Engineering properties of concrete made from gravels obtained in Southwestern Nigeria

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Abstract: This study investigates the engineering properties of concrete produced from gravels and also verify the suitability of local gravel aggregates obtained from Southwestern Nigeria in place of crushed granite. Preliminary investigations were carried out in five selected states (Ogun, Oyo, Osun, Ondo and Ekiti) in Southwestern Nigeria to determine the registered gravel mining pits. Fifteen gravel mining pits based on age and scale of mining operations were selected for this study. Appropriate gravel constituents in concrete mix were determined using Gs factor. Concrete cubes 150 mm, 150 × 300 mm² cylinder modes and 150 × 150 × 750 mm³ beams were cast with collected gravel. 1:2:4 mix ratio was employed. Sieves analysis, density, water absorption were carried out on aggregates, while compressive, flexural and split-tensile strengths of the concrete were determined for 28 days using ASTM and BS methods. High concrete strengths resulted from high FM, low AAV and average Gs of gravels. Gravel location with highest compressive, flexural and split-tensile strengths of concretes had 24.8, 3.5 and 2.8 N/mm² satisfying the minimum requirement of BS 811:1997 while that with lowest strengths had 9.6, 2.2 and 1.7 N/mm², respectively. Sources of gravel highly influence compressive, flexural and split-tensile strengths of the cubes and beams.

Subjects: Mathematics & Statistics; Physical Sciences; Engineering & Technology
Keywords: coarse aggregates; gravel aggregate; concrete; aggregates properties
1. Introduction
Unavailability or scarcity of construction materials with the resultant increase in cost had caused a
great depression in the construction industry in Nigeria. As a result, the demand of the housing sec-
tor of the construction industry has not been met over the years regarding the construction materi-
als like gravels (aggregate) as an important component of concrete (Dirisu & Olabiran, 1991; Idiak, 
2006). Aggregates generally occupy 70–80% volume of concrete and can therefore be expected to
have important influences on their properties (Fowler & Quiroga, 2003). They are granular materials
derived from natural rocks, crushed stones, or natural gravels and sand, in addition to their use as
economical filler, aggregates generally provide concrete with good dimensional stability and wear
resistance (Dahunsi, 2003). A good aggregate should produce the desired properties in both fresh
and hardened concrete (Jackson, 1984). Aggregate should be least porous, densest, and strongest
and contains less deleterious materials such as clay, silt and dust (Chowdhury, 1982). Brandy,
Clauser, and Vaccnri (2002) found that gravel are results of the natural disintegration of rock which
are at least 2 mm diameter, larger sizes may be called pebbles, cobble or boulders and are usually
rounded and as such required less amount of cement paste which saves about 4–5% cement paste.
Shetty (2005) reported that in concrete, aggregates and paste are the major factors that affect the
strength. Adebakin, Adu, and Ofuyatan (2015) reported the use of recycled aggregate from old con-
crete cubes is suitable with up to 75% replacement of natural aggregate with recycled aggregate,
the 28 days compressive strength of concrete is in close proximity with that of normal concrete.
Aggregate properties significantly affect the workability of plastic concrete and the durability,
strength, thermal properties, and density of hardened concrete (ACI, 1999). Lawal (2011) also
worked on gravel mining in Nigeria and examined the effects and characteristics of aggregates in
concrete. Bamigboye, Ede, Umana, Odewumi, and Olowu (2016) discovered that gravel aggregates
have not been adequately utilized as they should, partly because of the fear that gravel cannot with-
stand as much pressure as granite due to its chemical composition. This paper however went further
to establish gravel locations, cost and some other variables. In selection of gravels for construction
work, there are certain factors that should be looked into, though the choice is in most cases further
limited by the cost. Its cost depends upon the ease with which it could be quarried or mined, the
proximity of the quarry to the place of use, and the availability of transport facilities. General struc-
ture, fineness of grain, compactness, porosity and absorption, hardness, resistance to weather,
weight and strength are some of the characteristics of good gravels (Spencer & Cook, 1983).
Kosmatka, Kerhhoff, and Panarese (2002) concluded that close to half of the coarse aggregates
used in Portland Cement Concrete in North America are gravels while most of the remainder are
crushed stones. Therefore any advocacy for completely new or blended materials should be tested
both structurally and mechanically to ascertain the short-time and long-time behavior of the mate-
rials. This will certainly help to establish a well-define boundary or clearly spelt out limitation espe-
cially when local code of practice for design, construction and workmanship is yet to be published
for engineers and builders. Investigation of concrete properties produced from gravels obtained from
Southwestern Nigeria would enable the provision of data not only for the formulation of indigenous
standards, but would also help to avoid use of sub-standard gravels that might contribute to failures
of infrastructures. Engineering properties of concretes produced from gravels from selected loca-
tions in Southwestern Nigeria is the main focus of this paper.

