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Suitability of Awka-North (Nigeria) Sedimentary stones as Coarse Aggregate for Building Construction

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Abstract: *The research was conducted to investigate properties and strength behaviour of concrete incorporating Awka-North sedimentary stones (locally known as'ironstone') as coarse aggregate in concrete. Ironstone is abundantly available in eastern Nigeria especially Anambra and Enugu states. Though its engineering properties have not been investigated, it is being utilized as coarse aggregates in structural concrete around the locality due to its abundance and relative cheapness. Replacement of ironstone with crushed granite and river gravel up to 50% in 1:2:4 concrete was carried out. Cubes and beams of this concrete mix were cast and tested at different maturity dates to investigate compressive and flexural strengths among other physical properties. Optimum results were obtained at 50% replacement ofironstone with crushed granite or river gravel resulting in compressive strength of 22 N/mm^2 anda flexural strength of 7.81N/mm^2 at 28days. Economic analysis of producing 1m^3 ironstone-optimized concrete reveals a 15-20% reduction in the cost of optimum concrete mix production when compared to the use of conventional aggregates like crushed granite or river gravel. Use of ironstone in concrete production is recommended at 50% replacement of ironstone with conventional aggregates.*

Keywords: *Awka-north, Coarse Aggregate, Concrete, Compressive Strength, Ironstone, Sedimentary stones*

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I. Introduction

In recent past, there have been a number of building collapse in Nigeria and this is worrisome. Aggregates used for concrete whether local or processed have been found to be one of the contributory factors that affect collapse of structures. Over the past decades, the Awka-North iron-stones have been widely used as coarse aggregate in the eastern part of Nigeria for concrete production without proper laboratory test to ascertain its suitability and effectiveness. As a result, this project work seeks to reveal and provide relevant data for engineers making use of this locally sourced material for construction.

Iron stone is a sedimentary rock, either deposited directly as a ferruginous sediment or created by chemical replacement, that contain substantial proportion of the iron compound from which iron can be obtained commercially [1]. It is crushed and used as aggregates for construction in the rural areas of south-eastern Nigeria. The preparation of crushed stone aggregate is not easy as that of river gravel. The overburden must first be removed, the method depending on the formation of the top surface of the rock. The rock is next blasted and conveyed in lumps in trucks [2]. Ironstone is a heavily, fine-grained rock with brownish exterior (due to oxidation), and a grey interior. While the iron content of ironstone is very high in comparison to other types of stones, it actually comprises less than 50percent of the mineral contenthematite, a more valuable source of iron extraction. The iron content of ironstone is sometimes banded, appearing as a red and black layer within the stone [3]. Fig 1.0 shows a geological map of areas in Nigeria with huge deposits of ironstone.

Anambra sedimentary basin in the Lower Benue Trough of south-eastern Nigeria is abundantly blessed with large sedimentary deposit of lateritic iron-stone, consisting of loose angular fragments with some clayey sand. It is reported by Geological Survey Agency of Nigeria that 50.8 million tonnes of iron-stone in a bed about 9m thick, is overlain by clayey soil of about 15m thickness. By screening out the sandy matrix, material with an average iron content of 43 percent can be obtained. Iron stone is source of iron and also can be used as coarse aggregate for concrete production [3].

The cost of purchasing and transporting conventional aggregate (crushed granite or river gravel) is high compared to the locally sourced iron-stone.The locally sourced iron-stone is cheaper and readily available for use as coarse aggregate for concrete production. This research concentrates on the locally sourced aggregate gotten from Awka-North local government area of Anambra state, Nigeria and aims to optimize concrete mixes by incorporating this locally sourced aggregate (iron-stone). Fig 1.0 presents a geological map of the location of sedimentary stone in Nigeria.

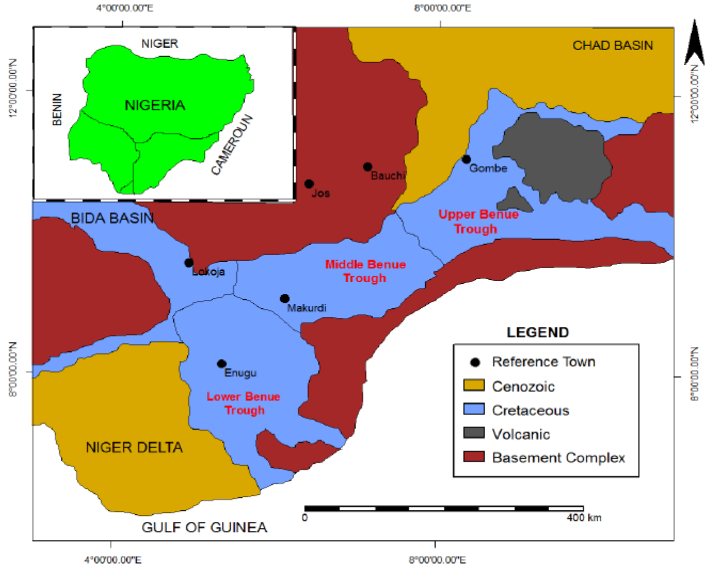

Fig.1.0 Geological map of Nigeria showing the location of sedimentary stone (Fatoye, 2013)

The aim of this research therefore is to assess/improve the strength properties of concrete made with Awka-North sedimentary stones (ironstones) by partially replacing ironstones with crushed granite and river gravel.

