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# Influence of Quantity and Quality of Fines in Dug-up Gravel on the Performance Characteristics of Concrete

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## Abstract

The effects of quantity and quality of fines in the two earlier identified dug-up gravels as aggregates, on the performance characteristics of concrete were investigated. This aims at providing scientific solutions to the failure of concrete structures resulting from use of poor quality aggregates. Gravel A (*Tiwantiwa*) and gravel B (*Majeroku*) which were two major gravel sources in Ile-Ife and Ikire areas of Osun State were procured. The quantity and quality characteristics of the fines in the gravels were determined through gradation, chemical and mineralogical composition analyses. Each of the gravel was sieved into fines (≤ 2 mm) and non-fines (2 mm ≤ particle size ≤ 20 mm). The fines (F) and non-fine (NF) were later re-combined at varying percentages as coarse aggregate portion to make concrete cubes and beams for compressive and flexural strength tests using 1:2:4 mixes. The results showed that the gravels were absent of deleterious chemical compounds or minerals, but contained some level of impurities. At 28-day, the average compressive strength of concrete made with 0% F + 100% NF as coarse aggregate for both gravels A and B was 18.5 N/mm$^2$ and 16.1 N/mm$^2$. These values were decreasing as the quantity of fines in the coarse aggregate increased up to 100% F with 0% NF. There is good agreement between the experimental and modelled strengths. The recommended characteristic strength of concrete made with both gravels at fines content not exceeding 20%, at 28-day and 56-day curing ages are 14 and 18 N/mm$^2$ respectively.

**Keywords:** Dug-up gravel, fines and non-fines, compressive and flexural strengths, characteristic strength, failure of concrete structures, organic matters, water absorption, coefficient of determination

## 1. Introduction

Concrete is a universal and versatile construction material but very bulky and not easily transported over too long distance across countries. Therefore, the more its constituents (cement and aggregates) are locally sourced the better its affordability. However, cement is expensive in Africa but aggregates are usually cheaper than other concrete constituents, this is one of the reasons that make the use of aggregates to be effective in cost reduction of concrete production. Specifications of aggregates for concrete are usually stated in terms of the need for them to be clean, inert, hard, non-porous and free from excessive quantities of dust and laminated particles. Additional requirements include absence of organic materials as well as clay and other deleterious materials or harmful substances which if present may interfere with bonding and adversely affect the strength development of concrete (Reynold and Steedman, 1988; ACI 221R, 1989; ACI E-701, 2007). These specifications are aimed at preventing inadequacies like low strength, poor bonding leading to failure (cracking, deflection or total collapsed), poor durability and inadequate structural performance of concrete structures. Despite these measures, many cases of collapsed concrete structures are reported almost on daily basis in Nigeria and both the experts and non-professionals in the construction industry have given various factors to be responsible for this. It should be noted that by the provisions of BS 8110 (1997), a structure is considered failed if as a result of some factors, it can no longer fulfil the purpose for which it was designed. This could be through excessive deflection, cracking and vibration or eventual collapse of the structure.

Aggregates for concrete are mostly derived from rocks which are composed of varied minerals by which they are expected to be durable and stable. In some circumstances, deleterious materials may be distributed throughout the entire rock or deposit, be present in only a part or be a localized feature within the source rock or deposit (Poole and Sims, 2003). Sands and gravels (usually unconsolidated raw material) are products of erosion through weathering of pre-existing rocks, usually transported by water and deposited as relatively thin layers at the foot of mountains, river valleys or along shorelines. However, due to some climatic factors such as rainfall pattern or changes to river catchment area over time, most gravel resources are characterised by rapid and local variations in size distributions, degree of sorting within layers, lenses of coarse and finer materials (Poole and Sims, 2003; Fang and Daniel, 2006). These call for effective quality control in the selection of aggregates for concrete production in order to minimize variation from batch-to-batch with consequent adverse effects on strengths.

The standard aggregate for concrete is crusher sand as fine aggregate and crushed stones as coarse aggregate. However, many building owners who cannot afford the high cost of these aggregates usually resort to use of dug-up gravel (which in most cases contain large quantity of fines) and sand without any expert advice. In most cases, no information on the quality characteristics of such gravel is available and the services of civil engineers are not engaged in the design and/or construction-supervision of the concrete structures. Concrete made with gravel had been reported by Giaccio and Zerbino (1998) to have lower compressive strength compared to that made with crushed aggregates. The absence of civil engineer to make necessary tests and adjustments to accommodate the low compressive strength of concrete made with dug-up gravel have led to many incidence of collapse of such concrete structures. A typical example of the adverse effects of fines content on the strength of concrete can be observed in Plate 1 showing a collapsed one-storey building identified in Ile-Ife area, Osun State. Close observation of the concrete specimens from the site showed that, apart from other structural problems like inadequate reinforcement for the first floor slab, the concrete used in the construction was of poor quality as it had low cement content and contained too much fines. These made it difficult for the concrete to develop adequate compressive strength, lost bond with the reinforcement and easily crumbled which eventually led to its collapse even under its self-weight.

Plate 1: A collapsed one-story building

According to Olajumoke *et al* (2009) collapse of concrete structures had imparted negatively on the socio-economic status of Nigerian as many useful lives and properties had been lost in such incidence in recent years. Also, other authors (Ometan, 1987; Diyoke, 2006; Okovido, 2006; Ephriam, 2007) have made submissions on some of the factors responsible for collapse of reinforced concrete structures to include faulty design and construction as well as use of poor quality aggregates. In addition, non-engagement of civil engineers in the design and construction-supervision of concrete structures and emergence of developers who are not professionals in construction industry, in recent time are parts of the problem.

However, as use of dug-up gravel for concrete is popular in developing countries and exclusive quarrying without fines may be difficult, standardization of use of the gravel is important. Hence, acceptable level of fines content for concrete of adequate properties needs to be established to reduce incidence of collapse of concrete structures. Therefore, generation of scientific data through research on the properties of dug-up gravel and concrete made with it is important for safe design and construction. This will assist the engineer to use realistic properties at the design and construction stages.

In the development of such standards, understanding of the geology of the quarrying area is important for appropriate use of dug-up gravel as aggregates in concrete. According to Rahaman and Malomo (1983) the geology of Nigeria is dominated by crystalline and sedimentary rocks, both of which occur in about equal proportions. In addition, Ile-Ife is reported to be located in the crystalline basement complex area of Southwestern Nigeria and the commonly recognised rocks in this area consist of gneisses, schist, amphibolites, migmatites, quartizite and pegmatite, of great structural complexity. The central Western Nigeria (where Ile-Ife lies) has soils that overlaid the basement complex rocks of the Precambrian age and are principally composed of metamorphic and igneous rocks (Smyth and Montgomery, 1962). These rocks vary in grain sizes and mineral compositions; pegmatite is coarse-grained, schist is fine-grained, quartzite is acidic and amphibolite is basic while granites and gneisses form about 60% of the basement complex metamorphic rocks found in this zone (Smyth and Montgomery, 1962; Ojanuga, 1978).

