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DETERMINATION OF THE COMPRESSIVE STRENGTH OF CONCRETE PRODUCED USING COARSE AGGREGATES LOCALLY SOURCED FROM ENUGU STATE, NIGERIA

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Abstract

The high cost of purchasing conventional granite aggregates from quarry deposits for concrete structural works in Enugu state has become a thing of concern and which necessitated this study. The study aims to determine the compressive strength of concrete cubes produced using locally sourced gravel from Awgu, Enugu Ezike, and Ugwuaji all in Enugu state, Nigeria. In achieving this, experiments conducted were the sieve analysis and compressive strength test. The aggregate sizes chosen were between the range of 7.5mm to about 20mm for the three samples. A total number of 36 cubes of 150x150x150mm cubes were cast and cured. The samples were tested using a compression test machine for a period of 3, 14,21, and 28 days respectively at the Department of Civil Engineering Laboratory, Enugu State University of Science and Technology, ESUT, Agbani, Enugu State. The result indicated that the minimum required 25N/mm^2 strength of concrete after 28 days of curing for a mix ratio of 1:1:2. (M25) target, the Awgu gravel yielded 29.96N/mm^2, Enugu Ezike gravel yielded 25.85N/mm^2 and Ugwuaji gravel yielded 26.30N/mm^2. In conclusion, though the remaining two samples yielded strengths above the minimum 25N/mm^2 and there is no significant variation in the compressive strength of concretes produced using coarse aggregates obtained from different locations in Enugu state; gravels obtained from Awgu (Mvuna Ituku Ozalla) produced the highest strength of 29.26 N/mm2 and would be most recommended for concrete production.

Keywords: Aggregate, Cement, Coarse Aggregate, Concrete, Enugu

Introduction

Aggregate is a stone or rocklike material used in many civil engineering and construction applications including Portland cement concrete, asphalt concrete, base materials for roads, ballast for railroads, foundations, plaster mortar, grout, and filler materials (Kamran, Mohammad, and Konstantinos, 2015). Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are the essential ingredient in concrete (Kosmatka and Wilson 2016). According to Lesovik *et al.* (2021), aggregates are defined as mineral constituents of concrete in a granular or particular form, usually comprising both coarse and fine fractions.

Aggregates are of two forms namely; coarse and fine aggregates based on their grain sizes (Kamran, Mohammad, and Konstantinos, 2015). Fine aggregates generally consist of natural sand or crushed stone with most of the particles smaller than 5mm (0.2 in.) and coarse aggregates consist of one or a

combination of gravels or crushed stones predominantly larger than 5mm (0.2 in.) and generally between 9.5mm and 37.5mm (⅜ and 1½ in.) (Kosmatka and Wilson, 2016). Aggregates take about three-quarters (3/4) of the volume of concrete with coarse aggregates taking between 50 and 60% of the concrete mix depending on the mix ratio used (Waziri, Bukar, and Gaji, 2011). Research by Ajagbe, Tijani, and Agbede (2018) stated that changes in coarse aggregates can change the compressive strength and fracture properties of concrete.

On this note, this study will compare the compressive strength of concrete produced using different coarse aggregates obtained in Enugu State. Noteworthy, no attention was given to determining the compressive strength of concrete produced using coarse aggregates obtained locally in Enugu state from the previous study even though Enugu is part of the South Eastern part of Nigeria. Therefore, by deducing this study to the Enugu state, more insight will be provided. Moreover, the Enugu state is rich in sandstone also known as surface stone. Therefore, the purpose of this study is to determine and compare the compressive strength of concrete produced with the coarse aggregates from Enugu state.

Literature Review

Aggregate and Concrete Production

Concrete is a composite building material or product of two major components which include the cement paste and the bulk inert mass. Cement when mixed with water forms the cementing medium. The inert mass part of the concrete component is the coarse and fine aggregate. These materials are filled and coated by cement paste occupying all the void space between the particles in a hunk of properly mixed concrete. It then begins to gain its strength with time when the setting process of the concrete starts (Kabir, Hasan, and Miah, 2012). Concrete according to Ajagbe *et al.* (2018) is a composite material that consists of cement, fine aggregate (sand), coarse aggregate (gravel or granite), and water, mixed in a prescribed proportion. Raheem and Bamigboye (2013) defined concrete as an artificial stone-like material used for construction purposes. Concrete is a building material with good compressive strength and resistance to fire (Oyenuga, 2001; Ede and Aina, 2015). The inability of concrete to resist compressive stress could be a result of undermining standards or a lack of awareness of the parameters that influence the compressive strength of concrete. The compressive strength of concrete is the strength of hardened concrete measured by the compression test. It is the measure of concrete's capacity to resist the loads which tend to compress it (Ajagbe *et el.*, 2018).