This was achieved through the following objectives;

i. Preliminary laboratory investigation on the coarse aggregate (iron-stone) such as, sieve analysis, bulk density, specific gravity, aggregate crushing value, aggregate impact value, porosity and void ratio, absorption and moisture content determination,
ii. Determination of compressive and flexural strength of concrete cubes and beams respectively cast from different aggregate mix proportions.
iii. Assessment of the workability of the freshly prepared concrete arising from the aggregate mix proportions.
iv. Assessment ofthe economic benefits of using the mixture of iron-stone as coarse aggregate in concrete production by comparing it with conventional aggregates.

1.1 Scope of the Research

The project work is limited to naturally occurring iron-stone within the Awka-North local government area of Anambra state, Nigeria. Crushed granite and river gravel as coarse aggregates were obtained from a local vendor in Makurdi, Nigeria. The fine aggregate is river sand obtained from the river Benue in Makurdi, Nigeria. Analysis was conducted to establish particle size distribution, bulk density, and specific gravity, aggregate crushing, aggregate impact value, absorption and moisture content, porosity and void ratio of the locally sourced iron-stone. An investigation into the compressive strength and flexural strength of Grade 20 concrete of mix ratio of 1:2:4 (and water-cement ratio of 0.5) was also conducted. Slump test and compaction factor tests were also carried out on the fresh concrete mix to ascertain workability of the different replacement by weights of iron stone with crushed granite and river gravel. Ironstone was replaced with crushed granite and river gravel at the following replacement levels: 10%, 20%, 30%, 40%, and 50%.Optimum percentage of mix proportions was established. Economic analysis was then done to compare costs of concrete obtained by using the local aggregate and concrete obtained from conventional aggregate. This research covers only physical and mechanical properties of the coarse aggregate, the fresh concrete mix and the maturedconcrete. Plate 1 shows a naturally occurring deposit of ironstone. Plate II (a, b and c) shows crushed ironstones (in form of coarse aggregates, Crushed granite and River gravel respectively.

Plate I: Ironstone in sedimentary deposit

Plate II (A) Crushed Ironstones

Plate II (b) Crushed Granite

Plate II (c) River Gravel

Granite is hard, tough and dense and is an excellent aggregate for concrete geologically; granite is coarsely crystalline in structure free from bedding planes and is composed of quartz, feldspar, mica and homblend. Granite is rock most often quarried as a "dimension stone" (a natural rock material that has been cut into blocks or slabs of specific length, width, and thickness). Granite is hard enough to resist most abrasion, strong enough to bear significant weight, inert enough to resist weathering, and it accepts a brilliant polish. These characteristics make it a very desirable and useful dimension stone in construction.

Gravel is composed of unconsolidated rock fragment that have a general particle size range and include size classes from granular to boulder sized fragments. Gravel can be sub-categorized into granule (>2mm to 4mm). Large gravel deposits are a common geological feature being formed as a result of the weathering and erosion of rocks. This action of rivers and waves tends to pile up gravel in large accumulations. This can sometimes result in gravel becoming compacted and concentrated into the sedimentary rock called conglomerate. Plate II (c) shows a picture of naturally occurring gravel collected from the river Benue, Nigeria. Where natural gravel deposits are insufficient for human purposes, gravel is often produced by quarrying and crushing hard wearing rocks such as sandstone, limestone or basalt [4].

The aggregate or main part of mortar is sand. It is dredged from pit or river beds and consists of particles of different sizes from dust up to 5mm in size. In the ground, and is usually found mixed with some clay earth which coats the particle of sand. If sand mixed with clay is used for mortar, the clay tends to prevent the cement or lime from binding the sand particles to gather and in time the mortar crumbles. However, a small quantity of silt or clay improves the workability since in large quantity its moisture sensitivity will be more pronounced causing shrinkage of mortar. It is therefore necessary that the sand be thoroughly washed so that there is no more than 5% clay in the sand [5].

II. Materials And Methods

The material investigated is concrete mixture of sedimentary stone (iron-stones), crushed granite, river gravel, cement and water. Ironstone was obtained from Awka-North local government area of Anambra state, Nigeria. The crushed granite was obtained from Makurdi, Benue state while the river gravel and river sand were obtained near the river Benue in Makurdi, also from Benue state, Nigeria. Ordinary Portland cement of grade 42R (satisfying BS 12:1996) was procured from the local market. Water was drawn from the university`s water supply system. This water meets the requirements of ASTM C1602.

2.1 Experimental Methods

A portion of the iron-stone was taken for preliminary laboratory investigations to assess some of its engineering properties. The tests conducted include sieve analysis, bulk density, specific gravity, aggregate crushing value, aggregate impact value, absorption and moisture content, porosity and void ratio. All experiments were carried out at the Civil Engineering Laboratories of the University of Agriculture Makurdi, Nigeria.

2.1.1 Sieve Analysis Test

One set of sieve of sizes 38.1*mm*, 19.05*mm*, 9.52*mm*, 4.76*mm*and a balance, readable and accurate to 0.1% of the weight of test sample were used for the test. A sample of coarse aggregate (iron-stone) approximately 3*kg* was air dried as well as the sieves air dried and clean. The sieves were arranged in descending order according to their sizes starting from the 38.1*mm to* 4.71*mm* sieve respectively. The sample introduced in the sieves then hand-shaken until the sieving process was achieved. The weight of materials on each sieve was ascertained and a table of value for percentage passing and retained as well as grading plot for each sample.

Fig. 2.1 and Fig.2.2 are the plots of particle size distribution for ironstone and crushed granite based on the sieve analysis test conducted. Fig 2.1 shows that ironstone falls under the BS 882 classification of all-in aggregate.