The focus of this study is standardization of the use of dug-up gravel in Southwestern Nigeria for production of concrete with adequate compressive strength, which improvement may have positive effects on other properties of hardened concrete. It also aims at determining the acceptable level of fines in dug-up gravel for safe use in concrete production as a follow-up to Olajumoke and Lasisi (2014). This research has potential for employment and wealth generation in the locality and the results are expected to be useful guides for the engineers and prospective house owners using dug-up gravel as aggregates in concrete. The main objectives of the study are to:

(i) Establish the quality characteristics of dug-up gravel from the two selected sources;

(ii) Determine the level of fines in the procured dug-up gravels;

(iii) Determine the extent to which sieving off the fines from the dug-up gravels influences the compressive and flexural strengths of hardened concrete; and

(iv) Determine acceptable level of fines in dug-up gravels for concrete of acceptable performance characteristics.

## 2. Materials and Methods

### *2.1 Geology of the Study Area*

Geological map of the study area was obtained from the Department of Geology, Obafemi Awolowo University, Ile-Ife, studied and used in conjunction with the information gathered from the field survey about various gravel quarry sites in Ile-Ife area. Different rock types such as gneisses, schist and amphibolite from which the gravel was being weathered were identifiable from the map. Then, in consultation with various suppliers of sand and gravel for construction purposes in Ile-Ife area, six active dug-up quarries sites were identified, visited and gravel materials inspected. It was noted that each of these quarry sites was approximately at the foot of hilly terrains. After discussions with the suppliers and masons (bricklayers), gravel from two popular quarry sites out of the six were selected for use in this investigation. The first one is *Tiwantiwa* (gravel A) which was obtained from around Ile-Ife area, while the second one is *Majeroku* (gravel B) which was procured from Ikire area. These two sites are in Osun state but are about 50 km apart. According to the masons, if a building owner could not afford crushed stones, *Majeroku* (gravel B) which is more expensive than *Tiwantiwa* (gravel A) is commonly used for slabs, beams and columns construction. No scientific reason was given for this other than their belief that it contained larger particle sizes compared to *Tiwantiwa* (gravel A).

### *2.2 Processing and Quality Characteristics Determination of the Dug-up Gravels and Sand*

The silt and clay fractions of the gravels were determined by wet sieving. Also, the gravels were dried-sieved using sieve sizes 20 mm and 2 mm respectively. The fractions that passed through the 20 mm but retained on 2 mm sieves were categorised as non-fine (NF) and kept for use in this study. Those retained on the 20 mm sieve size were discarded while those that passed through 2 mm sieve size were categorised as fines (F) and kept separately for further use. The selection of gravel size range of 2 mm and 20 mm was based on the BS 8110 (1997) provision that recommends for reinforced concrete elements with 25 mm concrete cover to reinforcement, a maximum aggregates ($h_{agg}$) size of not greater than the concrete cover minus 5 mm.

Also, particle size analysis was carried out on the samples of the dug-up gravels and the sand used. The fines content, specific gravity, mineralogical composition and the pH of the aggregates were determined using appropriate methods. The water absorption test of the concrete was carried out in accordance with ASTM C642 (1990). The organic carbon and organic matter of both gravels and the sand were determined in accordance with the procedure stated by Nelson and Sommers (1996). The major elements and chemical compound present in each of the gravel and the sand were determined through X-Ray Florescence (XRF) and X-Ray Diffraction (XRD) respectively, using particle sizes passing 0.425 mm sieve for these analyses.

### *2.3 Determination of Comprehensive and Flexural Strengths of Concrete made with both Gravels*

Different combinations at 20% interval (that is, proportion by weight) of fines and non-fines (unwashed but sieved) of the gravel from the two selected sources were prepared. Trial mixes were carried with each combination as coarse aggregate portion in the prescribed mix proportion 1:2:4 (cement: fine aggregate: coarse aggregate) with sand as fine aggregate portion. These were used to cast concrete cubes size 100 x 100 x 100 mm for the determination of optimum water-cement ratio (w/c). The w/c to give workable mix of all the combinations was got to be 0.8, and this was subsequently used throughout the experiment in the 1:2:4 prescribed mixes. The concrete cubes were prepared in accordance with BS 1881-108 (1983) procedures for compressive strength determination. Also, beams size 100 x 100 x 500 mm were cast from the same concrete and tested using two-point loading for the flexural strength determination. Necessary precautionary measures were taken during the course of the experiment to obtain accurate results.

## 3. Results and Discussions

### *3.1 Quarrying and Quality Characteristics of the Dug-up Gravel and Sand*

A typical quarry site where the dug-up gravel was collected and some sieved samples are shown in Plate 2. It was observed that the raw gravel on site as shown in Plate 2(a) contained more fines than the sieved (using sieve sizes 2 mm and 20 mm) samples shown in Plate 2(b).

Also, wet sieving of both dug-up gravels and the sand using sieve size 0.075 (No. 200) mm, showed that *Tiwantiwa* (gravel A), *Majeroku* (gravel B) and sand contained 8.3%, 7.7% and 12.8% of silt and clay fractions, respectively. These quantities based on ASTM C 33M – 13, are not within acceptable limits (< 1% for coarse and < 5% for fine) for aggregates in concrete. Therefore, reduction of the quantities of silt and clay fractions in these aggregates to produce hardened concrete of adequate properties is inevitable. According to ACI E-701 (2007) large quantity of silt and clay fractions may increase the amount of water required for workable concrete as well as causing delayed setting and hardening that may affect strength and durability of concrete. Similarly, using sieve size 2 mm on the gravel, the percentages of fine portions in *Tiwantiwa* and *Majeroku* dug-up gravels are 26% and 27%, respectively. Also, gravel A was found to be mainly amphibolite rocks-derived and contained a lot of muscovite materials while gravel B was found to be mainly granite rocks-derived and contained a lot of quartz materials. These identified rocks from which the gravels were derived conform to earlier works of Rahaman and Malomo (1983); Smyth and Montgomery (1962), Ojanuga (1978) and Olajumoke *et al* (2007).