1.1. Study area
Southwestern Nigeria lies between latitudes 6°N and 9°N of Greenwich Meridian and longitudes 2.5°E
and 6°E of the Equator. It is one of the six geo-political zones of Nigeria and comprises six states. The
states in this zone include Lagos that lies on latitude 6.27°N and longitude 3.28°E with land area of
3,345 km²; Oyo State on latitude 7.4°N and longitude 4.0°E with land area of 35,742.84 km²; Ogun
State with land area of 16,409.26 km² is located between Latitudes 6.2°N and 7.8°N and Longitudes
3°E and 5°E; Ekiti State is between latitudes 7°15' and 8°5' north of the equator and longitudes 4°5' and
5°45' East of Greenwich Meridian, with land area of 6,353 km²; Osun State has land area of
10,456 km and located on Latitudes 7°45'N and Longitudes 4°E; and Ondo State which is bonded in
the east by Edo and Delta States, in the north by Ekiti and Kogi States, in the west by Osun and Ogun
States and in the south by Atlantic ocean. Ondo is located on Latitudes 7°10'N and Long. 5.05°E.
In this study area shown in Figure 1 there are many infrastructures such as high rise office buildings, residential, commercial and industrial buildings, as well as wide and expansive networks of highways and rural roads. These diverse infrastructures are made from different materials, mostly concrete, the constituents of which include gravels.

1.2. Availability of gravels
The factors which affect the local availability and supply of construction gravel include demand and supply of the resource. The following factors have influences on future demand of gravel in Nigeria; population growth, personal income, statewide economic growth, state infrastructural needs and personal interest. Gravel like other natural resources occurs where nature placed it, not where people need it. Even where nature has placed it, mining and supply of aggregate (gravel) near populated areas can be further limited due to land use conflicts. Some of these conflicts are: sterilization; building over a deposit as cities grow or extend into rural areas, encroachment; new residential development near existing quarries and gravel pits, depletion; extracting the resources in existing mines at a higher rate, difficulty of permitting new mines and competing land uses such as perpetual conservation easements (Langer & Glanzman, 1993).

2. Methodology
In order to select gravel pits for the collection of samples for this study, the research instrument adopted for the work was structured in two parts—questionnaires which consisted of 18 and 16 questions that were targeted at gravel suppliers and bricklayers respectively. As a result of this 15 major commercially operated pits or sites were selected for the collection, testing and analysis/discussion of samples. The gravel samples were collected at different levels both vertically and horizontally to have a better representation of samples in a particular location. They were kept in polythene bags which were sealed to prevent moisture so as not to affect the natural conditions of the samples. The gravel aggregates used for this study were sourced locally from five states in Southwestern Nigeria; Ogun, Oyo, Osun, Ondo and Ekiti States as shown in Plates 1–3. The samples were coded according to state and town of collection as OG. 01 AB for Ogun State, OY. 02 IG for Oyo State, OS. 01 OS for Osun State, OD. 01 MD for Ondo State and EK.01 AD for Ekiti State. Ogun River at Majidun in Ikorodu, Lagos State were used as fine aggregates. Washed gravel was used as coarse aggregates. The ratio of fine to coarse aggregate adopted was 45:55 (ACI, 1992; Krell & Wischers, 1988). The Lafarge Elephant Portland Cement grade (42.5R) was used as binders for this study while portable water was used for the mixing. Also, 1:2:4 mix ratio with 0.60 water/cement ratio was adopted. All the aforementioned were used as constant parameters for all the samples. The physical test adopted for this study were particle size distribution to determine the grading of aggregates, water absorption and aggregates crushing value tests were determined, specific gravity was determined using BS 1881-122:1983. Absorption, and voids in Hardened Concrete were determined using ASTM C642-13-16 (n.d). The specimen was dried at 100 to 110°C and immersed in water at 21°C. Also
carried out were density to determine the solidity of hardened concrete, slump test to determine the degree of consistency of fresh concrete. Compressive, split tensile strength and flexural test were carried out on hardened concrete. The compressive strength $f_c$ was determined in accordance with BS 1881-108:1983 using 150 mm cubes as shown in Plates 4 and 5. The flexural strength test, beams were cast, cured for 28 days and tested for flexure (modulus of rupture) using the three point loading method. After curing, the beams were tested using Universal Testing Machine (UTM) at a rate of
increase in stress of 0.02 N/mm²/s in line with BS 1881-118:1983. Split tensile test was carried out as prescribed by BS 1881-117:1983. The results obtained from the laboratory were compared with permissible limits given in different standard codes and specifications using ANOVA.