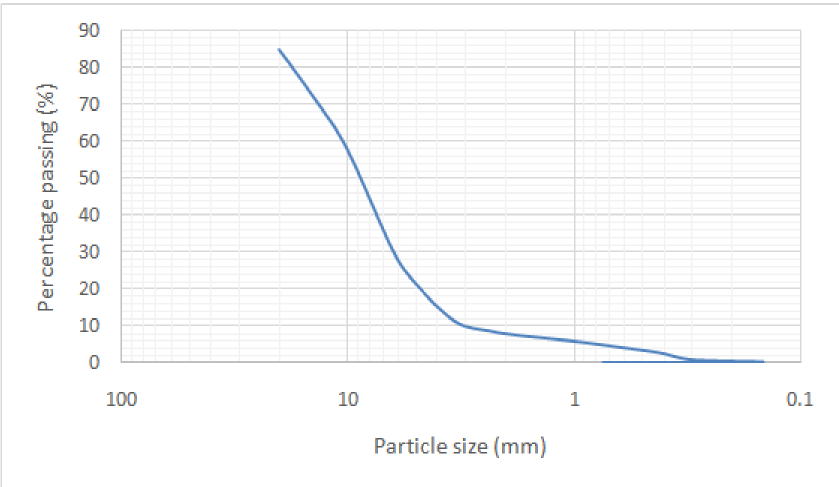

Fig 2.1 Particle size distribution of ironstone

The grading of crushed granite falls under the BS 882 classification of coarse aggregate containing particles the majority of which are larger than 5*mm* as seen in Fig. 2.2

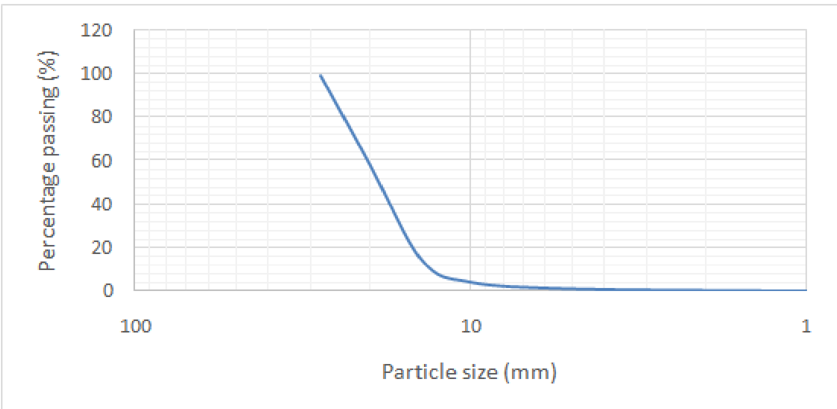

Fig 2.2 Particle size distribution of crushed granite

Fig 2.3 and Fig.2.4 are the results of particle size distribution for river gravel and river sand based on the sieve analysis test conducted.

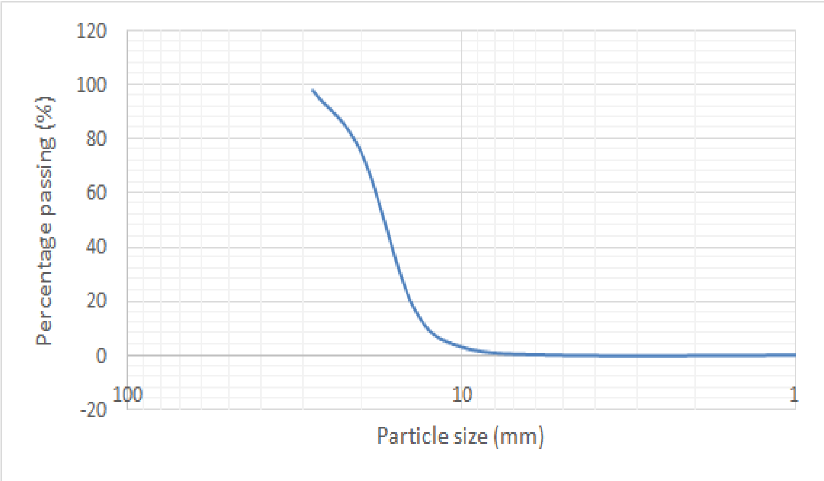

Fig 2.3 Particle size distribution of river gravel

The grading of river gravel is similar to that of crushed granite and the particle sizes falls under BS 882 classification of coarse aggregate. It contains particles greater than 5*mm* based on the result in Fig.2.3 and 20*mm* sizes were selected for further experiment.

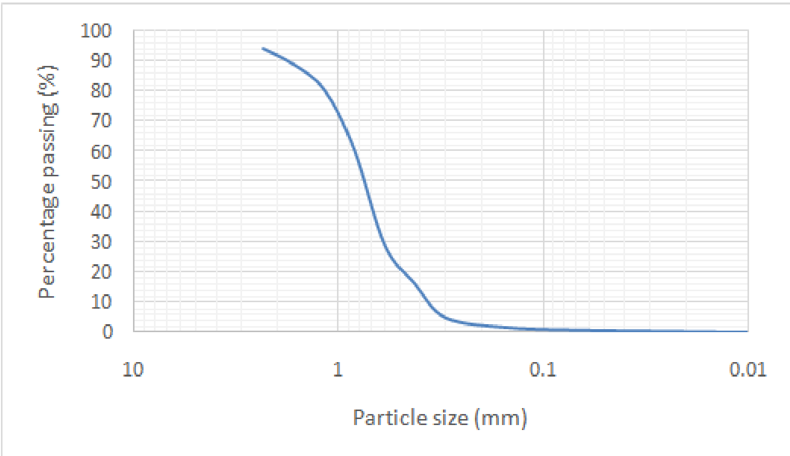

Fig 2.4 Particle size distribution of river sand

The result in Fig 2.4 shows that the river sand contains particle sizes majority of which are smaller than 5*mm* and can be classified as fine aggregate based on BS 882 classification. The sample used for experiment was properly air dried.