(a) Typical dug-up gravel quarry site (b) Typical samples of sieved gravel

Plate 1: Typical quarry site and sieved samples of the gravel used in the study

Table 1 shows the summary of results of some engineering and quality characteristic tests carried out on both gravels and the sand as aggregates in concrete. It can be observed from Table 1 that the soil organic matter in *Majeroku* (gravel B) is 2.9% which is greater than that of *Tiwantiwa* (gravel A) of 1.8%. Therefore, the strength of gravel B concrete may be adversely affected by the soil organic matter than that of gravel A. In addition, visual observation showed that *Tiwantiwa* gravel contained dried leaves and plant debris as major physical impurities while *Majeroku* gravel contained mica flakes and earthworm casts (which are high in organic matter) as impurities. These have potential to make compaction of fresh concrete made with the gravel to be less effective. However, *Majeroku* gravel contained more quartz materials (which is a high resistance rock) than the *Tiwantiwa* gravel. When samples of the three aggregates were soaked in water, the level of impurities in each sample could be assessed by which the solution of sample B (*Majeroku*) was darker in colour than the other two samples A (*Tiwantiwa*) and C (fine sand). This is an indication of level of organic matter impurities in the soil samples. Therefore, reduction in the soil organic matter content of this type of gravel is necessary for production of good quality concrete. The organic carbon is usually taken as 58% of the soil organic matter (Nelson & Sommers, 1996).

Furthermore, Table 1 shows that the pH of both gravels and the sand ranged between 6.2 and 7.6. The importance of pH of aggregates for concrete is in relation to the corrosion resistance of concrete as concrete with low pH value has high corrosive tendency. By Fitzpatrick (1991) classifications, *Tiwantiwa* and *Majeroku* gravels are considered slightly alkaline (pH fell within 7.3 – 7.6) while the sand is slightly acidic (pH fell within 6.0 – 6.5). These show that both gravels and the sand are good enough as aggregates for concrete; they are not likely to induce any corrosive effect on the reinforcement. Also, the specific gravity of both gravels is not less than 2.6; hence they are not lightweight aggregates (Reynolds and Steedman, 1988). Therefore, concrete made with both gravels cannot be considered as lightweight.

Table 1: Engineering property and quality characteristics of both gravels and sand

| Description | Liquid limit (LL) | Plastic limit (PL) | Plasticity index (PI) | % silt & clay (< 0.075mm) | pH in water | Organic matter (%) | Organic carbon (%) | Specific gravity | Uniformity coefficient ($U_c$) |
|---|---|---|---|---|---|---|---|---|---|
| *Tiwantiwa* | 17.7 | 14.7 | 3.0 | 8.3 | 7.3 | 1.8 | 1.0 | 2.75 | 20.0 |
| *Majeroku* | 27.8 | 18.9 | 8.4 | 7.7 | 7.6 | 2.9 | 1.7 | 2.65 | 7.6 |
| Sand | 17.4 | none | none | 12.8 | 6.2 | 2.1 | 1.2 | 2.50 | 3.9 |

The Atterberg limit test results shown in Table 1 for both gravels and the sand indicate that the liquid limits (LL) for *Tiwantiwa* gravel, *Majeroku* gravel and sand are 17.7%, 27.8% and 17.4% respectively. A soil of LL less than 20% is of low plasticity while that with LL greater than 20% but less than 35% is of medium plasticity (Bowles, 1988). The plasticity indices (PI) of *Tiwantiwa* gravel and *Majeroku* gravel are 3.0% and 8.4% respectively, while the sand is expectedly non-plastic. The PI values of both gravels are less than 10% which is an indication of good engineering soils. However, by the results of Atterberg limits tests, *Tiwantiwa* gravel has better engineering properties than *Majeroku* gravel.

### *3.2 Mineralogical Analysis of the Gravels and sand*

The mineralogical analysis of *Tiwantiwa* and *Majeroku* gravels showed both to be of similar composition. *Tiwantiwa* gravel was found to contain some clay minerals with stained dirty reddish brown but the exact species could not be identified by means of petrographic microscope. Quartz was found to be the most abundant light fraction while heavy fractions were muscovite (alkalis feldspar) consisting of microline in various stages of alteration to clay minerals. Opaque which are oxides of iron (Fe) and titanium (Ti) consisting of ilmanite, hematite and goethite were also observed while tourmaline and zircon were trace elements. The *Majeroku* gravel had in addition minor altered feldspar. The sand was found to contain trace clay minerals with yellowish to reddish brown plus some opaque, zircon, tourmaline and quartz.

Generally, apart from the clay fraction in both gravels, the identified minerals have not been reported to have deleterious effects on the properties of concrete. However, this aspect would be subject of further studies. In summary, both gravels and the sand were not found to contain too much deleterious substances that could render them unsuitable for concrete production.

### *3.3 X-Ray Diffraction and X-Ray Fluorescence Analyses of the Aggregates*

The results of X-ray diffraction (XRD) analysis of the three aggregates using search and match method is shown in Table 2. The analysis was to assess the geological and chemical characteristics of the aggregates for concrete production. The chemical compound in *Tiwantiwa* (gravel A) is Sodium Iron Aluminium Silicate Hydroxide [$(Na, K)_2 6Fe_5(Si, Al)_8O_{22}(OH)_2$ and the dominant mineral is Arfvedsonite. For *Majoroku* (gravel B) the chemical compound is Potassium Sodium Iron Silicate Hydroxide [$(K, Na)_4Fe_2(Si_4O_{10})_2(OH, F)$] and the dominant mineral is Fenaksite. For the sand, the chemical compound is Potassium Sodium Iron Magnesium Titanium Silicate Hydroxide [$Na_2K_2(Fe, Mn)_5Mg_2Ti_2Si_8O_{24}(OH, O)_7$] and the dominant mineral is Magnesium-astrophylite. All these compounds have not been reported to have deleterious effects on the strength of concrete. However, due to the presence of potassium and sodium hydroxides in the aggregates, future study will be focused on the possible effects of alkali-silica reaction of the concrete made with both gravels.

Table 3 also shows the results of X-ray fluorescence (XRF) analysis carried out on *Tiwantiwa* gravel, *Majeroku* gravel and the sand with the quantitative proportion of the major elements in each aggregate. The concentration of these elements in both gravels and the sand is similar and this indicates the similarity of the source rocks from which the aggregates were derived.