3. Results and discussion
Having completed the laboratory tests, the results were analysed using ANOVA and discussed in relation to relevant standards. Some of the engineering properties of fresh and hardened concrete measured were density, slump, water absorption, compression, flexural and split tensile strength. All the concrete specimens were made with gravel as coarse aggregate. Some of these characteristics of the concrete measured in the laboratory are shown in Table 1.

3.1. Test on fresh concrete

3.1.1. Slump
Table 1, third column shows the values of the slump. Relating these values after (Bartos, 1992), it can be analyzed that mixes of OS. 01 OS sample with zero slump and OG. 03 OB, OD. 03 OK as well as EK. 01 AD having slump values of 3, 2 and 4 mm respectively fall under “no slump or stiff consistency”. Samples OS. 02 IK and OD. 02 IJ each has slump of 5 mm. The two were grouped under “very low consistency”. Similarly, OG. 01 AB, OG. 02 AG, OY. 01 IG, OY. 02 IB and EK. 02 IJ with slumps of 30, 25, 26, 17 and 26 mm respectively were classified as “low consistency”. Other samples such as OS. 03
MD, OD. 01 OD and EK. 03 IG measuring 70, 65, and 55 mm slumps respectively showed “medium consistency”. The only mix that exhibits collapsed slump which is an indication of too much water was OY. 03 IS.

### 3.1.2. Density

Table 1, column seven reports the average density of concrete produced using the selected gravels as coarse aggregate. The values of the densities ranges from 2,123.5 kg/m³ for OS. 02 IK concrete specimen to 2,429.6 kg/m³ for EK. 02. IK concrete specimen. All the densities of concrete specimens therefore fall within the range of normal weight or dense concrete and by extension all the gravels can be used to produce normal weight concrete.

| State  | Gravel sample       | No. of cubes | Ave. slump (mm³) | Ave. weight (kg) | Ave. density (kg/m³) | Ave. load (kN) | Ave. compressive strength (N/mm²) |
|--------|---------------------|--------------|------------------|-----------------|----------------------|---------------|----------------------------------|
| Ogun   | OG. 01 AB (Abeokuta) | 3            | 30               | 7.93            | 2,350.6              | 326.7         | 14.52                            |
|        | OG. 02 AG (Ago-Iwoye)| 3            | 25               | 7.98            | 2,365.5              | 325.0         | 14.45                            |
|        | OG. 03 OB (Obafemi Owode) | 3 | 3 | 7.6 | 2,251.8 | 365.0 | 16.22 |
| Oyo    | OY. 01 IG (Igboora) | 3            | 26               | 8.05            | 2,385.2              | 418.3         | 18.59                            |
|        | OY. 02 IB (Erunmi Ibadan) | 3 | 17 | 7.97 | 2,360.5 | 255.0 | 11.33 |
|        | OY. 03 IS (Iseyin)  | 3            | Col.             | 7.98            | 2,365.5              | 445.0         | 19.78                            |
| Osun   | OS. 01 OS (Oshagbo) | 3            | 0                | 7.78            | 2,306.2              | 206.7         | 9.63                             |
|        | OS. 02 IK (Ikire)   | 3            | 5                | 7.17            | 2,123.5              | 276.7         | 12.3                             |
|        | OS. 03 MD (Modakeke) | 3 | 70 | 7.83 | 2,321.0 | 451.7 | 20.07 |
| Ondo   | OD. 01 OD (Ondo)    | 3            | 65               | 7.97            | 2,360.4              | 426.7         | 18.96                            |
|        | OD. 02 IJ (Iju Itagbolu) | 3 | 5 | 7.93 | 2,350.6 | 453.3 | 20.15 |
|        | OD. 03 OK (Oke Igbo) | 3 | 2 | 7.92 | 2,345.7 | 350.0 | 15.55 |
| Ekiti  | EK. 01 AD (Ado-Ekiti) | 3 | 4 | 7.97 | 2,360.5 | 558.3 | 24.81 |
|        | EK. 02 IK (Ikole-Ekiti) | 3 | 26 | 8.2 | 2,429.6 | 521.7 | 23.18 |
|        | EK. 03 IG (Igbara-Odo) | 3 | 55 | 7.97 | 2,360.5 | 401.7 | 17.85 |
### 3.2. Test on hardened concrete