2.1.2 Specific Gravity of Sample

A pycnometer, a balance of 1*kg* capacity, 1.5litres capacity glass jar and ground disc, and a drying duster were required for the test. The weight of empty pycnometer $W_1$was ascertained after which the sample of surface dried iron-stone of 500g was introduced to it, the cap replaced and was weighed W_2. The weight of the pycnometer having its content of iron-stone was filled with water and weighed W_3. Finally, the pycnometer was emptied of its content and refilled with water and weighed again W_4. The process was repeated to ascertain the average specific gravity. Specific gravity is given as:

$$\frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

Table 2.1shows the results for specific gravity of various aggregates used for the experiment. Aggregates are the major constituent of concrete and as such its specific gravity is an important factor affecting the density of resulting concrete.

Table 2.1: Specific gravity of river sand, ironstone, crushed granite and river gravel

Description	**SAND**		**IRONSTONE**		**GRANITE**		**RIVER GRAVEL**	
Soil Specimen	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Mass of gas jar, plate, Sample and water (w_3) g	109.57	113.89	127.80	134.40	112.00	111.00	114.0	113.0
Mass of gas jar, plate, andsample (w_2) g	36.16	43.73	67.50	66.70	46.00	43.00	50.00	48.00
Mass of gas jar, plate and water (w_4) g	104.71	104.65	100.70	107.80	101.00	102.00	101.00	102.00
Mass of gas jar and plate (w_1) g	28.40	28.35	21.70	21.70	28.20	28.00	28.00	28.20
(w_2-w_1) g	7.76	15.38	45.80	45.00	18.00	14.80	22.00	19.80
(w_4-w_1) g	76.31	76.30	79.00	86.1	73.00	73.00	73.80	74.00
(w_3-w_2) g	73.41	70.16	60.30	67.70	66.00	68.00	64.00	65.00
{(w_4-w_1) − (w_3-w_2)} g	2.90	6.14	18.70	18.40	7.00	5.80	9.00	9.00
$G_s = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$	2.68	2.50	2.51	2.55	2.57	2.55	2.58	2.62
Average Specific Gravity	**2.58**		**2.53**		**2.56**		**2.60**	

The results in Table 2.1, conformsto the range of specific gravity of most natural aggregates base on [6]. According to [6], most natural aggregate falls within the range of 2.6-2.8. Ironstone has the least specific gravity which should be as a result more voids being present and high absorption capacity of the aggregate.

2.1.3 Water Absorption and Moisture Content Test

The water absorption of aggregate was determined by measuring the increase in weight of an oven-dried sample when immersed in water for 24 hours. The ratio of the increase in weight to the weight of the dry sample expressed as percentage was the absorption of required aggregate. The result of water absorption test is presented in Table 2.2. Ironstone possesses double the capacity of water absorption of conventional crushed granite or gravel. However it meets the requirements of BS 882 for coarse aggregate for concrete production.

Table 2.2 Water absorption and moisture content of ironstone and crushed granite

Sample	**Ironstone**		**Crushed Granite**	
	Test 1	Test 2	Test 1	Test 2
Wet weight (w_1) g	599.50	595.50	1214.00	1208.00
Dry weight (w_2) g	569.50	567.50	1184.00	1183.00
(w_1-w_2) g	30.00	28.00	30.00	25.00
Water absorption *m* (%)	5.27	4.93	2.53	2.11
$m = \frac{w_1 - w_2}{w_2} \times 100$ **Average *m* (%)**	5.10		2.32	

The high absorption rate of ironstone reduces the strength/durability requirement and workability of the hardened concrete. It was also observed that with a constant water/cement ratio of 0.5, less workable concrete was being achieved. Ironstone requires a relatively higher water-cement ratio as a result of its absorption characteristics.

2.1.4Bulk Density Test

The bulk density or unit weight of an aggregate gives valuable information regarding the grading and shape of the aggregate. It shows how densely-packed the aggregate is when filled-in in a standard manner. A portion of ironstone was filled in a container of known weight and then subjected to standard compaction. The weight of the aggregate which gives the bulk density was ascertained by weighing the sample and container and finally subtracting the container weight and dividing it by the volume of the container as presented in Table 2.3.

Table 2.3 Bulk density of ironstone

Sample	**Ironstone**	
	Test 1	Test 2
Weight of sample and container (w_1) g	596.00	605.00
Weight of container (w_2) g	281.00	281.00
(w_1-w_2) g	195.65	190.90
Volume of container (v) cm^3	315.00	324.00
Bulk density (g/cm^3) $= \frac{w_1 - w_2}{v}$	1.61	1.69
Average bulk density(g/cm^3)	**1.65**	

The unit weight test result of the ironstone shows that it is poorly graded giving a loosely packed aggregate of 1.65*g/cm*^{3} compared to the crushed granite sample. This might be as a result of the manual method employed in crushing the parent ironstone rock which determined the shape of aggregate produced.

