Effect of aggregate type on Compressive strength of concrete
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ABSTRACT

The utilisation of three types of aggregate for concrete work is investigated in this paper. Normal concrete is being produced from different types of aggregate and this imparts different property to the resulting concrete. The most important property of concrete is its compressive strength. For the purpose of this work, three types of coarse aggregates, quartzite, granite, and river gravel, were used. The fine aggregate is normal sand obtained from a borrow pit. Preliminary laboratory investigation was conducted to ascertain the suitability of using the aggregates for construction work. Tests conducted include sieve analysis, bulk density, and specific gravity. Nominal mix (1:2:4) was adopted for this work and mix compositions were calculated by absolute volume method. For each type of coarse aggregate 75 cubes (150x150mm) were cast to allow the compressive strength to be monitored at 3, 7, 14, 21, and 28 days. Test result show that concrete made from river gravel has the highest workability followed by crushed quartzite and crushed granite aggregates. Highest compressive strength at all ages was noted with concrete made from quartzite aggregate followed by river gravel and then granite aggregate. Compressive strength models were proposed as a function of age at curing. Where concrete practitioners have options, aggregate made from quartzite is advisable to be used for concrete work.

Keywords: Aggregate, Concrete, Compressive strength, Models.

1. Introduction

The compressive strength of concrete depends on the water to cement ratio, degree of compaction, ratio of cement to aggregate, bond between mortar and aggregate, and grading, shape, strength and size of the aggregate (Roccoand Elices, 2009; Elices and Rocco, 2008). Concrete can be visualized as a multi-phase composite material made up of three phases; namely the mortar, mortar/aggregate interface, and the coarse aggregate phase. The coarse aggregate in normal concrete are mainly from rock fragments characterised by high strength. Therefore, the aggregate interface is not a limiting factor governing the strength requirement (Beshr, Almusallam, and Masleuhuddin 2003). The onset of failure is manifested by crack growth in the concrete. For normal concrete the crack growth is mainly around the cement paste or at the aggregate/cement paste interfacial zone. The strength of concrete at the interfacial zone essentially depends on the integrity of the cement paste and the nature of the coarse aggregate.

The effect of using crushed quartzite, crushed granite, limestone, and marble as coarse aggregate on the on the mechanical properties of high-performance concrete was investigated (Wu, Chen, Yao, and Zhang, 1997). The outcome of the study revealed that the strength, stiffness, and fracture energy of concrete for a given water/cement ratio depend on the type of aggregate. Basalt, limestone and gravel have been used as coarse aggregate to produce
normal and high-performance concrete (Özturan, and Çeçen, 1997). The research work revealed that for high performance concrete at 28 days, basalt produced the highest strength, whereas gravel gave the lowest compressive strength. Normal strength concrete made with basalt and gravel gave similar compressive strength while the concrete containing limestone attained higher strength. The effects of content and particle size distribution of coarse aggregate on the compressive strength of concrete have been investigated (Meddah, Zitouni, and Belâabes 2010). Three types of coarse aggregates were mixed in four different proportions for concrete production. Plasticizers and Superplasticizers were used in some mixes to reduce the water to cement ratio. The outcome of their work showed that the mixture with a ternary combination of granular fraction with a maximum size of 25mm, without admixtures have shown the highest compressive strength. At a lower water to cement ratio, the binary granular system produced the highest compressive strength.

This paper reports the result of a research undertaken to investigate the effect of three different types of coarse aggregate on the compressive strength of normal concrete. Several models were proposed and statistically validated.

2. Materials and Method

2.1 Materials

2.1.1 Cement: Commercially available Ordinary Portland Cement was used for this purpose. This cement has a specific gravity of 3.15.

2.1.2 Aggregate: Three types of coarse aggregates; crushed quartzite, crushed granite, and river gravel; were used. The fine aggregate is normal sand obtained from a borrow pit. Preliminary laboratory investigation was conducted to ascertain the suitability of using the aggregates for construction work.

2.1.3 Water: Potable drinking water obtained from Civil Engineering Laboratory, Federal University of Technology Minna, Nigeria was used for this work. This water is therefore suitable for concrete work (BS 3148, 1980).