Table 2: Geological and chemical characteristics of both gravel and sand

| Description | Major chemical compound from XRD analysis | Name of chemical compound | Dominant minerals |
|---|---|---|---|
| ***Tiwantiwa* (Gravel A)** | $(Na, K)_2\ 6Fe_5(Si, Al)_8O_{22}(OH)_2$ | Sodium iron aluminium silicate hydroxide | Arfvedsonite |
| ***Majeroku* (Gravel B)** | $(K, Na)_4Fe_2(Si_4O_{10})_2(OH, F)$ | Potassium sodium iron silicate hydroxide | Fenaksite |
| **Sand** | $Na_2K_2(Fe, Mn)_5Mg_2Ti_2Si_8O_{24}(OH,O)_7$ | Potassium sodium iron magnesium titanium silicate hydroxide | Magnesium-astrophylite |

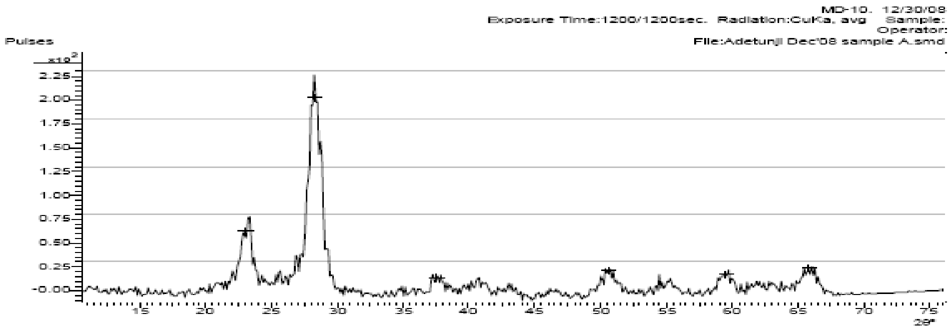
Table 3: Summary of the X-Ray fluorescence (XRF) analysis of both gravel and sand

| Sample | Elements | Concentration value | Concentration error | Unit |
|---|---|---|---|---|
| ***Tiwantiwa* (Gravel A)** | Cl | 197 | ±9 | ppm |
| | K | 5981 | ±152 | ppm |
| | Ca | 1446 | ±57 | ppm |
| | Ti | 3777 | ±69 | ppm |
| | Cr | 82 | ±5 | ppm |
| | Mn | 472 | ±13 | ppm |
| | Fe | 2.4895 | ±0.0110 | Wt% |
| | Cu | 796 | ±23 | ppm |
| | Zr | 313 | ±11 | ppm |
| | Rb | 434 | ±22 | ppm |
| ***Majeroku* (Gtravel B)** | Cl | 174 | ±9 | ppm |
| | K | 5936 | ±153 | ppm |
| | Ca | 2224 | ±71 | ppm |
| | Ti | 2325 | ±66 | ppm |
| | Cr | 155 | ±9 | ppm |
| | Mn | 1634 | ±32 | ppm |
| | Fe | 2.3294 | ±0.0144 | Wt% |
| | Cu | 1430 | ±41 | ppm |
| | Zr | 406 | ±13 | ppm |
| | Rb | 812 | ±35 | ppm |
| **Sand** | Cl | 170 | ±9 | ppm |
| | K | 5346 | ±144 | ppm |
| | Ca | 1662 | ±64 | ppm |
| | Ti | 4528 | ±99 | ppm |
| | Cr | 64 | ±6 | ppm |
| | Mn | 319 | ±15 | ppm |
| | Fe | 2.3884 | ±0.0156 | Wt% |
| | Cu | 1670 | ±47 | ppm |
| | Zr | 225 | ±10 | ppm |
| | Rb | 522 | ±30 | ppm |

Also, the spectra obtained from the search and match for the *Tiwantiwa* and *Majeroku* gravels as well as that of the sand are shown in Figures 1 to 3, respectively. Various peaks of the chemical compounds in each aggregate are clearly identifiable. These results which show similarity of the positions of distinct peaks in the spectra of both gravels are in agreement with that of mineralogical analysis of the aggregates that showed the chemical compounds in both gravels to be similar. This is also in line with the work of Rahaman and Malomo (1983) that identified the dominant rock types in the basement complex of South-western Nigeria to be similar.

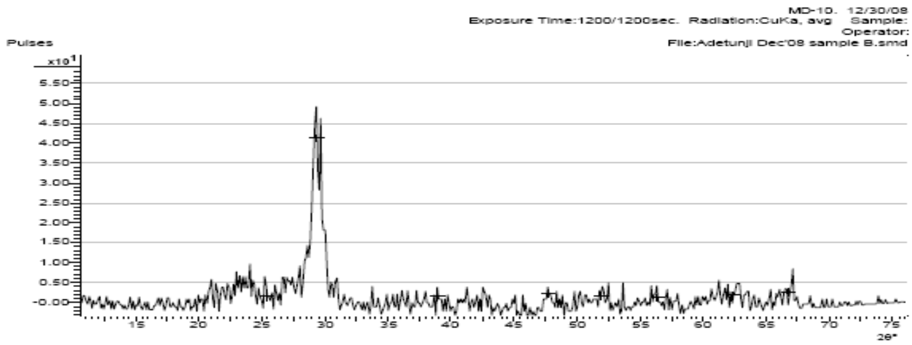
### *3.4 Particle Size Distribution*

The particle size distribution curves of the aggregates had been presented in Olajumoke and Lasisi (2014). The sand was found to contain much higher fines content (≤ 2 mm in this study) than those of the two gravels. The quantities of fines in both gravels are almost the same as stated in 3.1 above, and the fineness of gravel A was found to be slightly higher than that of gravel B. The fines content in aggregate for concrete is to prevent coarse mix which should not be excessive but be enough to make the concrete plastic, workable and give good finish.



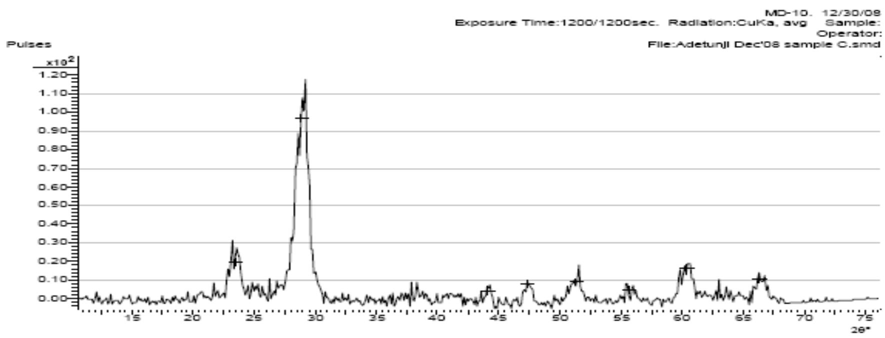

| 2θ° | d | I int | I max | I rel | I corr | FWHM |
|---|---|---|---|---|---|---|
| 23.04 | 3.86057 | 4962 | 63.0 | 36.1 | 39.6 | 1.3658 |
| 28.25 | 3.15935 | 13746 | 202.7 | 100.0 | 100.0 | 1.2357 |
| 37.47 | 2.40004 | 774 | 14.3 | 5.6 | 5.2 | 0.99624 |
| 50.65 | 1.80217 | 1206 | 21.0 | 8.8 | 7.5 | 1.0398 |
| 59.51 | 1.55327 | 1126 | 17.8 | 8.2 | 6.9 | 0.9763 |
| 65.81 | 1.41901 | 2106 | 24.3 | 15.3 | 12.7 | 1.1848 |