Traditionally, the strength of concrete is characterized by the 28 days' value. Strength is the design property of concrete. Durability, permeability, and volume stability are also important Characteristics in some cases of designing concrete structures but strength is the most paramount. It is expected that the strength of concrete increases with time at a continuously diminishing rate. The process of growth in strength is known as 'hardening'. The concrete compressive strength to be used is required in designing a concrete structure. The design strength of the concrete normally represents the strength on the 28th day. 28 days is a considerable time to wait for the results of the test conducted on concrete strength in construction works. It also represents the quality control process of concrete mixing, placing, compaction, proper curing, etc. This is because concrete mix design is a process based on code recommendation and requires some previous experience (Kheder *et al*, 2003). Researchers are very keen to explore concrete behavior and for this reason, prediction of the concrete strength is being marked as an active area of research. Therefore, many studies are being carried out in this area. Concrete fails, however, when it can no longer provide adequate strength to support the load it's designed for (Ezeokonkwo, 2014). But, due to the increasing cost of producing concrete

using conventional materials such as cement, river sand as fine aggregate, and granite as coarse aggregate in Nigeria, researchers have been working on alternative, economical, and readily available materials that would serve as perfect substitutes for such materials while still meeting up to the required standard for concrete in the industry (Udoeyo, 2006).

Abdullahi (2013) in his study, propounded that aggregate type has an effect on the compressive strength of normal concrete and concluded that concrete made from crushed quartzite shows higher compressive strength at all ages when compared to concrete with granite as a coarse aggregate. However, Aginam *et al* (2013) gave a contrary view with the compressive strength of the normal concrete produced with granite as the coarse aggregate higher when compared with the concrete made with washed and unwashed gravel as a coarse aggregate component.

Muhit *et al*. (2013) in their study, evaluated the effects of "impact crushed" and "vertically shafted" coarse aggregates on the concrete blocks and reached the conclusion that the slump values for the two types of crushed aggregates decreased moderately with water/cement ratio and concrete samples made with "vertically shafted" coarse aggregate having relatively higher slump value than those with made with "impact crushed" coarse aggregate. The compressive strength of "impact crushed" aggregate concrete however is higher compared to the "vertically shafted" aggregate with the decrease in the water-cement ratio. Jimoh and Awe (2007) also evaluated the size of aggregate that will improve the properties of the structural normal concrete and in their conclusion, they stated that the use of quarry dust and 20mm granite improved the concrete strength by 34% over the strength produced by concrete with sand and gravel of 28mm maximum size. Also, as coarse aggregates' size increases, normal concrete strength decreases. With the concrete containing quarry dust as a fine aggregate, the rate of fall in strength is at its peak.

Xie *et al.* (2012) confirmed these earlier findings that with the increase in the maximum coarse aggregate size, the compressive strength tends to decrease. Ajamu and Ige (2015) investigated the effect of size in higher-grade concrete using high-volume fly ash and propounded that the maximum size of coarse aggregates of 12.5mm gave the highest compressive, splitting, and flexural strengths; hence the aggregate sizes influence strength Furthermore, the study by Ajamu and Ige (2015) on the effect of coarse aggregate size noted that compressive strength of concrete is directly proportional to the size of coarse aggregate and the flexural strength of concrete is inversely proportional to the size of coarse aggregate.

However, the result of the study conducted by Alli, Odewumi, and Alli (2018) on the compressive strength of concrete indicates that the different coarse aggregates used for concrete production possess different compressive strength values; the mean compressive strength in N/mm^2 of cube cast concrete with palm kernel as the aggregate at 7, 14, 21 and 28days gave $3.64N/mm^2$, $3.82N/mm^2$ $4.00N/mm^2$ and $4.22N/mm^2$ respectively, while the concrete made using gravel as the aggregate gave the strength of 12.53 N/mm^2, 12.98 N/mm^2, 13.33 N/mm^2, 16.67 N/mm^2. For concrete made of granite, the strength is 14.53 N/mm^2, 15.56 N/mm^2, 18.67 $N/mm^{2,}$ and $20.44N/mm^2$ respectively. They concluded therefore that, the concrete made with granite as the aggregate produced a higher compressive strength value of 20.44 N/mm^2, at 28days as compared to the compressive strength of concrete made using gravel and palm kernel shell as the coarse aggregate which gave a compressive strength value of 16.67 N/mm^2 and $4.0N/mm^2$ respectively. Specifications of the intended work pre-determine materials which are suitable for construction that will be the most cost-effective. Before the execution of the intended project, it is important to ascertain the strength of these materials. A previous study by Golestanifar and Ahangari (2010)

stated that other factors could affect the compressive strength of concrete as follows; the presence of deleterious materials, alkali reactivity, soundness, grain shape, water absorption, grain weathering, specific gravity, and absorption resistance.