2.2 Method

2.2.1 Mixture Proportions

A nominal mix ratio of 1:2:4 (Cement: Fine Aggregate: Coarse Aggregate) was adopted for the purpose of this work and a water-cement ratio of 0.6 was used. The mix composition was computed using the absolute volume method from equation (1) and the batch compositions are shown in Table 1.

\[
\frac{W_w}{1000} + \frac{W_c}{1000SG_C} + \frac{W_{fa}}{1000SG_{fa}} + \frac{W_{ca}}{1000SG_{ca}} = 1 (m^3)
\]

where:
- \(W\) = Weight of water (Kg)
- \(C\) = Weight of cement (Kg)
- \(S\) = Weight of sand (Kg)
- \(SG_{C}\) = Specific gravity of cement (3.15)
- \(SG_{FA}\) = Specific gravity of sand
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SG<sub>CA</sub> = Specific gravity of coarse aggregate

### Table 1: Mix composition of concrete (1m<sup>3</sup>)

| Aggregate type    | C (kg/m<sup>3</sup>) | W (kg/m<sup>3</sup>) | FA (kg/m<sup>3</sup>) | CA (kg/m<sup>3</sup>) |
|-------------------|----------------------|----------------------|-----------------------|-----------------------|
| Crushed quartzite | 315                  | 189                  | 630                   | 1260                  |
| River gravel      | 312                  | 187.2                | 624                   | 1248                  |
| Crushed granite   | 317                  | 190.2                | 634                   | 1268                  |

2.2.2 Casting, Curing and Testing of Specimen

There are three sets of mix ingredients as shown in Table 1. The required volumes of mix ingredient were measured and mixing was done thoroughly to ensure that homogenous mix is obtained. Before casting, the slump of the concrete is measured in accordance to BS 1881: Part 102 (1983). For each type of coarse aggregate 15 cubes (150x150mm) were cast in accordance to BS 1881: Part 108 (1983). After one day of casting, the concrete cubes were removed from the mould and were transferred to a water tank for curing until the time of test. The curing of the cube was done according to BS 1881: Part 111 (1983). The concretes were tested for compressive strength at 3, 7, 14, 21, and 28 days. Three cubes were crushed using the compressive testing machine and the average taken as the compressive strength of the concrete.

3. Model development

Models for compressive strengths have been developed using the experimental results. These models are shown in Figure 1. Excel package was used for the model development. Various regression models were tried using the chart wizard and the trends of the graphs are used to choose the best model that adequately represents the data. Linear regression was performed using the data analysis menu in the tools option of excel package. Several model statistics and graphical plots were obtained which can be used to explain the adequacy of the regression models. The analysis was done at 95% confidence interval. The level of significance is therefore 0.05.

4. Result and Discussion

The experimental results are discussed as follows:

4.1 Properties of Aggregates

The results for the sieve analysis test on the aggregates are shown in Figures 1-4. The grading curve for the aggregates falls within the lower and upper limit of the grading requirement for aggregate from natural sources BS 882 (1992). This implies that the aggregates are suitable for construction work. However, the grading curve for crushed granite (Figure 2) shows a reasonable fall out from the gradation limit and a significant portion of the curve is below the lower limit requirement. Such aggregate may require greater fines to achieve reasonable workability.

The values of the specific gravities of the aggregates are from 2.60 to 2.70 (Table 2). These values are within the ranges for the specific gravity of aggregates from rock fragments...
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(Olanipekun, Olusola, and Ata 2006; Neville, 1995). This further buttresses the point that the aggregates can be used for construction work. The loose bulk density measures the volume that the aggregate will occupy in concrete. The result for the loose bulk density is also shown in Table 2. The loose bulk densities for fine and coarse aggregates are in the range of 1123.29 kg/m\(^3\) and 1457.22 kg/m\(^3\). The ratio of the loose bulk density to the compacted bulk density is between 0.87 to 0.96 (Neville, 1995). The value of the ratio obtained for coarse aggregate is within the specified limit as shown in Table 2. However, for fine aggregate a value of 0.71 is obtained which is outside the recommended range. This indicates that the fine aggregate is unstable and contains void. Adequate compaction is therefore required to obtain durable concrete matrix.

![Figure 1: Sieve analysis for crushed quartzite aggregate](image1.png)

![Figure 2: Sieve analysis for crushed granite aggregate](image2.png)
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**Figure 3**: Sieve analysis for river gravel

**Figure 4**: Sieve analysis for fine aggregate

**Table 2**: Properties of aggregate

| Properties                        | Quartzite aggregate | River gravel   | Granite aggregate | Fine aggregate |
|-----------------------------------|---------------------|----------------|-------------------|----------------|
| Specific gravity                  | 2.66                | 2.60           | 2.70              | 2.66           |
| Loose bulk density                | 1351.20             | 1457.22        | 1355.31           | 1123.29        |
| Compacted bulk density            | 1521.82             | 1655.83        | 1516.77           | 1572.81        |
| Ratio of loose bulk density to compacted bulk density | 0.887884 | 0.880054 | 0.89355 | 0.714193 |

**4.2 Slump**

The result for the slump test of the fresh concrete is shown in Figure 5. The slumps obtained are in the medium range (35–70mm). The highest slump was obtained with concrete made with river gravel. River gravel has a relatively smooth surface and round in shape, being water-worn due to the action of running water and thereby enhanced the workability of fresh
concrete. This aggregate requires less amount of paste to coat its surface and thereby leave more paste for lubrication so that interactions between aggregate particle during mixing is minimized (Mindess, Young, and Darwin, 2003). Quartzite and granite aggregates are crushed from rock fragments and this gives the aggregate a characteristic rough and fairly angular in shape. Aggregate of this nature requires more amount of water when used for concrete work to provide for aggregate coating and lubrication (ACI Committee 211.1-91). The concrete containing crushed quartzite and granite aggregates therefore shows lower workability compared to concrete made with river gravel.

