could not achieved using aggregates available in Akure metropolis. Olanitori and Olotuah (2005) achieved a concrete of compressive strength between 8 N/mm² and 12 N/mm². In the light of the shortcomings that may be associated with aggregates, it has become imperative to research into these aggregates that are readily available in our environment and know at what optimum mix ratio a minimum concrete strength is obtained. The research into the characteristics and behaviour of locally available aggregates is expected to improve the knowledge of the structural engineers as well as all the civil engineers that make use of concrete for civil engineering works.

LOCATION, MATERIALS AND METHODS
Location
The study area is Akure, the administrative capital of Ondo State. Akure became the state capital of Ondo State in 1976. The town is located within 7° 15′ north of the Equator and Longitude 5° 05′ East of the Greenwich Meridian. In 2006, the provisional population for Akure was put at 353,211 (2006 census) out of which 175,494 are male and 177,716 are female. Figure 1.0 shows the location of Akure in Ondo state as well as Nigeria.

Generally, the people have almost the same life pattern. A large majority are civil servant and a consistently people of entrepreneurship. The increased relative political influence of Akure as a State capital since 1976, when Ondo State was created has been partly responsible for its rapid development. This is because, the decentralization exercise, which accompanied the policy that led to the creation of the State led to the creation of jobs, which attracted many people.
MATERIALS

Sand

Akure pit-sand is an aggregate whose grain sizes range from 0.075 mm to 2.36 mm. Chemical analysis showed that the material contains various minerals like SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, Na₂O, K₂O and TiO₂, which provide specifically a diversity of physical and mechanical properties. In spite of the reactivity of some minerals with cement, sand is considered as an inert component that may affect the resulted mix property by its texture, size, distribution, strength and other secondary properties. In general, sand contains water, some of which is absorbed within and some other is attached to the surface. The latter is a cause of variation of mix properties because of its downward movement which makes the water content non-uniform. Table 1 displays the properties of pit-sand sample from Akure, Nigeria.

Table 1: Determined properties of Pit-sand from Akure

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity, Gₚ</td>
<td>2.34</td>
</tr>
<tr>
<td>Bulk Density (kg/m³)</td>
<td>1390</td>
</tr>
<tr>
<td>Absorption</td>
<td>2.42</td>
</tr>
<tr>
<td>Fineness modulus</td>
<td>1.82</td>
</tr>
</tbody>
</table>

Cement

Cement is a hydraulic powder that reacts with water and hardens under water to form a hardened rock. In this research ordinary Portland cement is used. In concrete, cement is the first component that reacts with water; its reaction is always accompanied with hydration heat whose value may be high or low according to the cement components mainly including: C₃S, C₂S, C₃A, C₆AF and gypsum. Strength of cement is of first importance because its role is to bond all aggregates together to form a unique rock.

Coarse Aggregate

The type and source of coarse aggregate used in the production of concrete in Akure, Metropolis has a considerable influence on the compressive strength of concrete. Crushed but smooth coarse aggregate of the maximum size of 14 mm is commonly used in making concrete. The properties of the coarse aggregate used in this investigation are as listed in Table 2.

Table 2: Coarse aggregate properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness modulus</td>
<td>5.78</td>
</tr>
<tr>
<td>Specific gravity, Gₚ</td>
<td>2.65</td>
</tr>
<tr>
<td>Bulk Density (kg/m³)</td>
<td>1635</td>
</tr>
<tr>
<td>Absorption</td>
<td>1.86</td>
</tr>
</tbody>
</table>