#### 3.2.1. Compressive strength

Based on BS 8110-2:1985 it was found that specimens EK. 01 AD, EK. 02 IK, OS. 03 MD and OD. 02 IJ having concrete cube strength of 24.81, 23.18, 20.07, and 20.15 N/mm² respectively as shown in Table 1 are all grade 25 concrete. Other specimens expect OY. 02 IB, OS. 01 OS and OS. 02 IK are in the category of grade 20 concrete. The low values of some of these specimens might be due to one or more of the following factors;

- The variation in moisture content.
- The grading of the aggregates.
- The human or mechanical errors or inaccuracies in weighing and batching.
- The manner in which the cubes are made, etc.

#### 3.2.2. Flexural strength

The tensile strength of concrete otherwise known as modulus of rupture is much smaller than the compressive strength and is in most cases usually effectively eliminated by cracking, whether the crack is visible or not. Consequently, the tensile strength of concrete is not usually taken into account for design purposes, though it can be important inasmuch as it influences and contributes to the flexural strength of concrete paving (Shetty, 2005). A study of Table 2 shows a range of flexural strength from lowest value of 2.17 N/mm² for specimen OS. 01 OS to the highest value of 3.49 N/mm² for specimen EK. 01 AD. These values of flexural strength is well within the permissible values given by BS EN 1992-1:2004.

#### 3.2.3. Split tensile strength

Splitting tensile strength is one of the parameters that controls the rate of reinforcement corrosion and also indicates the potential for an increase in the usefulness of the service life of concrete.

### Table 2. Flexural strength of gravel concretes

| Beam specimen | No. of beam | Ave. weight (kg) | Ave. density (kg/m³) | Load (kN) | Point of fracture (mm) | Ave. flexural strength (fₚ) (N/mm²) |
|---------------|-------------|------------------|----------------------|----------|------------------------|-------------------------------------|
| OG. 01 AB     | 2           | 39.93            | 2,366                | 28       | 318                    | 2.65                                |
| OG. 02 AG     | 2           | 39.91            | 2,362.8              | 30       | 300                    | 2.65                                |
| OG. 03 OB     | 2           | 38.81            | 2,362.8              | 30       | 315                    | 2.73                                |
| OY. 01 IG     | 2           | 40.21            | 2,391.3              | 32       | 320                    | 3.04                                |
| OY. 02 IB     | 2           | 39.84            | 2,365.35             | 26       | 305                    | 2.35                                |
| OY. 03 IS     | 2           | 40.0             | 2,367.9              | 33       | 318                    | 3.11                                |
| OS. 01 OS     | 2           | 39.57            | 2,288.7              | 27       | 270                    | 2.18                                |
| OS. 02 IK     | 2           | 37.48            | 2,145.5              | 26       | 319                    | 2.49                                |
| OS. 03 MD     | 2           | 40.16            | 2,390.1              | 33       | 320                    | 3.12                                |
| OD. 01 OD     | 2           | 39.77            | 2,367.75             | 35       | 295                    | 3.08                                |
| OD. 02 IJ     | 2           | 39.83            | 2,365.3              | 35       | 300                    | 3.11                                |
| OD. 03 OK     | 2           | 40.03            | 2,359.1              | 32       | 295                    | 2.79                                |
| EK. 01 AD     | 2           | 40.0             | 2,365.35             | 37       | 322                    | 3.50                                |
| EK. 02 IK     | 2           | 40.5             | 2,415.3              | 36       | 315                    | 3.38                                |
| EK. 03 IG     | 2           | 39.66            | 2,363.85             | 35       | 285                    | 2.97                                |
Abdullah (2012) confirmed that improvement in split tensile strength results in an increase in the useful service life of concrete by decreasing cracks due to reinforcement corrosion.

Table 3 shows the results of splitting tensile strength of concrete. The values range from minimum of 1.72 N/mm² for sample OS. 01 OS to maximum value of 2.80 N/mm² for specimen EK. 02 IK. These results conform to (Hannant, 1972) values of tensile strength in relation to strength class. The values ranging from 1.7 to 2.8 N/mm² for strength class C12/16 and C25/30 respectively. Critical examination of this standard also confirms an assertion that splitting tensile strength is generally greater than direct tensile strength and lower than flexural strength—modulus of rupture (Hannant, 1972). Shetty (2001) recommended minimum split tensile of 10 N/mm² for 1:2:4 mix proportion at 28 days and 4 N/mm² for 1:3:6 mix proportion at 28 days.