Figure 1: Peaks of major chemical compounds in *Tiwantiwa* gravel




| 2θ° | d | I int | I max | I rel | I corr | FWHM |
|---|---|---|---|---|---|---|
| 25.35 | 3.51363 | 1664 | 2.1 | 70.9 | 75.2 | 13.8 |
| 29.34 | 3.04361 | 2346 | 42.0 | 100.0 | 100.0 | 1.0188 |
| 38.87 | 2.31707 | 46 | 2.0 | 2.0 | 1.8 | 0.42697 |
| 47.69 | 1.90694 | 93 | 2.9 | 4.0 | 3.5 | 0.58468 |
| 51.87 | 1.76249 | 158 | 2.2 | 6.8 | 5.9 | 1.273 |
| 56.30 | 1.63403 | 76 | 1.9 | 3.2 | 2.8 | 0.67698 |
| 62.30 | 1.49017 | 711 | 2.5 | 30.3 | 25.7 | 4.0594 |
| 66.81 | 1.40025 | 247 | 3.3 | 10.5 | 8.9 | 1.2086 |

Figure 2: Peaks of major chemical compounds in Majeroku gravel




| 2θ° | d | I int | I max | I rel | I corr | FWHM |
|---|---|---|---|---|---|---|
| 23.46 | 3.79233 | 1709 | 20.1 | 23.9 | 26.2 | 1.4715 |
| 28.90 | 3.08976 | 7156 | 97.4 | 100.0 | 100.0 | 1.3391 |
| 44.09 | 2.05389 | 111 | 4.7 | 1.6 | 1.4 | 0.43511 |
| 47.34 | 1.92026 | 305 | 8.4 | 4.3 | 3.7 | 0.66681 |
| 51.35 | 1.77916 | 557 | 9.9 | 7.8 | 6.7 | 1.0162 |
| 55.67 | 1.65090 | 271 | 5.4 | 3.8 | 3.2 | 0.85216 |
| 60.35 | 1.53359 | 1125 | 16.8 | 15.7 | 13.3 | 1.0099 |
| 66.31 | 1.40962 | 917 | 10.8 | 12.8 | 10.7 | 1.233 |

Figure 3: Peaks of major chemical compounds in the sand

### *3.5 Effects of Quantity and Quality of Fines on Compressive Strength of the Concrete*

Figures 4 and 5 show the compressive strength (CS) development of concrete made with both gravels (*Tiwantiwa* and *Majeroku*) at different levels of fines as coarse aggregate portion in 1:2:4 (cement: fine aggregate: coarse aggregate) mix proportion. Generally for both gravels, the concrete made with sieved samples (0% F + 100% NF) as coarse aggregate gave the highest CS at all the curing ages. It can also be observed that there is substantial increase in the CS of concrete made with this sample at 56-day curing over that of 28-day curing ages. For concrete made with gravels A and B, the CS at 56-day are 20.0 N/mm$^2$ and 20.3 N/mm$^2$ while at 28-day they were 18.5 N/mm$^2$ and 16.1 N/mm$^2$, respectively. These show that the best form of both gravels as coarse aggregate in concrete for maximum CS using 1:2:4 mix proportions, is to sieve off the fines (particle sizes ≤ 2 mm). Therefore, for optimum use of both gravels in concrete, the 56-day characteristic strength is recommended for design of concrete structures. This is based on the fact that most concrete constructions take more than 56 days before they are loaded with the design loads.

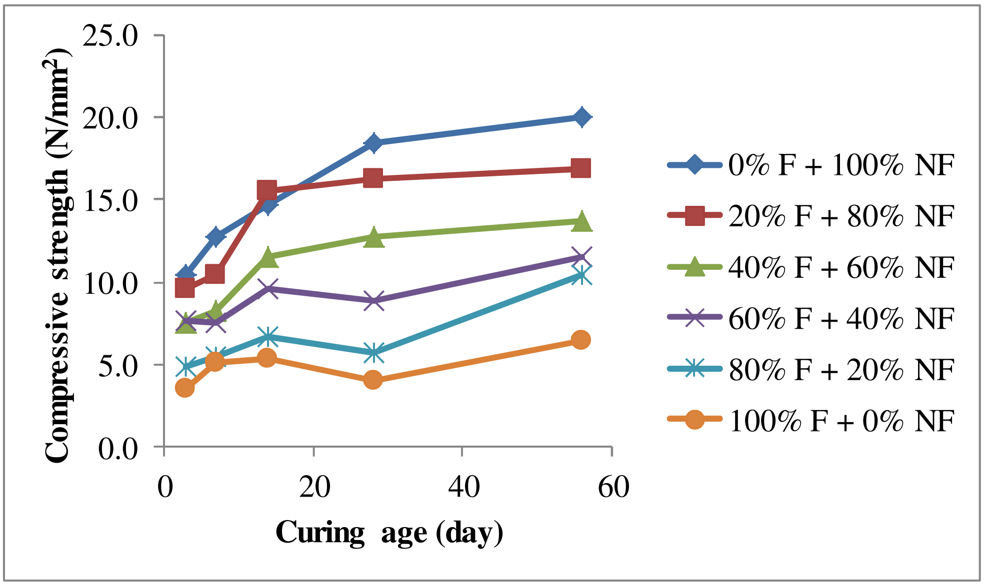



Figure 4: Compressive strength development of concrete made with different combinations of fines (F) and non-fines (NF) of gravel A as coarse aggregate over the curing ages

From Figure 4, the CS development of concrete made with coarse aggregate containing 0% F, 20% F and 40% F of gravel A was progressing over the curing ages. However, concrete made with coarse aggregate containing 60% F, 80% F and 100% F showed abnormality as the CS at 28-day was lower than that of 21-day before the strength started to increase thereafter. This abnormality may be due to the quantity and quality of the fines. Also, in Figure 5, concrete made with coarse aggregate containing low quantity of fines (0% F and 20% F) of gravel B followed the normal trend of CS development in concrete at the curing ages. For concrete made with coarse aggregate of higher quantity of fines (40% F, 60% F, 80% F and 100% F), the abnormality occurred at 7-day curing as the CS fell below that of 3-day. The reason for the abnormality may be due to the presence of earthworm casts (which is high in both organic matter and organic carbon contents) in gravel B as shown in Table 1. These together with mica flakes have potential to adversely affect the rate of hydration in the concrete at the early age which may lower the rate of CS development. Therefore, the gravel suppliers and the Masons (Bricklayers) need to be educated on the importance of avoiding these impurities in the gravel for improved concrete strength. This can be carried out by relevant engineering Societies or Associations through occasional seminars, workshops and awareness programmes for the gravel suppliers and the Masons as well as for the general public.