Methods and Materials

For this study, the coarse aggregates used were gravel, locally sourced from three local government areas in the three senatorial districts of Enugu state southeast part of Nigeria. The first is the Mvuna borough pit, Ituku Ozalla, in Awgu L.G.A., the Ofante borough pit of Umuogbuagu Enugu Ezike in Igboeze North L.G.A. and the Obeagu borough pit of Ugwuaji Awkunanaw in Enugu south L.G.A. all in Enugu state. The 36 concrete cube samples obtained were identified as follows AWnx, EEnx, and UGnx where AW represents the aggregates from Mvuna-Ituku Ozalla of Awgu, EE represents the aggregates obtained from Ofante -Umuogbuagu Enugu Ezike while UG represents aggregates obtained from Ugwuaji. The nx subscript represents the days of crushing and the sample tag respectively. The fine aggregate used was obtained from Ugwuaji/Amaechi River. The cement used was a Dangote brand of ordinary Portland cement 3x (42.5R). the water used for this study was portable water sourced from Ninethtmile Enugu state.

25N/mm^2 concrete mix design was targeted with a ratio of 1:1:2 of cement sand and coarse aggregates for each of the aggregate samples and batched by weight to ascertain if the locally sourced coarse aggregates can be used for standard concrete production which ranges from 25N/mm^2 to 45N/mm^2. A water-cement ratio of 0.60 was used. 36 concrete cube samples were produced and submerged in a water pool tank for curing. Three concrete cubes of 150x150 x150 mm from each of the aggregate sample was tested for each testing age of 3 days, 14 days, 21 days, and 28 days. The concrete cubes were tested at 3days old to give the contractors who are always time conscious in project delivery within Enugu state an idea of what strength to expect from concrete produced using locally sourced coarse aggregates from the state. An average temperature of 25˚c ≤T≤29˚c in the laboratory was maintained to avert any thermal-induced cracking on the cubes. On every testing day of the cubes, three concrete samples from each of the aggregate types were removed from the pool and allowed to drain off water for about one hour before taking it to the compression testing machine. Before the compression test, the cubes were weighed and the mass of each of them was noted. The cubes were tested with an automated compression testing machine and the compressive strength of each of the cubes was noted.

One-Way ANOVA test was used to test the hypothesis at 5% significant level to determine if significant variation exist among the compressive strengths of concrete produced using coarse aggregate obtained from the selected locations in Enugu state.

Hypothesis

H$_0$: There is no significant difference in the compressive strengths of concrete produced from different sources in Enugu State.

Sieve Analysis

To achieve this, the following steps were taken; a 1.5kg sample of coarse aggregate was taken and the IS sieves were arranged in descending order as follows 20, 12.5, 10, 4.15, 2.36, 1.25. the sample was filled to the highest sieve and sieved well for up to 10 minute. After completion of the sieve, the weight of the aggregate retained in each sieve was noted. The cumulative weight passing through the sieve was calculated as a percentage of the total sample weight. The same procedure was followed for more samples. The aggregate retained on each sieve was calculated in percentage based on the total weight of the soil sample taken. Based on the result, the graph was plotted. Particle size was mentioned on X-axis and the percentage was finer on Y- axis**.**

Experimental Procedure

The procedures adopted to derive the compressive strength result; The various samples of aggregates were brought to the laboratory in an air-dry condition. The mix proportion of the sample aggregate was 1:1:2 of cement, sand, and coarse aggregates respectively and it was mixed thoroughly to give a uniform color after the desired quantity for each batch of the concrete was taken. The quantities of cement, each size of aggregate, and water for each batch were determined by weight, to an accuracy of 0.1 percent of the total weight of the batch The concrete was mixed by hand in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete was of such a size as to leave about 10 percent excess after molding the desired number of test specimens. The specimen was poured into the mold as fast as practicably possible to avoid loss of water or any of the materials.