2.1.5 Porosity and Void ratio

This was calculated with the formula below after the specific gravity of the coarse aggregate (iron-stone) in saturated and surface dried condition was ascertained. Percentage voids is given as; $\frac{G_s-\gamma}{G_s}\times 100$. where G_s is the specific gravity and γ is the bulk density in *Kg/litre*.This gives a value of 0.34 while percentage void is 0.34×100 = 34%. The estimated void ratio and percentage void of the ironstone (0.34 and 34%) shows that it contain more void and will produce less durable concrete as later seen from the result of compressive and flexural strength test in Table 2.9 and 2.10 which was found to be low compared to the optimized mixture of granite and river gravel used as coarse aggregate.

2.1.6 Aggregate Impact Value of sample

The test is carried out to account for toughness of coarse aggregate and is usually considered the resistance of coarse aggregates to failure by impact. The aggregate impact testing machine complete with standard and tamping rod, 3*kg* balance, and BS test sieves of sizes 12.7*mm*, 9.52*mm*, and 2.40*mm* were used for the test. Clean and oven-dried sample that passed the 12.7*mm* sieve and retained on the 9.52*mm* sieve was prepared for the test.

The 7.6*cm* diameter cylinder was filled with the sample in three equal layers giving 25 strokes of the 22.9*cm*metal tamping rod to each layer. The top surface of the aggregate was then leveled to the nearest gram and the same weight of material was used for each test. By placing the whole of the sample in the cup fixed firmly in position to the base of the impact machine and applying 25 blows of the tamping rod, the sample was subjected to 15 blows by allowing the hammer to fall freely after which the crushed aggregate was sieved on the 2.40*mm* sieve and the percentage passing by weight was then determined.

Two tests were carried out and the mean wasreported. The impact value was expressed as percentage of fines passing the 2.40*mm* sieve (to the nearest whole number) to total weight of the sample. Table 2.4 shows the aggregate impact value calculations;

Table 2.4 Aggregate impact value of iron stone

Sample	**Ironstone**	
	Test 1	Test 2
Weight of sample and container (w_1) g	596.00	605.00
Weight of container (w_2) g	281.00	281.00
Weight of sample passing sieve 2.36mm (w_3) g	111.00	128.00
(w_1-w_2)g	315.00	324.00
Aggregate impact value (AIV) **AIV=** $\frac{w_3}{w_1-w_2}\times 100$	35.24	39.50
Average AIV (%)	37.37	

The aggregate impact value test result indicates that the ironstone is not suitable for use as coarse aggregate in concrete used for wearing surfaces but suitable for non-wearing surface since it is less than the maximum 45% prescribe by BS 882. The aggregate impact value is inversely related to the aggregate toughness, hence, the higher the value of impact, the lower the toughness.

2.1.7 Aggregate Crushing Value

A 152*mm* diameter open-ended steel cylinder with plunger and base plate, standard metal tamping rod, 3*kg* balance and B.S test sieves of sizes 12.7*mm*, 9.5*mm* and 2.40*mm* wereused for the test. An oven-dried sample of ironstone (5*kg*) was prepared. The sample was placed on the cylinder on top of the base plate and filled in three layers giving 25 blows to each layer with the aid of the tamping rod. Leveling off the top of the aggregate with the tamping rod and insertion of the plunger was done so that it rests horizontally on the surface of the aggregate.Test was carried out on the sample using the compression machine with load of 40KN/min applied to it for ten minutes (total of 400KN). On removing the material from the cylinder, it was sieved on the 2.40*mm* BS test sieve. Determining the weight of the fines passing the sieve 2.40*mm* and expressing this as a percentage of the total weight of aggregate used gave the aggregate crushing value (ACV). The test was carried out twice to ascertain the average value for the ACV. Table 2.5 presents Aggregate crushing value for ironstone.

Table 2.5 Aggregate crushing value of iron stone

Sample	Ironstone	
	Test 1	Test 2
Weight of sample and container (w_1) g	15300.00	15475.00
Weight of mould (w_2) g	11966.00	11966.00
Weight of sample passing sieve 2.36mm (w_3) g	990.00	1120.00
(w_1-w_2)g	3334.00	324.00
Aggregate impact value (AIV) **ACV=** $\frac{w_3}{w_1 - w_2} \times 100$	29.69	31.90
Average ACV (%)	30.80	

Aggregate crushing value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load. An ACV of 45% is permissible for ordinary concrete and 30% for concrete used for wearing surfaces. The aggregate crushing value test result was found to be 30.80% which is suitable for use in concrete produced for non-wearing surfaces. It is less than the maximum prescribe value of 45% by [7] and has no relationship with compressive or flexural strength but gives an insight on the anticipated result.

2.1.8 Slump Test

This test was carried out on the green concrete with a metallic cone of 300*mm* height, having a bottom diameter of 200*mm* and a top diameter of 100*mm*, on a representative sample of the concrete. The cone was placed on a smooth, flat non-absorbent base and held in position. The mould was filled to about one-third of its height with the concrete which is tamped, using 25 strokes of a 16*mm* rod. The filling was completed by two further layers similar in height to the first and the top stroked off so that the mould is exactly filled. The mould was slowly lifted vertically from the concrete cone which gave the slump values, that is the difference in height between the mould (300*mm*) and the height of concrete after the mould is lifted. It was measured in mm.