METHODS

Proportioning of concrete ingredient using linear programming technique was focused. Linear equations were solved using the Microsoft Excel Spreadsheet Solver and preliminary concrete mix ratio of 1:2:1:1:1.8 was obtained. This primary concrete mix ratio was used to generate a set of other trial concrete mix ratios, i.e., 1:2:4.5; 1:2:5; 1:2.5:6; and 1:3:5. The soil (pit-sand) sample used as fine aggregate in concrete was oven-dried for 24 hours before further tests were carried out. The sand and granite used as aggregates were graded using the sieve sizes for grading according to BS812: part 103 (1985). Hence, the percentage passing through each set of sieves was determined. The concrete ingredients were then mixed using the method of batching by weight in accordance with the provision of BS 812: Part 104 (1985). Pit-sand having maximum particle size of 2.36 mm, determined from particle size distribution method, was first measured, and spread with shovel, after which ordinary Portland cement was added and thoroughly mixed. The resulting mix was then mixed with coarse aggregate (granite) of maximum particle size of 14 mm and the required amount of water. The resulting concrete was poured in the standard concrete cube mould of 150 x 150 x 150 mm in three layers. Each layer was given 25 blows for compaction using British Standard rod as recommended by BS1881: Part 111 (1983). The fresh concrete was tested in accordance with British Standards (1881: Part 102 (1983), BS812: part 103 (1985), BS1881: Part 106 (1983)) for slump, compacting factor, and Air-entrained volume. The concrete cubes were removed after 24 hours from the moulds, weighed and kept under water for curing in the curing tank. After every 7 days 3 samples of concrete cube were removed from the curing tank, weighed and tested for compressive strength. The values of compressive strength were read and recorded. The same procedure was followed for the trial concrete mix ratios 1:2:4; 1:2:4.5; 1:2:5; 1:2.5:6; and 1:3:5.

RESULTS AND DISCUSSION

Results of tested properties of materials

The properties of the fine and coarse aggregates from Akure are as presented in Table 3. It is clear from the
results that both materials exhibit qualities lower than the recommended minimum in BS812: Part101 (1985).

| Table 3: Summary of materials properties in the Study |
|-----------------|-------|-----|
| Pit-sand        | Coarse | Cement |
| Fineness Modulus | 1.82  | 5.78 |
| Specific gravity, Gs | 2.34  | 2.65 |
| Bulk Density (kg/m³) | 1390  | 1635 |
| Absorption      | 2.42  | 1.86 |

Particle Size Distribution of Akure Pit-Sand

According to the Unified Soil Classification System, the sand sample is a fine–grained soil (sand) because more than half of the coarse fraction is between the No 4 (4.75 mm) and No 200 (0.075 mm) sieve size. However, from Figure 2, the coefficient of uniformity, \( C_u \) and coefficient of curvature (\( C_c \)) are 2.59 and 1.06 respectively. Since, \( C_u < 4 \) and \( C_c = 1.06 \) which is between 1 and 3 in the Unified Soil Classification System, the soil is classified as poorly graded sand. More than half of the coarse fraction is not retained on the No 4 sieve showing that the aggregate is poorly distributed. From Figure 2, the grading of coarse aggregate does not comply with the requirement of BS812: Part101 (1985) which has effect on the water requirement of a concrete mix.

Chemical Composition of Pit-sand

Figure 4 gives the result of chemical composition analysis carried-out on the pit-sand used as fine aggregate. The Akure pit-sand contains higher percentage of undissolved metal and lower silicate (77.40%) as compared with some standard sand like Ottawa sand (silicate of about 99.3%) in Canada which affect the bond between the matrix and the aggregate particles and thus the strength of concrete (Fijabi, 2011).

Application of Linear Programming to Concrete Ingredient Proportioning

The concept of linear programming technique has been applied to concrete mix design having least cost while satisfying given workability requirements, minimum water-cement ratio and the specified compressive strength in the hardened state. The objective function, for which a minimum is sought, is the cost of concrete per cubic meter, expressed as the sum of the unit costs of the individual ingredients.
**Required ConcreteStrength Constraint**

Compressive strength of concrete has been generally taken to be a function of the water-cement ratio which is given as

\[ f_{cu} = M \times (A) - D \]  

(1)

In equation (1), \( A = \frac{W}{C} \) (water-cement ratio by weight); and \( f_{cu} \), \( M \) and \( D \) are compressive strength in N/mm² at 28 days, slope of a straight line (obtained from strength versus water-cement ratio relationship) and \( D = f_{cu2} - M \times A_2 \)

Where \( f_{cu2} \) and \( A_2 \) are maximum compressive strength and water-cement ratio on the strength versus water-cement ratio relationship

The strength constraint then assumes the form

\[ W - 0.77*C \leq 0 \]  

(2)

where \( W = \) quantity of water in kg per unit volume of concrete; \( C = \) quantity of cement in kg per unit volume of concrete. Equation (2) is meant to provide adequate concrete strength (Cannon and Krishna Murti, 1971)

**Workability Constraint**

The following relationship for workability, suggested by Murdock, (1960) has been utilized in this present study.

\[ CF = 0.74 + \left[ \frac{10(0.25)}{FS \times FA(A_2 - 2)} + 0.67 \right] \]  

(3)

in which \( CF = \) compaction factor; \( FS = \) surface index of the aggregate; \( FA = \) angularity index of the aggregate; and \( A_2 = \) aggregate-cement ratio by volume.