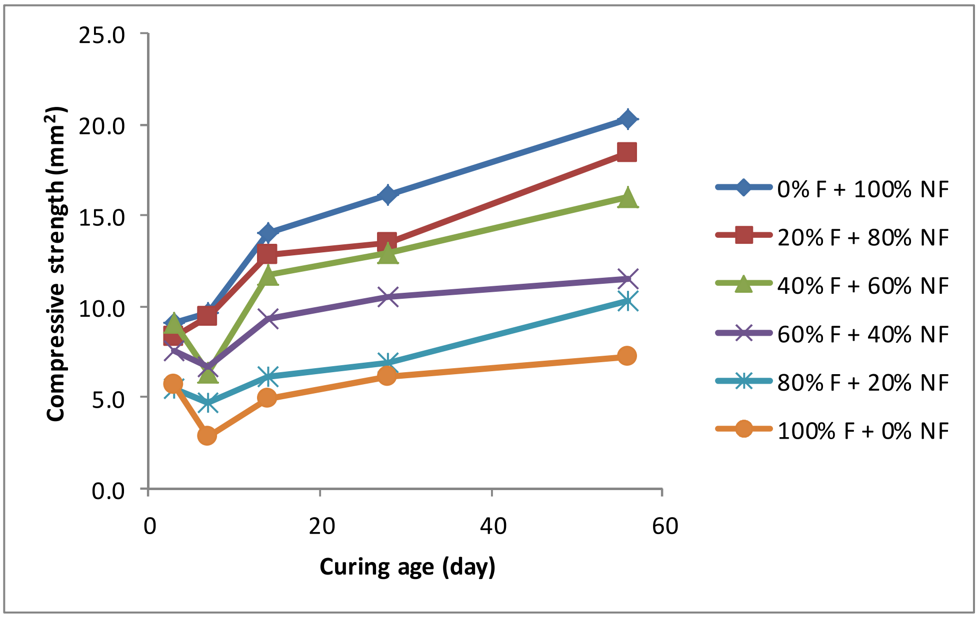



Figure 5: Compressive strength development of concrete made with different combinations of fines (F) and non-fines (NF) of gravel B as coarse aggregate over the curing ages

Tables 4 and 5 show the details of statistical analysis of variance (ANOVA) carried out on the CS of the concrete made with different combinations of fines (F) and non-fines (NF) of both gravels as coarse aggregate at 28-day curing age. The difference in the CS development of concrete made with both gravels is significant ($P < 0.05$) especially in concrete made with fines content higher than 20%. It can be observed that at 28-day curing age, characteristic strength ($f_k$) of 16 N/mm$^2$ and 14 N/mm$^2$ can be used for concrete made with 0% F + 100% NF of gravel A and B as coarse aggregate in the design of reinforced concrete elements. This is because there was adequate bond among the concrete constituents and the concrete will continue to gain strength, though at lower rate. Similar analysis for the same concrete at 56-day curing showed that the characteristic strength of concrete made with both gravels is 18.68 N/mm$^2$ and 18.22 N/mm$^2$ respectively. Therefore, a characteristic strength of 18 N/mm$^2$ can be used for concrete made with both gravels as coarse aggregate in the form 0% F + 100% NF for the design of structural elements. Also, for concrete made with gravel A at 20% F and 80% NF as coarse aggregate, the characteristic strength at 28-day and 56-day curing ages are 14.14 N/mm$^2$ and 14.60 N/mm$^2$ respectively. Those of gravel B at the same curing ages are 11.84N/mm$^2$ and 16.43N/mm$^2$, respectively. Therefore, for concrete made with gravels A and B as coarse aggregate at not more than 20% F, characteristic strength of 14 N/mm$^2$ and 16 N/mm$^2$ at 56-day curing age are recommended, respectively.

Table 4: Summary of the analysis of variance (ANOVA) for compressive strength of concrete made with *Tiwantiwa* (gravel A) as coarse aggregate at 28-day curing age

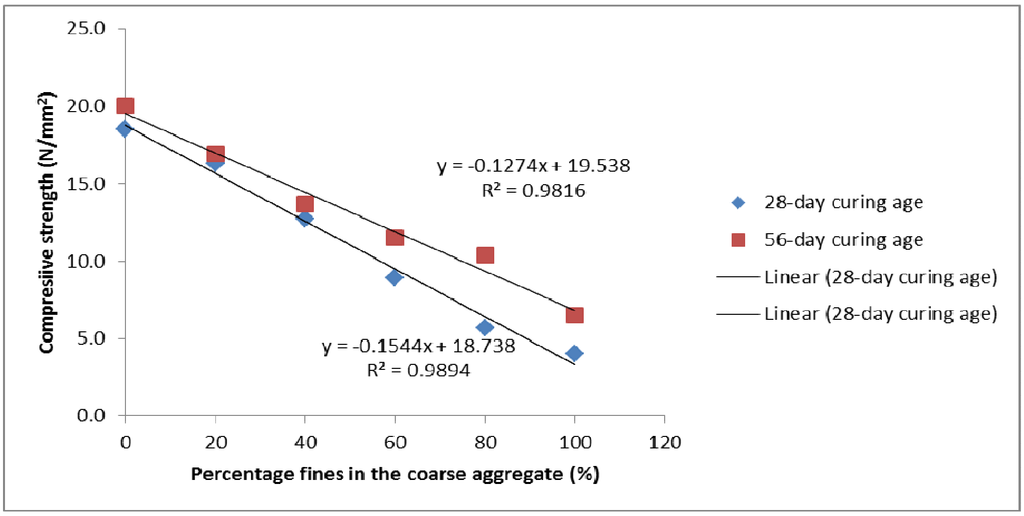
| Form of gravel | Mean compressive strength (kN/mm$^2$) | Characteristic strength (kN/mm$^2$) | Standard deviation | Standard error | 95% confidence interval for mean strength (kN/mm$^2$) | | $P_{value}$ | Decision | Reason | $F_{value}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lower bound | Upper bound | | | | |
| **0% F + 100% NF** | 18.53 | 16.53 | 1.20 | 0.694 | 13.06 | 24.01 | 0.000 | Significant | P<0.05 | 37.843 |
| **20% F + 80% NF** | 16.33 | 14.14 | 1.32 | 0.761 | 10.58 | 22.09 | | | | |
| **40% F + 60% NF** | 12.67 | 10.98 | 1.05 | 0.842 | 7.67 | 17.67 | | | | |
| **60% F + 40% NF** | 8.93 | 7.34 | 0.945 | 0.546 | 6.59 | 11.28 | | | | |
| **80% F + 20% NF** | 5.73 | 4.37 | 0.808 | 0.467 | 3.73 | 7.78 | | | | |
| **100% F + 0% NF** | 4.03 | 3.26 | 0.451 | 0.260 | 2.91 | 5.15 | | | | |

Table 5: Summary of the analysis of variance (ANOVA) for compressive strength of concrete made with *Majeroku* (gravel B) as coarse aggregate at 28-day curing age