The results in Table 2.6, shows the slump value for each replacement of ironstone with crushed granite and river gravel respectively**.**

Table 2.6 Slump test result for constant water/cement ratio of 0.5

Replacement	Slump (mm)
100%I 0%G 0%R	10.5
0%I 100%G 0%R	35.0
0%I 0%G 100%R	50.5
90%I 10%G 0%R	10.0
80%I 20%G 0%R	13.0
70%I 30%G 0%R	12.5
60%I 40%G 0%R	17.5
50%I 50%G 0%R	22.0
90%I 0%G 10%R	12.5
80%I 0%G 20%R	11.0
70%I 0%G 30%R	15.5
60%I 0%G 40%R	18.5
50%I 0%G 50%R	24.5
90%I 5%G 5%R	10.0
80%I 5%G 15%R	15.0
70%I 5%G 25%R	16.0
60%I 5%G 35%R	18.5
50%I 5%G 45%R	22.0
80%I 15%G 5%R	12.0
70%I 25%G 5%R	12.5
60%I 35%G 5%R	16.5
50%I 45%G 5%R	20.5

The result above in Table 2.6 shows that the degree of workability with ironstone is low and will produce less workable concrete except the water cement ratio is increased. According to [6], the slump value of 24.*50mm* for concrete with 50% partial replacement with crushed granite *is* low. Such concrete can however be used for lightly reinforced sections with vibration or mass concrete foundations without vibration.

2.1.9 Compacting Factor Test

This test was carried out on the fresh concrete using the compacting factor machine, which comprises of two inverted cone-shaped hoppers and a cylindrical container. The hoppers and the cylinder are arranged in a vertical position, i.e., upper hopper, lower hopper and a cylinder, with the surfaces polished to reduced friction. The upper hopper was filled with concrete, leveled to the brim without compaction. The hinge at the bottom of the upper hopper was released to allow the concrete fall into the lower hopper which is smaller than the upper one. The bottom of the lower hopper was released also to allow the concrete to fall into the cylinder. Excess concrete was cut by two float slid across the top of the mould. The net mass of concrete in the known volume of the cylinder was determined, the density of concrete in the cylinder also calculated and the ratio of this density to the fully compacted concrete is defined as the compacting factor. The later density can be obtained by actually filling the cylinder with concrete in four layers, each tamped or vibrated. Compaction factor is given as the ratio of partially compacted weight to fully compacted weight.The results in Table 2.7, shows the compacting factor value for each replacement of ironstone with crushed granite and river gravel respectively**.**

Table 2.7 Compacting Factor Test result for water/cement ratio of 0.5

Replacement	**Slump (mm)**
100%I 0%G 0%R	0.9019
0%I 100%G 0%R	0.9275
0%I 0%G 100%R	0.9282
90%I 10%G 0%R	0.9160
80%I 20%G 0%R	0.9015
70%I 30%G 0%R	0.9375
60%I 40%G 0%R	0.9250
50%I 50%G 0%R	0.9360
90%I 0%G 10%R	0.0926
80%I 0%G 20%R	0.9127
70%I 0%G 30%R	0.9250
60%I 0%G 40%R	0.9350
50%I 0%G 50%R	0.9310
90%I 5%G 5%R	0.9150
80%I 5%G 15%R	0.9260
70%I 5%G 25%R	0.9255
60%I 5%G 35%R	0.9260
50%I 5%G 45%R	0.9368
80%I 15%G 5%R	0.9275
70%I 25%G 5%R	0.9350
60%I 35%G 5%R	0.9250
50%I 45%G 5%R	0.9311

The compacting factor test result indicates that as the percentage of ironstone increases, the compacting factor decreases. The water/cement ratio has to be increased to make the fresh concrete mix more workable. This is as a result of high absorption capacity of the ironstone. More workable concrete mix was achieved as replacement with river gravel and granite was increased from 0 to 50% accordingly. The result in Table 2.7 above shows that the resulting concrete degree of workability is low based on [6]'s classification.

2.1.10 Compressive strength test results

The compressive strength test was carried out on (150x150x150)mm concrete cubes at 7, 14 and 28 days maturity after curing using a 1500kg capacity ELE elector hydraulic jump power testing machine. Each concrete cube was weighed and placed in the testing machine between two metal plates. Having properly positioned each cube, load was applied until the cube failed and the load at failure recorded against each sample. The load at failure divided by the effective area of the cubes in square millimetres were taken as the compressive strength of the cubes. The mean of the compressive strength of cubes were obtained as the compressive strength.Fig 2.5 shows a graph of compressive strength test for various percentage replacement levels of ironstone with crushed granite and river gravel