To express \( A_2 \) in terms of the aggregate-cement ratio by weight; we have

\[ A_2 = \frac{C}{\left( \frac{A_2}{C} \right)} \]  

(4)

where \( C_G = \) specific gravity of cement, \( G_A = \) specific gravity of aggregate, \( A/C = \) aggregate-cement ratio by weight. To ensure adequate workability, a lower limit of compacting factor was imposed. Substituting Equation (4) into Equation (3) and solving mathematically we have

\[ 7.40W - B_2*C - B_4*CA - B_4*FA \leq 0 \]  

(5)

Where

\[ B_2 = 1.650 - \left( \frac{2FA_{CA} \times FS_{FA}(CFL - 0.4958))}{G_C/G_A} \right) \]  

(6)

\[ B_3 = FS_{FA} \times FA \left( \frac{G_C/G_A}{GA_{FA}} \right)(CFL - 0.4958) \]  

(7)

\[ B_4 = FS_{CA} \times FA \left( \frac{G_C/G_A}{GA_{FA}} \right)(CFL - 0.4958) \]  

(8)

in which \( CFL = \) lower limit of compacting factor, \( FS = \) surface index of the aggregate, \( FA = \) angularity index of the aggregate, \( C = \) cement, \( W = \) Water. The parameters \( FA_{CA}, FS_{FA}, FA_{CA}, FS_{CA}, G_C, GA_{CA}, GA_{FA}, \) and \( CP \) are taken to be 2, 0.356, 2, 1.075, 3.13, 2.65, 2.34, and 0.850 respectively. Hence, substituting all the parameters into Equation (6); (7); and (8), the limiting workability constraints assume the form:

\[ 7.40*W - 1.20*C - 1.15*CA - 0.39*FA \leq 0 \]  

(9)

**Water to Cement Ratio Constraint**

Table 6.3.4 of ACI, (1991) gives the maximum permissible water-cement ratio for concrete in severe exposure. This specification results in a constraint expressed as:

\[ W/C \leq R \] or \[ W - 0.5*C \leq 0 \]  

(10)

assuming \( R = 0.5 \)

**Volume Constraint**

Equation (11) constrains the total volume of water, cement, coarse aggregate, fine aggregate to the concrete volume,

\[ \frac{W}{\rho_c} + \frac{C}{G_c} + \frac{CA}{G_{CA}} + \frac{FA}{G_{FA}} = V \]  

(11)

Where \( G_c = \) specific gravity of cement = 3.13, \( G_a = \) specific gravity of coarse aggregate = 2.65, \( G_f = \) specific gravity of fine aggregate = 2.34, \( \rho_w = \) density of water which is taken to be 1000 kg/m³. Substituting these data into Equation (11) we have

\[ 0.001W + 0.32C + 0.37CA + 0.38FA = 2604.16 \]  

(12)

**Objective Function and Constraints**

The objective function, for which a minimum is sought, is the cost of concrete per cubic meter, expressed as the sum of the unit costs of the individual ingredients. That is,

\[ \text{Min } Z = 33C + 0.5FA + 3.5CA + 0.05W \]  

(13)

Where \( C, FA, CA \) and \( W \) are cement, fine aggregate, coarse aggregate and water respectively. The objective function is subject to the constraints expressed in Equations (2), (9), (10) and (12).