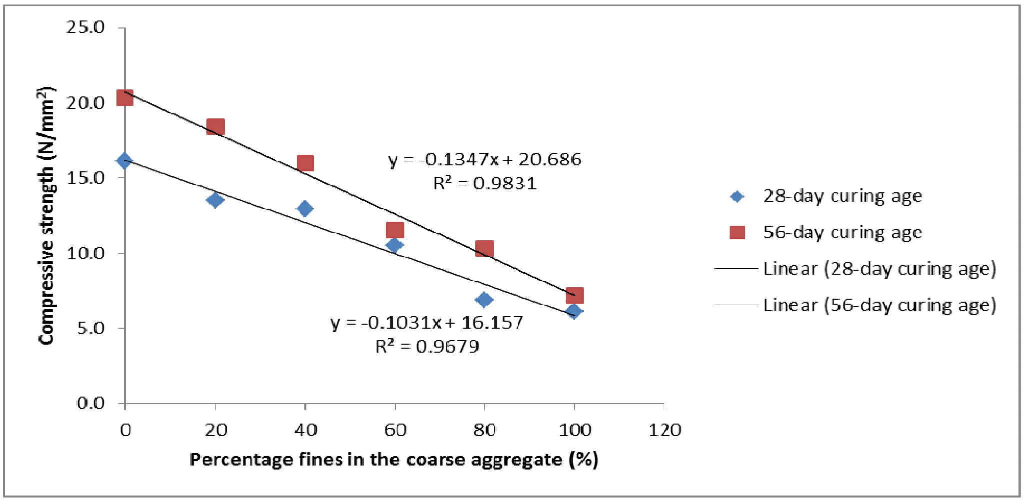
| Form of gravel | Mean compressive strength (kN/mm²) | Characteristic strength (kN/mm²) | Standard deviation | Standard error | 95% confidence interval for mean strength (kN/mm²) | | $P_{value}$ | Decision | Reason | $F_{value}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lower bound | Upper bound | | | | |
| **0% F + 100% NF** | 16.13 | 14.22 | 1.16 | 0.667 | 13.26 | 19.00 | 0.000 | Significant | P<0.05 | 51.008 |
| **20% F + 80% NF** | 13.47 | 11.84 | 1.01 | 0.581 | 10.47 | 16.46 | | | | |
| **40% F + 60% NF** | 12.87 | 11.65 | 0.76 | 0.437 | 10.99 | 14.75 | | | | |
| **60% F + 40% NF** | 10.47 | 8.81 | 1.03 | 0.593 | 7.92 | 13.01 | | | | |
| **80% F + 20% NF** | 6.93 | 5.85 | 0.64 | 0.581 | 4.43 | 9.43 | | | | |
| **100% F + 0% NF** | 6.07 | 5.90 | 0.12 | 0.067 | 5.78 | 6.35 | | | | |

### *3.6 Modelling the Relationship between the Compressive Strength of Concrete made with both Gravels at different Quantity of Fines as Coarse Aggregate*

Figure 6 shows that there is inverse linear relationship between the fines content and the compressive strength (CS) of concrete made with both gravels as coarse aggregate. As the fines content in the coarse aggregate increased there was decrease in the CS of concrete. By this regression analysis, there is high correlation between the quantity of fines in the coarse aggregate and the CS of concrete made with both gravels. Also, the CS at 28-day and 56-day of concrete made with gravel A is diverging while that of gravel B is converging. The values of their coefficients of determination ($R^2$) are 0.9896 and 0.9816 for concrete made with gravel A at 28-day and 56-day while that of gravel B are 0.9679 and 0.9831 at 28-day and 56-day, respectively. Therefore, the CS of concrete made with both gravels as coarse aggregate containing up to 20% F was found acceptable. However, at fines content above 20%, it is recommended that the fines (particle sizes ≤ 2 mm) in either gravel be sieved off using appropriate sieve size before use as coarse aggregate in concrete. Otherwise, such gravel can be used without adding any fine aggregate (i.e. use in raw form) as stated by Olajumoke and Lasisi (2014). According to Olajumoke and Lasisi (2014) if the fines content is not more than 30%, the mix proportion in that case should be 1:6 (cement: raw gravel) and the recommended characteristic strength for design of reinforced concrete elements can be taken as 15 N/mm². By the results of current study, dug-up gravel of fines content less or equal to 20% is acceptable as coarse aggregate portion in 1:2:4 concrete mixes for elements of structural importance. However, the CS of concrete made with gravel of higher fines content as coarse aggregate is not acceptable for elements of structural importance but could be used for mass concrete.




(a) Effect of fines content of gravel A on the compressive strength of concrete




(b) Effect of fines content of gravel B on the compressive strength of concrete

Figure 6: Effects of fines content on the compressive strength of concrete made with gravels A and B as coarse aggregate in 1:2:4 mix proportion at 28-day and 56-day curing ages

Furthermore, the level of agreement of estimated CS of concrete made with both gravels based on equations (1a) to (2b) and that of the experimental values are shown in Table 6. Equations (1a) to (2b) are derived from Figure 6. There is good agreement in the results as the percentage of variation between the experimental and modelled ones is generally low. This means that using constant water-cement (w/c), equations (1a) to (2b) can be used to estimate the CS of concrete made with different fines content of both gravels as coarse aggregate in concrete.

Table 6: Level of agreement between the estimated and experimental results of the compressive strength of concrete made with different forms of both gravels

| Gravel type | Gravel form | Compressive strength at 28-day ($N/mm^2$) | | Percentage of variation (%) | Compressive strength at 56-day ($N/mm^2$) | | Percentage of variation (%) |
|---|---|---|---|---|---|---|---|
| | | **Experimental** | **Modeled** | | **Experimental** | **Modeled** | |
| A | 0% F + 100% NF | 18.53 | 18.74 | 1.13 | 20.0 | 19.54 | -2.30 |
| | 20% F + 80% NF | 16.33 | 15.65 | -4.16 | 16.9 | 16.99 | 0.53 |
| | 40% F + 60% NF | 12.67 | 12.56 | -0.87 | 13.7 | 14.44 | 5.40 |
| | 60% F + 40% NF | 8.93 | 9.47 | 6.04 | 11.5 | 11.89 | 3.39 |
| | 80% F + 20% NF | 5.73 | 6.39 | 11.52 | 10.4 | 9.35 | -10.10 |
| | 100% F + 0% NF | 4.03 | 3.30 | -18.11 | 6.5 | 6.80 | 4.62 |
| B | 0% F + 100% NF | 16.13 | 16.16 | 0.19 | 20.3 | 20.69 | 1.92 |
| | 20% F + 80% NF | 13.47 | 14.10 | 4.68 | 18.4 | 17.99 | -2.23 |
| | 40% F + 60% NF | 12.87 | 12.03 | -6.53 | 16.0 | 15.30 | -4.38 |
| | 60% F + 40% NF | 10.47 | 9.97 | -4.76 | 11.5 | 12.60 | 9.57 |
| | 80% F + 20% NF | 6.93 | 7.91 | 14.14 | 10.3 | 9.91 | -3.79 |
| | 100% F + 0% NF | 6.07 | 5.85 | -3.62 | 7.2 | 7.22 | 0.28 |