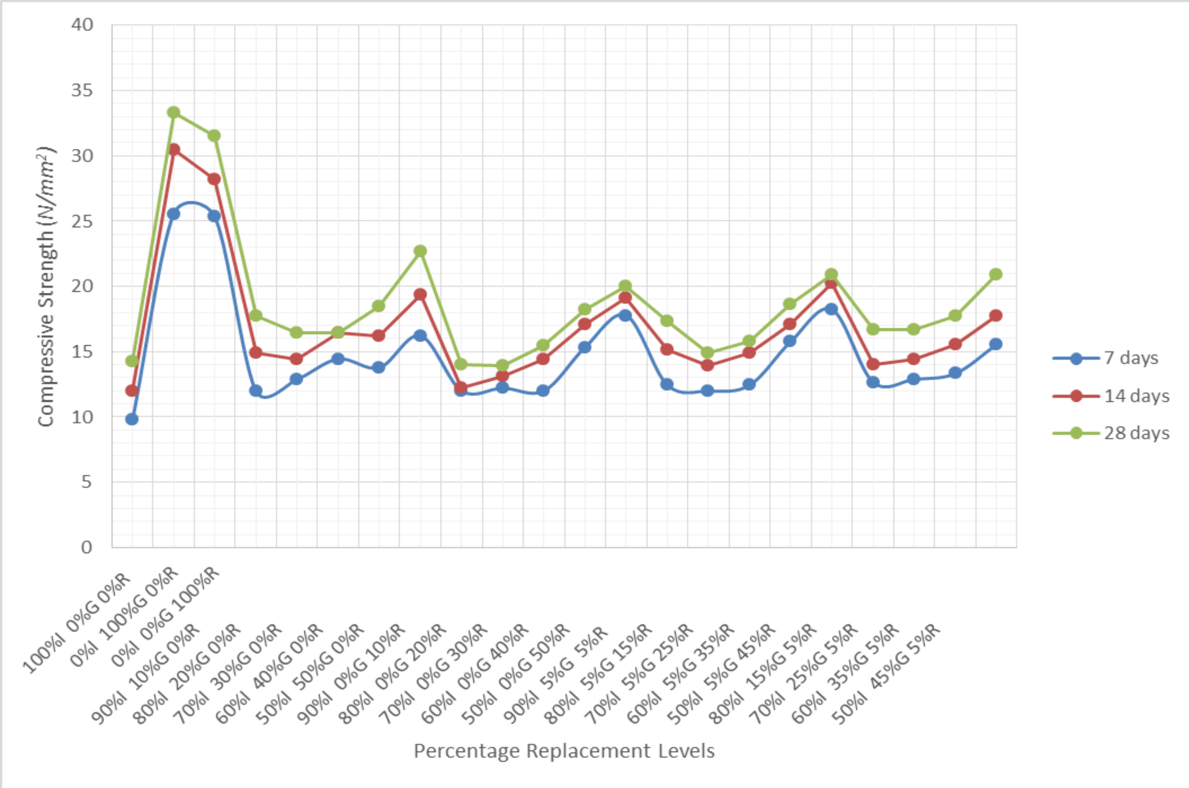

Fig 2.5: Graph of Compressive Strength Test for Various Percentage Replacement Levels of Ironstone with Crushed Granite and River Gravel

Note: 100%I, 0%G, 0%R refers to a concrete mixture of 100% ironstone, 0% Crushed Granite and 0% River Gravel.

The graph in Fig. 2.5 shows the compressive strength of the resulting concrete from various replacements of ironstone with crushed granite and river gravel. The compressive strength of the concrete increased with age and also with each replacement of ironstone with crushed granite and river gravel. Optimum strength was achieved at 50% replacement of ironstone with crushed granite which gave a value of 22.67N/mm^2 at 28days. 20.89N/mm^2 strength was achieved when ironstone was replaced with 45% of crushed granite as well as river gravel. The reduction in strength of concrete made with ironstone is attributed to its physical characteristics which include, water absorption and moisture content, porosity and void ratio, bulk density and specific gravity based on the test results.

2.1.11 Flexural strength Test

The flexural strength test was carried out on the simply supported plain concrete beams ($450mm \times 100mm \times 100mm$) that was loaded at its third point using the universal testing machine available at the University of Agriculture Civil Engineering Laboratory. The resulting bending momentinduced compressive and tensile stresses in the top and bottom fibres of the beam respectively as load was applied. The beam failed in tension and the flexural strength (modulus of rupture) was calculated using the formula $f_{cr} = \frac{FL}{bd^2}$, where F is the maximum applied load, L the distance between the supports, and b and d are the beam breadth and depth respectively at the section at which failure occurred.

The flexural strength of the concrete increased with each replacement of ironstone with crushed granite and river gravel as shown in Fig 2.6. The flexural strength of concrete increased from 0 to 50% replacement of ironstone with crushed granite and river gravel. Fig 2.6presents agraph of flexural strength test for various percentage replacement levels of ironstone with crushed granite and river gravel.

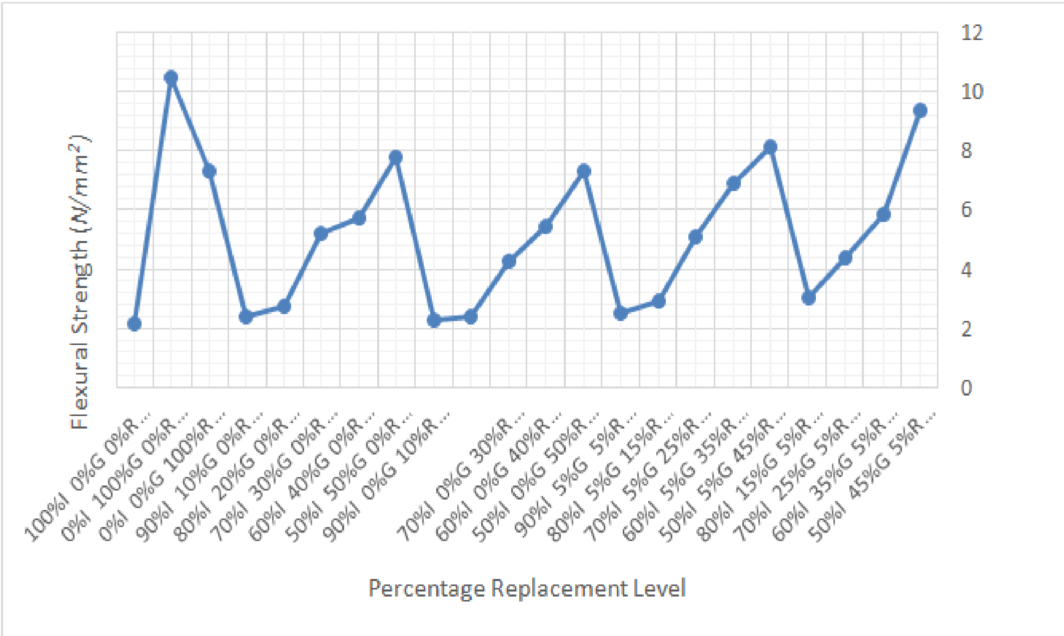

Fig 2.6: Graph of Flexural Strength Test for Various Percentage Replacement Levels of Ironstone with Crushed Granite and River Gravel

Note: *100%I, 0%G, 0%R refers to a concrete mixture of 100% ironstone, 0%Crushed Granite and 0% River Gravel*

III. Economic Analysis

In other to carry out economic comparison between concrete mixture of ironstone used as coarse aggregate and other conventional aggregates (crushed granite and river gravel) already in use, the cost, transport and labour of each of the material are critically analysed. The unit cost (in Nigerian Naira)of each material is expressed per m^3.