3.2.4 Water absorption capacity
Table 4 shows the results of the water absorption capacity of concrete. The absorption tests are not used frequently except for routine quality control of precast products. The results reveal that specimen OS. 02 IK has the highest value of absorption capacity of 6.80%, while specimen OS. 03 MD has the lowest water absorption capacity of 4.32%. From this finding, it can be inferred that specimen OS. 02 IK is the most porous of all the samples, while specimen OS. 03 MD is the least porous. However, going by the assertion that most good concretes have absorption well below 10 per cent, it can be inferred that all the selected gravel aggregate samples from Southwestern Nigeria produce good quality concrete in terms of water absorption characteristic of concrete products.
4. Conclusions
The study has established that:

(1) OS. 03 MD, OD. 01 OD and EK. 03 IG show medium consistency while others fall under very low and stiff consistency.

(2) All the densities of concrete specimens fall within the range of normal weight or dense concrete.

(3) EK. O1 AD, EK. 02 IK, OS. 03 OB and OD. 02 IJ produced grade 25 concrete while OY. 02 IB, OS. 01 OS, and OS. 02 IK are in the category of grade 20 concrete.

(4) EK. O1 AD produced the highest value of 3.49 N/mm² flexural strength while OS. 01 OS produced the lowest value of 2.17 N/mm². The values of flexural strength fall within the permissible values given by EN 1992-1-1 (2004).

(5) Engineering properties of concrete cubes and beams produced from gravel sourced from different locations in Southwestern Nigeria varied. Gravelly concretes with high strength could be used in construction of low rise buildings and rural roads while those with low strength could be employed in applications (walkways) where high strength is not required.

(6) The engineering properties of concrete (compressive, flexural and split-tensile strengths, consistency measured with slump, density, and absorption capacity of concrete) made with the gravel as coarse aggregate though varied from location to location are within specified standards. Therefore the results provide data bank for technical and economical infrastructural developments in Southwestern Nigeria.

Table 4. Water absorption capacity of gravelly concretes

| Concrete sample | No. of cubes | Ave. weight of saturated specimen (kg) | Ave. weight of oven dried specimen (kg) | Ave. water absorption capacity (%) | Ave. value of water absorption capacity (%) |
|-----------------|--------------|---------------------------------------|----------------------------------------|-----------------------------------|------------------------------------------|
| OG. 01 AB       | 3            | 7.70                                  | 7.30                                   | 5.48                              | 5.44                                     |
| OG. 02 AG       | 3            | 8.00                                  | 7.65                                   | 4.58                              | 5.02                                     |
| OG. 03 OB       | 3            | 7.65                                  | 7.30                                   | 5.38                              | 5.05                                     |
| OY. 01 IG       | 3            | 7.95                                  | 7.60                                   | 4.61                              | 5.30                                     |
| OY. 02 IB       | 3            | 7.90                                  | 7.50                                   | 5.33                              | 5.09                                     |
| OY. 03 IS       | 3            | 7.90                                  | 7.60                                   | 3.95                              | 4.52                                     |
| OS. 01 OS       | 3            | 7.50                                  | 7.18                                   | 4.46                              | 5.08                                     |
| OS. 02 IK       | 3            | 7.00                                  | 6.60                                   | 4.00                              | 6.80                                     |
| OS. 03 MD       | 3            | 7.80                                  | 7.50                                   | 4.00                              | 4.32                                     |
| OD. 01 OD       | 3            | 7.85                                  | 7.40                                   | 6.08                              | 5.27                                     |
| OD. 02 IJ       | 3            | 7.75                                  | 7.35                                   | 5.44                              | 4.46                                     |
| OD. 03 OK       | 3            | 7.80                                  | 7.35                                   | 6.12                              | 4.97                                     |
| EK. 01 AD       | 3            | 7.85                                  | 7.45                                   | 5.37                              | 4.48                                     |
| EK. 02 IK       | 3            | 8.10                                  | 7.70                                   | 5.20                              | 5.01                                     |
| EK. 03 IG       | 3            | 8.00                                  | 7.63                                   | 4.85                              | 4.70                                     |

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