**The Result of Optimization**

The optimisation was performed using the Microsoft Excel Spreadsheet. The optimum mix ratio obtained was 1:2.1:1.8 for \( C: FA: CA \)

**Characteristic Compressive Strength**

The characteristic compressive strength, \( f_{cu} \) for the concrete at different ages was obtained from

\[ f_{cu} = f_m - 1.64 \sigma \]  

(14)

Where \( f_{cu} \) is the characteristic compressive strength of the concrete at any age, \( f_m \) is the mean target strength of the concrete at any age and \( \sigma \) is the standard deviation of the sample values. From Figure 4 the results clearly show that the materials used were of poor quality resulting in low characteristic strength at 28 days as compared with the recommendation given by BS8110: Part 1 (1997).
Fresh Concrete Properties
From Table 4, the compactor factors obtained for all concrete mix ratios show that concrete is neither too fluid nor too solid. The consistency of the concrete measured by slump values, the void volume, vebe-time and the density of the concrete for the tested concrete mix ratios using Akure pit-sand are in compliance with the recommendation given by BS812: Part101 (1985).

Table 4: Fresh concrete properties

<table>
<thead>
<tr>
<th>Mix Ratio</th>
<th>Compaction Factor</th>
<th>Fresh Concrete Properties</th>
<th>Air Content (%)</th>
<th>Concrete Density kg/m³</th>
<th>Vebe-Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compaction Factor</td>
<td></td>
<td>Air Content (%)</td>
<td>Concrete Density kg/m³</td>
<td>Vebe-Time (sec)</td>
</tr>
<tr>
<td>1:2:8:1.8</td>
<td>0.99</td>
<td>52</td>
<td>2.5</td>
<td>2379.26</td>
<td>1.44</td>
</tr>
<tr>
<td>1:2:4</td>
<td>0.94</td>
<td>56</td>
<td>2.2</td>
<td>2515.56</td>
<td>2.31</td>
</tr>
<tr>
<td>1:2:4.5</td>
<td>0.93</td>
<td>63</td>
<td>2.6</td>
<td>2512.59</td>
<td>2.66</td>
</tr>
<tr>
<td>1:2:5</td>
<td>0.94</td>
<td>65</td>
<td>2.4</td>
<td>2509.63</td>
<td>2.53</td>
</tr>
<tr>
<td>1:2:5:6</td>
<td>0.96</td>
<td>54</td>
<td>2.3</td>
<td>2462.22</td>
<td>2.02</td>
</tr>
<tr>
<td>1:3:5</td>
<td>0.95</td>
<td>58</td>
<td>2.5</td>
<td>2456.30</td>
<td>2.25</td>
</tr>
</tbody>
</table>

Effect of Concrete Water Absorption on Characteristic Strength of Concrete at Different Ages
Figures 6 to 11 display the relationship between compressive strength and the percentage of water absorption for different concrete mix ratios. The pit-sand used has the ability to retain higher moisture content, which made it react with alkalis from the cement to cause cracking which in turn reduced the compressive strength of concrete. The maximum sizes of aggregates used in this research are smaller compared with the maximum size of aggregate given in BS812: Part 106 (1985). This implies that the smaller the maximum size of aggregate, the higher the water content, the higher the slump value and the lower the compressive strength of concrete. Generally, there is no regular pattern for describing the variation of concrete strength with water absorption for the type of aggregates used in this study. This observation supports the fact that the resulting compressive strength should be treated probabilistically.
CONCLUSION

Physical and chemical properties of commonly used aggregates in one of the cities in the south-western Nigeria were investigated. The concept of optimization was applied to concrete mix design having least cost while satisfying the given concrete workability requirements and the specified compressive strength in the hardened state. The design variables in the optimization process are cement, aggregates (fine and coarse), and water. Compressive strength which is the function of the water-cement ratio was used to establish the required strength constraint from assumed cylinder strength versus water-cement ratio relationship. The optimization process was done using the Microsoft Excel Spreadsheet Solver of linear programming. Consequently, the optimum mix ratio of 1:2.1:1.8 for was obtained. This mix was tested along with other experimental trials.

Based on experimental tests the optimum coarse aggregate/total aggregate and total aggregate/cement ratios were found to be 0.46 and 3.9 respectively at an optimal mix of 1:2:5. The concrete compressive strength at 28 days using a mix of 1:2:4 for the local available materials was found to be 10.13 N/mm² as compared with the minimum compressive strength of 20 N/mm² recommended by BS8110: Part1 (1997). The experimental value is therefore 50% of the minimum strength recommended. However, the compressive strength at 28 days corresponding to the experimental optimal was 10.44 N/mm² with water-cement ratio of 0.77.

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