![Figure 5: Slump](image)

### 4.3 Compressive Strength

The result for the compressive strength test on the concrete is shown in Figure 6. For the three types of concrete, it was observed that the compressive strength increases with age at curing. For all the ages at curing, the highest strength was obtained from concrete made with crushed quartzite, followed by river gravel and the lowest strength was recorded with concrete containing crushed granite. The amount of paste required is believed to depend on the amount of void spaces to be filled and the total surface of the aggregate to be coated with paste (Mindess, Young, and Darwin 2003). The significant portion of the gradation curve for the crushed granite aggregate as earlier mentioned, falls outside the recommended range and it is lower than the lower limit. This implies that the coarse aggregate has greater voids to be occupied by mortar. This may affect the workability of the concrete, unless mixture proportioning adjustment is carried out to improve on the rheology. This produces concrete with relatively lower workability where the paste is not necessarily sufficient to coat the aggregate and provide the necessary lubrication as can be seen in Figure 5. This attribute has the potential of producing concrete with weaker mortar/aggregate interface. The growth of crack upon application of load may commence in this region leading to a lower compressive strength as shown in Figure 6. Intermediate strength development was observed with concrete containing river gravel aggregate. River gravel, although the gradation characteristic is good, has rounded particles and may not properly interlock each other during compaction resulting to reduction in strength compared to where full or higher compaction is achievable.
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Figure 6: Compressive strength of concrete

The models for compressive strength of concrete as a function of the age at curing for different aggregate types are shown in Figure 6. The regression output is shown in Table 3. For concrete made from quartzite aggregate, the adjusted coefficient of determination (adjusted $R^2$) is very high, about 0.9779. This implies that about 97.79% of the variability in compressive strength is accounted for by the regression model (Montgomery, Peck, and Vining 2001). This result suggests that the developed model is adequate to explain the data. The $p$-value for the constant term and variable are $4.5119 \times 10^{-05}$ and 0.0014 respectively. The observed levels of significance, $p$-values, for the test on regression coefficient are all less than 0.05. This implies that the contribution of the constant term (intercept) and the variables in the model are significant and should be retained in the model. The analysis of variance (ANOVA) gives F test for significance of regression, $F_0 = 132.94$. This calculated $F_0$ is compared with the theoretical value and a $p$-value for the significance of regression is obtained as 0.0014. Therefore, the hypothesis that the coefficient of the variables in the model should be zero is rejected because the $p$-value is very small (0.0014 is less that 0.05); suggesting that at least some of these parameters are nonzero and the terms contribute significantly to the model. The ANOVA test suggests that the developed model adequately explains the data. Similar explanations apply to other models using the appropriate model statistics shown in Table 3.

Figure 7 shows diagnostic plots to further validate the adequacy of the fitted models. The plot of residual versus age at curing shows that the residual of the compressive strength fluctuates in a random manner. The errors are independent since autocorrelation is not observed (Montgomery, Peck, and Vining 2001). This confirms that the terms in the models are adequate. The plot of experimental and predicted compressive strength versus the age at curing show scattered plots that are very close to each others. This further agrees that the model fits the data adequately.
**Table 3: Regression output for compressive strength models**

| Aggregate type | R²  | Adjusted R² | F₀  | Significance of regression | P-value | Intercept | Variable |
|----------------|-----|-------------|-----|----------------------------|---------|-----------|----------|
| Quartzite      | 0.9779 | 0.9706      | 132.94 | 0.0014                   | 4.5119x10^-05 | 0.0014 |
| River gravel   | 0.9880 | 0.9840      | 246.41 | 0.00056                  | 4.59872x10^-05 | 0.00056 |
| Granite        | 0.9664 | 0.9551      | 86.17  | 0.00265                 | 0.00034 | 0.002646 |

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**Figure 7:** Diagnostic plots

I. Concrete made with quartzite as coarse aggregate

II. Concrete made with river gravel as coarse aggregate

III. Concrete made with granite as coarse aggregate
5. Conclusion

Aggregate type has effect on the compressive strength of normal concrete. Highest compressive strength was achieved from concrete containing crushed quartzite, followed by concrete containing river gravel. Concrete containing crushed granite shows the least strength development at all ages. Linear polynomial model as a function of age at curing is adequate to account for the variability in the compressive strength data. It is suggested that crushed quartzite aggregate may be employed for concrete work in places where concrete practitioners have variety of choices available.

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