To ensure symmetric distribution of the composites, the concrete was well vibrated using a hand. The specimen was removed from the mold by removing concretes at the top edge of the scoop as the concrete was allowed to slide from the mold. the test specimens were stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27°C ± 2°C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients. The bearing surfaces of the testing machine were wiped clean and other material was removed from the surfaces of the specimen which were in contact with the compression platens. The specimen was placed in the machine in such a manner that the load was applied to opposite sides of the cubes. The load was applied with the machine without shock and increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load breaks down and no greater load was sustained. The maximum load applied to the specimen was then recorded and the appearance of the concrete and any unusual features in the type of failure was noted.

Results and Discussion

Sieve analysis results

Tables 1, 2 and 3 represent the sieve analysis result for Awgu,fffgv Enugu Ezike, and Ugwuaji coarse aggregates respectively.

Table 1: Sieve analysis for Awgu gravel

B.S sieve sizes	Weight retained (g)	Percentage Weight retained (%)	Cumulative % weight retained	Cumulative % weight passing
20	0	0	0	100
12.5	32	2.11	2.11	97.89
10	564	37.25	39.36	60.64
4.75	610	40.29	79.65	20.35
2.36	270	17.83	97.48	2.52
1.25	38	2.52	100	0
Total	1514	100%		

Table 1, shows the weight retained in the sieve, percentage weight retained, cumulative percentage weight retained, and cumulative percentage of weight of aggregate passing through the various sieve sizes. Table 1 reveals that at the use of 20, 12.5, 10, 4.75, 2.36, and 1.25 sieve sizes, the cumulative % weight retained are; 0, 2.11, 39.36, 79.65, 97.48, and 100 percent respectively, while cumulative % weight passing are 100, 97.89, 60.64, 20.35, 2.52 and 0 percent respectively. The grading in Table 1 varies which means that there will be adequate bonding of the aggregates.

Table 2 shows the sieve analysis results for coarse aggregate obtain from Enugu Ezike. It shows that at the use of 20, 12.5, 10, 4.75, 2.36, and 1.25 sieve sizes, the cumulative % weight retained are 0, 0.059, 32.26, 82.92, 97.7 and 100% respectively, while the cumulative % weight passing is 100, 99.41, 67.74, 17.08, 2.30 and 0.00 respectively.

Table 2: Sieve analysis for Enugu Ezike gravel

B.S sieve sizes	Weight retained (g)	Percentage Weight retained (%)	Cumulative % weight retained	Cumulative % weight passing
20	0	0	0	100
12.5	9	0.59	0.59	99.41
10	482	31.67	32.26	67.74
4.75	771	50.66	82.92	17.08
2.36	225	14.78	97.7	2.30
1.25	35	2.3	100	0.00
Total	1522	100%		

Table 3: Sieve analysis for Ugwuaji gravel

B.S sieve sizes	Weight retained (g)	Percentage Weight retained (%)	Cumulative % weight retained	Cumulative % weight passing
20	0	0	0	100
12.5	14	0.91	0.91	99.09
10	502	32.70	33.61	66.39
4.75	748	48.73	82.34	17.66
2.36	240	15.64	97.98	2.02
1.25	31	2.02	100	0.00
Total	1535	100%		

Table 3 shows the sieve analysis results for coarse aggregate obtain from Ugwuaji. It shows that at the use of 20, 12.5, 10, 4.75, 2.36, and 1.25 sieve sizes, the cumulative % weight retained are 0, 0.91, 33.61, 82.34, 97.98 and 100% respectively, while the cumulative % weight passing is 100, 99.09, 66.39, 17.66, 2.02 and 0.00 respectively. Also, from Table 3, the sizes of the aggregates vary to an extent thus, guaranteeing good bonding of the aggregates when used for concrete work.