For 28-day concrete of gravel A: $$y = -0.1274x + 19.538 \quad (1a)$$

For 56-day concrete of gravel A: $$y = -0.1544x + 18.738 \quad (1b)$$

For 28-day concrete of gravel B: $$y = -0.1374x + 20.686 \quad (2a)$$

For 56-day concrete of gravel B: $$y = -0.1031x + 16.157 \quad (2b)$$

Where:

$y$ is the compressive strength ($N/mm^2$) and $x$ is the percentage quantity of fines (%)

### *3.7 Effects of Quantity and Quality of Fines in the Gravel on the Flexural Strength and other Properties of Concrete*

It can be observed from Table 7 that for fresh concrete made with both gravels, the workability (slump) was inversely proportional to the fines content of coarse aggregate because as the fines content increased the slump reduced. This is due to the fact that as the fines content increased the surface area to be lubricated for hydration products increased and more water was required for this. In this study, the water-cement ratio was made constant (w/c = 0.80) and this means that concrete made with aggregate of high fines content would be stiffer than the one with low fines content. However, the workability of concrete made with 0% F + 100% NF, 20% F + 80% NF and 40% F + 60% NF as coarse aggregate was found acceptable for both gravels in normal concrete work.

Table 7: Properties at 28-day of fresh and hardened concrete made with both gravels at different levels of fines as coarse aggregate

| Gravel type | Form of gravel | Slump (mm) | Water absorption (%) | Flexural strength ($N/mm^2$) | Compressive strength ($N/mm^2$) | $\frac{FS}{CS} X 100\%$ |
|---|---|---|---|---|---|---|
| A | 0% F + 100% NF | 20 | 4.07 | 3.16 | 18.53 | 17.1 |
| | 20% F + 80% NF | 10 | 4.34 | 2.43 | 16.33 | 14.9 |
| | 40% F + 60% NF | 5 | 5.57 | 1.82 | 12.67 | 14.4 |
| | 60% F + 40% NF | 0 | 7.24 | 1.62 | 8.93 | 18.1 |
| | 80% F + 20% NF | 0 | 9.57 | 3.16 | 5.73 | 55.1 |
| | 100% F + 0% NF | 0 | 11.89 | 0.20 | 4.03 | 5.0 |
| B | 0% F + 100% NF | 25 | 3.91 | 2.39 | 16.13 | 14.8 |
| | 20% F + 80% NF | 15 | 4.01 | 1.98 | 13.47 | 15,0 |
| | 40% F + 60% NF | 10 | 4.95 | 1.66 | 12.87 | 12.9 |
| | 60% F + 40% NF | 5 | 6.25 | 1.42 | 10.47 | 13.6 |
| | 80% F + 20% NF | 0 | 7.45 | 2.39 | 6.93 | 34.5 |
| | 100% F + 0% NF | 0 | 10.96 | 0.39 | 6.07 | 6.4 |

Some of the tested beams for flexural strength (FS) determination using two-point loading are shown in Plate 3 with the failure pattern. Generally, they all failed within the middle-third span which indicates acceptability of the results. It can be observed from Table 7 that for concrete made with the two gravels, as the fines content in the coarse aggregate increased the FS decreased except for that of 80% F + 20% NF. Similar trend was observed in the CS. Ghosh *et al,* (1972) had earlier shown that for normal concrete, the FS is about 10% of its CS. This criterion is met by concrete made with both gravels at 0% F + 100% NF, 20% F + 80% NF and 40% F + 60% NF as coarse aggregate, respectively. Therefore, gravel containing up to 40% F can be used as coarse aggregate in concrete for which FS is of importance.

Plate 3: Some of the tested beams

Also, Table 7 shows the effects of fines content on the water absorption (WA) property of concrete made with both gravels. It can be observed that as the fines content in the coarse aggregate increased, the WA potential of the concrete made with both gravels increased as well. However, concrete made with gravel A had higher WA potential than that of gravel B. It should be noted that high WA potential of concrete can lead corrosion of reinforced concrete structures in damped environment which can adversely affect both aesthetics and structural performance of such concrete structures.

## 4. Conclusions

The impurities (plant debris and leaves) in *Tiwantiwa* gravel were easily picked and had little effect on the quality characteristics and strengths of concrete, while the impurities (mica flakes and earthworm casts) in *Majeroku* gravel had adverse effect on the quality characteristics and compressive strength of concrete. Therefore, earthworm casts should be avoided in gravel for concrete production as it was identified as a major source of organic matter in the *Majeroku* gravel.

Both gravel A and B were found to contain 26% and 27% fines (particle sizes ≤ 2 mm), respectively. In addition, either gravel with fines (F) content of less or equal to 20% was found acceptable as coarse aggregate portion in 1:2:4 concrete mixes for elements of structural importance. The compressive strength of concrete made with gravel of higher fines content was not found acceptable for similar structural elements, but could be used as mass concrete.

The increase in fines content of the gravels had adverse effects on the flexural strength and water absorption potential of the hardened concrete, but concrete of gravel A was found more vulnerable under water exposure than those made with gravel B. Noting that most concrete structures take longer time before loaded with ultimate designed load, a characteristic strength of 18 $N/mm^2$ at 56-day curing age for concrete made with sieved (0% F + 100% NF) gravels A and B as coarse aggregates is recommended for design of reinforced concrete elements. There exists good agreement between the experimental and modelled results of compressive strength of concrete made with both gravels containing up to 20% F as coarse aggregate.

Determination of quantity of fines in gravel as a guide for any treatment or adjustment to mix proportions before use is important for production of concrete with acceptable strengths. Therefore, in order to reduce the ugly incidence of collapse concrete structures, the services of civil engineers who are better trained to handle concrete structures should be engaged in the design and construction-supervision of concrete structures and materials usage.

The concrete made with *Tiwantiwa* gravel at less or equal to 20% F as coarse aggregate has better compressive strength than that of corresponding Majeroku gravel. However, the best form to use both gravels as coarse aggregates for maximum strength of hardened concrete is to sieve off the fines using appropriate sieve size (2 mm in this study).

The results of this study and similar ones on the appropriate use of dug-up gravel in South-western Nigeria should be made available to the suppliers for improvement on the quarrying and in enhancing the quality of the materials. This would be an effort at reducing the incidence of collapse building structures resulting from use of poor quality aggregates. Occasional seminars, workshops and awareness programmes for the gravel suppliers and the Masons as well as for the general public (prospective house owners) could be organised to achieve this goal. Further studies on the performance characteristics of concrete made with dug-up gravel will be carried out.

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