4.12.1Concrete mixture

Cement	Sand	Aggregate
1	2	4
0.1	0.3	0.6

<u>Cement:</u>

1 bag of cement = $50kg = 490N = 0.49KN$ density of cement (ordinary Portland) $= 22KN/m^3$ (Table 3 RCDH)

$\therefore$ Volume of 1 bag = $\frac{Mass}{Density} = \frac{0.49KN}{22KN/m^3} = 0.02m^3$

Volume $= 0.02m^3$

$0.02m^3$ of cement = 1 bag

$0.1m^3$ of cement = 5 bags

Since 1 bag of cement = ₦2,200.00

5 bags of cement =

$\frac{5}{1} \times$ ₦2,200.00

= ₦11,000.00

<u>Sand:</u>

1 tipper load of sand (trip) $= 3.8m^3$

1 tipper load of sand = ₦8,000.00

$\therefore$ $0.3m^3$ = $\frac{0.3m^3}{3.8m^3} \times$ ₦8,000.00

= ₦631.59

<u>Aggregate:</u>

Case 1: Optimum mixture of 50% ironstone and 50% crushed granite

1 tipper load of aggregate = $3.8m^3$
1 tipper load of ironstone = ₦25,000.00
1 tipper load of granite = ₦65,000.00

$$\therefore \quad 0.6m^3 = \frac{0.6m^3}{3.8m^3} \times ₦45{,}000.00$$
$$= ₦7{,}105.26$$

Case 2: Optimum mixture of 100% crushed granite
1 tipper load of aggregate = $3.8m^3$
1 tipper load of crushed granite = ₦65,000.00

$$\therefore \quad 0.6m^3 = \frac{0.6m^3}{3.8m^3} \times ₦65{,}000.00$$
$$= ₦10{,}263.16$$

Case 3: Optimum mixture of 100% river gravel
1 tipper load of aggregate = $3.8m^3$
1 tipper load of river gravel = ₦50,000.00

$$\therefore \quad 0.6m^3 = \frac{0.6m^3}{3.8m^3} \times ₦50{,}000.00$$
$$= ₦7{,}894.74$$

<u>Water:</u> ₦30 per bag of cement
For 5 bags = ₦150.00

<u>Total:</u>

Case 1: = ₦11,000.00
631.00
7,105.26
150.00
Total = ₦18,886.85

Case 2: = ₦11,000.00
631.00
10,263.16
150.00
Total = ₦22,044.75

Case 3: = ₦11,000.00
631.00
7,894.74
150.00
Total = ₦19,676.33

<u>Labour:</u> is 10% of the total of each cases.

Case 1: $= \frac{10}{100} \times ₦18{,}886.85$
= ₦1,888.69
\+ 18,886.85
Grand total = ₦20,775.54

Case 2: $= \frac{10}{100} \times ₦22{,}044.75$
= ₦2,204.48
\+ 22,044.75
Grand total = ₦24,249.23

Case 3: $= \frac{10}{100} \times ₦19{,}676.33$
= ₦1,967.63
\+ 19,676.33
Grand total = ₦21,643.96

Table 3.1 shows a 15% reduction in cost for the optimum mix (partially replacing ironstone with conventional coarse aggregate).

Table 3.1: Results of Cost Analysis

Cases	**Quantity (m^3)**	**Unit cost (₦)**	**Reduction in cost (%)**
Case 1	1	20,775.54	15
Case 2	1	24,249.23	0
Case 3	1	21,643.96	11

IV. Conclusion

Based on the analysis conducted on concrete made of ironstone partially replaced with crushed granite and river gravel to optimize its strength properties, the following conclusion can be drawn:

- Strength properties of concrete made with ironstone that is used as coarse aggregate can be optimized using crushed granite and river gravel.
- Low degree of workability is achieved in the replacement of ironstone with river gravel up to 50% replacement in concrete production.
- The compressive and flexural strength of the concrete increases with age and with each replacement of ironstone with crushed granite and river gravel up to 50% percent replacement.
- An optimum compressive strength of 21.99N/mm^2 and flexural strength of 7.81N/mm^2 is achieved with mix proportion of 50% each of ironstone and granite for the former and 50% ironstone, 45% crushed granite and 5% river gravel for the later.
- The use of ironstone in concrete production has low degree of workability and strength but economically justifiable when compared with other conventional aggregate such as crushed granite and river gravel.
- The use of optimized concrete mixture made with ironstone used as coarse aggregate is economically justifiable. 15-20% reduction in cost when compared with the cost of other materials already in use.

4.1 Recommendations

As a result of the relatively poor physical and mechanical properties of ironstone, 50% replacement with either crushed granite or river gravel or some other conventional aggregate is recommended concrete to be used for building construction. More research is needed on the strength behaviour of ironstone in richer concrete mixes in order to enhance a more general conclusion

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