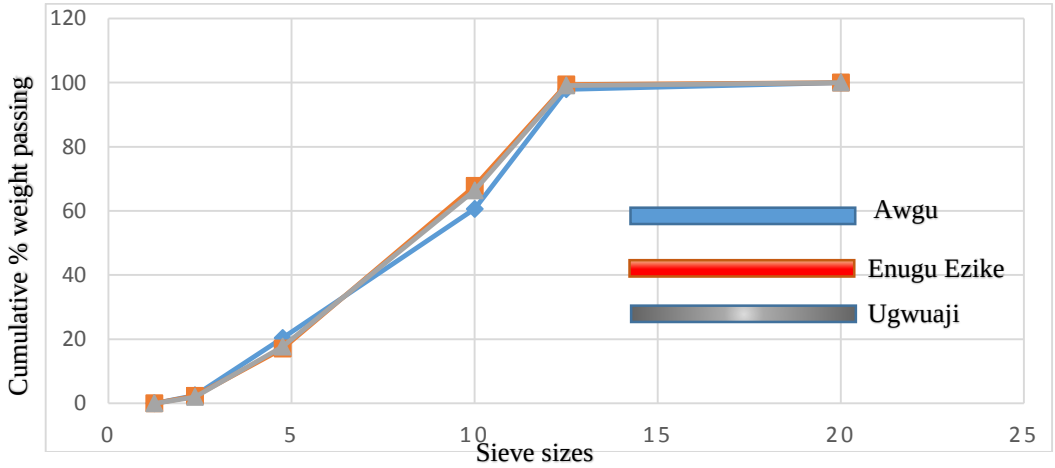


Figure 1: Graphical Representation of the Gradation of the Gravel Obtained from three Locations in Enugu State.

Figure 1 is a graphical presentation of the gradation curve, which shows the changes in the curves as the sizes of the aggregate change to the sieve size. The three curves represent the gradation of coarse aggregates obtained from Awgu, Enugu Ezike, and Ugwuaji as the graph key reveals.

Table 4: Compressive Strength Test Result of Concrete Produced using Coarse Aggregate Obtained from Mvuna Ituku- Ozalla Awgu LGA Enugu State.

Duration (days)	Cube reference	Mass (kg)	Density kg/m^3 (v = 3.38 x 10^{-3})	Average density kg/m^3	Cross-section area (mm^2)	Crushing Load (N)	Stress (N/mm^2)	Average Stress (N/mm^2)
3days	AW_{1A}	7.42	2,195.27	2207.10	22500.00	360 X 10^3	16.00	17.26
	AW_{1B}	7.56	2,236.69		22500.00	400 X 10^3	17.78	
	AW_{1C}	7.40	2,189.35		22500.00	405 X 10^3	18.00	
14 days	AW_{2A}	8.52	2520.71	2575.94	22500.00	420 x 10^3	18.67	19.04
	AW_{2B}	8.77	2594.67		22500.00	435 x 10^3	19.33	
	AW_{2C}	8.83	2,612.43		22500.00	430 x 10^3	19.11	
21 days	AW_{3A}	8.40	2,485.21	2507.89	22500.00	590 x 10^3	26.22	26.96
	AW_{3B}	8.32	2,461.54		22500.00	610 x 10^3	27.11	
	AW_{3C}	8.71	2,576.92		22500.00	620 x 10^3	27.56	
28 days	AW_{4A}	8.50	2,514.79	2492.11	22500.00	650 x 10^3	28.89	29.26
	AW_{4B}	8.54	2,526.63		22500.00	665 x 10^3	29.56	
	AW_{4C}	8.23	2,434.91		22500.00	660 x 10^3	29.33	

Table 4 shows the average compressive strength of the concrete produced using coarse aggregate from Mvuna Ituku Ozalla Awgu LGA Enugu State, for the 3 days, 14 days, 21days, and 28days as 17.26, 19.04, 26.96, and 29.26 respectively. From Table 8, the strength of the concrete increases as the age of the concrete increase.

Table 5: Compressive Strength Test Result of Concrete Produced using Coarse Aggregate Obtained from Umuogbuagu in Enugu Ezike, Igboeze North LGA Enugu State.

Duration (days)	Cube reference	Mass (kg)	Density kg/m^3 (v = 3.38 x 10^{-3})	Average density kg/m^3	Cross-section area (mm^2)	Crushing Load (N)	Stress (N/mm^2)	Average Stress (N/mm^2)
3days	EE1A	6.88	2035.50	1984.22	22500	365 x 10^3	16.22	16.59
	EE1B	6.67	1973.37		22500	380 x 10^3	16.89	
	EE 2C	6.57	1943.79		22500	375 x 10^3	16.67	
14 days	EE2A	8.48	2508.88	2499.01	22500	425 x 10^3	18.89	18.81
	EE2B	8.37	2476.33		22500	410 x 10^3	18.22	
	EE2C	8.49	2511.83		22500	435 x 10^3	19.33	
21 days	EE3A	8.75	2588.76	2521.70	22500	490 x 10^3	21.78	22.30
	EE3B	8.25	2440.83		22500	510 x 10^3	22.67	
	EE3C	8.57	2535.50		22500	505 x 10^3	22.44	
28 days	EE4A	8.71	2576.92	2590.70	22500	570 x 10^3	25.33	25.85
	EE4B	8.90	2633.14		22500	585 x 10^3	26.00	
	EE4C	8.66	2562.13		22500	590 x 10^3	26.22	

Table 5 shows the result obtained from the crushing test using coarse aggregate from Enugu Ezike, Igboeze North LGA Enugu State. Table 5 reveals the average compressive strength of the concrete at 3 days, 14 days, 21 days, and 28 days old as 16.59, 18.81, 22.30, and 25.85N/mm^2 respectively.

Table 6 shows the crushing test result for the compressive strength of concrete produced using coarse aggregate obtained in Ugwuaji Awkunano, Enugu South LGA, Enugu State. The result shows that at 3 days, 14 days, 21 days and, 28 days old of the concrete, the compressive strength improved progressively from 17.26, 21.72, 23.73 and, 26.30 N/mm^2 respectively.

Table 6: Compressive Strength Test Result of Concrete Produced using Coarse Aggregate Obtained from Ugwuaji Awkunano in Enugu South LGA Enugu State.

Duration (days)	Cube reference	Mass (kg)	Density kg/m^3 (v = 3.38 x 10^{-3})	Average density kg/m^3	Cross-section area (mm^2)	Crushing Load (N)	Stress (N/mm^2)	Average Stress (N/mm^2)
3days	UG1A	7.20	230.18	2145.96	22500.00	370 x 10^3	16.44	17.26
	UG1B	7.26	2147.93		22500.00	400 x 10^3	17.78	
	UG1C	7.30	2159.76		22500.00	395 X 10^3	17.56	
14 days	UG2A	8.23	2434.91	2515.78	22500.00	480 x 10^3	21.35	21.72
	UG2B	8.52	2520.71		22500.00	496 x 10^3	22.04	
	UG2C	8.76	2591.72		22500.00	490 x 10^3	21.78	
21 days	UG3A	8.40	2485.21	2544.87	22500.00	545 x 10^3	24.22	23.73
	UG3B	8.65	2557.69		22500.00	535 x 10^3	23.78	
	UG3C	8.76	2591.72		22500.00	522 x 10^3	26.20	
28 days	UG4A	8.56	2532.54	2503.94	22500.00	592 x 10^3	26.31	26.30
	UG4B	8.48	2508.88		22500.00	594 x 10^3	26.40	
	UG4C	8.35	2470.41		22500.00	589 x 10^3	26.18	

Table 7: ANOVA test to determine if significant variation exist in the compressive strength of concrete produced using coarse aggregate obtained from different locations in Enugu State.

ANOVA

Compressive strength of concrete	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10.216	2	5.108	.234	.796
Within Groups	196.611	9	21.846		
Total	206.827	11			

From Table 7, the result from the ANOVA test shows that the significant value is 0.796 (i.e., p=0.796), which is higher than 0.05. This implies that, there is no statistically significant difference in the mean of compressive strength of concrete produced from different sources in Enugu State.

However, decision rule states that; if the p-value is less than or equal to (≤) 0.05, we reject the null hypothesis, but if the P-value is greater than (>) 0.05, we accept the null hypothesis. Therefore, the null hypothesis is accepted in preference to the alternative hypothesis

Conclusion

On determining the compressive strength of concrete produced using Agwu stone, Enugu Ezike stone, and Ugwuaji stone for ages of 3 days, 14 days, 21 days, and 28 days, this study concludes that the compressive strength of concrete produced using stones obtained from the aforementioned locations in Enugu state are; 17.26, 19.04, 26.96, and 29.26 N/mm^2 respectively for Mvuna Ituku Ozlla of Awgu Stone; 16.59, 18.81, 22.30 and 25.85N/mm^2 respectively for Enugu Ezike stone and; 17.26, 21.72, 23.73 and 26.30 N/mm^2 respectively for Ugwuaji stone. However, on the 28th day, none of the concrete yielded a compressive strength that is less than 25N/mm^2 which implies that the coarse aggregates are suitable for concrete production. Ugwaji gravel produced the highest absorption rate of about 0.67% followed by Awgu gravel of about 0.57% and the least Enugu Ezike stone of about 0.55% average. This indicates that Ugwaji stones are more porous and as such lose their strength due to that.

In conclusion, the study indicated that there is no significant variation in the compressive strengths of concretes produced using coarse aggregates obtained from different locations in Enugu state. However, Gravels obtained from Awgu (Mvuna Ituku Ozalla) produced the highest strength of 29.26 N/mm^2 and would be most recommended for concrete production.

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