International Journal of Engineering Technology and Management Sciences
Website: ijetms.in Issue: 3 Volume No.8May - June – 2024
DOI:10.46647/ijetms.2024.v08i03.071 ISSN: 2581-4621

The Use of Basaltic Rock as An Aggregate in Concrete

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***Abstract*—** The purpose of this research is to investigate the adequacy according to Civil Engineering Standard of using basalt aggregates in concrete mixes. Basalt aggregates which are an extrusive igneous rock has gained significant development due to its properties and availability in Biu. The researcher examines the aggregate gradation, rate of water absorption, density, workability of the basalt aggregate and determination of compressive strength of the concrete cubes after 7days, 14days and 28 days of curing which is backed up by a statistical analysis of the model in the concrete mix by varying the percentage of basalt aggregate. Meanwhile a conventional limestone mix was used as control mix. The results of this investigation show a general improvement in the mix properties as a result of introducing Biu Borno State basalt aggregates in the mix design.
***Keywords*—Basalt, Limestone, Compressive Strength, water absorption.**

INTRODUCTION

This Basalt rocks are usually formed when the volcanic basaltic Lava rapidly cools from the deep interior of the earth's crust equivalent to plutonic gabbro-norite magma and gets exposed to the Earth surface. Gas cavities are absent in the basalt lows and these floors are generally quite thick and extensive. The texture of basalt rocks is coarsely porous as those holes are left by gas bubbles. The specimens of these rocks are mostly fine-grained, hard and compact due to its properties, it is used for engineering construction.

Sudha et al. (2019) studied the mechanical properties like compressive strength, split tensile strength of basalt reinforced concrete in beam column joint. The behaviour of beam column joint with 0.75%, 1% and 1.25% basalt fiber were studied under cyclic loading. The results showed that the beam column joint shows better performance by the addition of basalt fibers. The study concluded that addition of basalt fiber into the concrete will enhance the flexural, compressive, split tensile strength and toughness of the concrete. Also, it will reduce the size of cracks during failure.

Kishore et al. (2015) focused on the effect of basalt aggregate content and its combination with limestone aggregate in concrete mix. Different percentage combination of basalt and limestone aggregate were used in this study. Compressive strength, workability, specific gravity, Los Angeles abrasion tests were performed to evaluate the performance of basalt aggregate in concrete mixes. The test results concluded that concrete mix with basalt aggregate is more workable than limestone aggregate and also the higher strength is obtained by the introduction of basalt aggregate in concrete mixes.

Rathod et al. (2013) studied the flexural strength and compressive strength behaviour of basalt fiber reinforced concrete and normal concrete. Separate specimens were cast with 1 % and 2 % of basalt fiber. The results show that the flexural strength and compressive strength of specimens with basalt fiber is higher compared with normal concrete. Also, by the addition of 2% of fiber, the 14 days flexural strength increased about 40% to 50% and 28-days compressive strength increased about 83% to 92%.

Due to the inflation of construction materials such as gravel, sand, reinforcement and cement, therefore this research focuses on providing alternative aggregate that will provide low cost and high durable materials most especially for concrete by using basalt aggregate.

The objectives of the study are;

To determine the workability of using crushed basaltic rock as concrete aggregate by conducting slump test.

To determine how long basalt can resist failure resulting from bending stresses by conducting compressive strength test at varying percentage of basalt.

To determine the gradation of crushed basalt in compliance with the design, production and specifications of aggregates by conducting sieve analysis.

To determine the density of cubes before absorption, after absorption in water and the moisture content.

Materials and Method

In this section the materials used for this research were fully explained.

The Basaltic Rock Usage as Concrete Materials

The materials used in this research are as follows:

- Basalt

Crushed basalt was obtained from Biu environment and the crushed samples was gotten by buying the required quantity of basalt aggregate

- Cement

The ordinary Portland cement manufactured by Ashaka cement company limited, Biu was used in this course of study.

- Aggregate
- Coarse Aggregate

The coarse aggregate used in the course of study was obtained from the local basalt rock crusher in Biu, Borno state in which the 100% of the sample had pass through the smallest sieve. The maximum size of the aggregate is 20mm and minimum size of 10mm and conform to the specification of ASTM with the following properties; specific gravity of 2.90, Aggregates crushing value (ACV) 24.37% and Aggregate impact value (AIV) 12.5%.

- Fine Aggregate

The fine Aggregate used for this course of experiment were obtained from the local suppliers in Biu and it is in accordance to ASTM (1987) with specific gravity of 2.61 and fineness modulus of 2.41.

- Water

The water to cement ratio is 0.45-0.55 which is in accordance to table II-3 requirements for concrete for structures and general construction. Water plays an important role in concrete mix design, in fact water is the key ingredient used in this experiment, which when mixed with cement forms a paste that binds the aggregate together to form concrete. Water is the main agent that cause the hardening of concrete through a process called hydration. Hydration is the process in which water molecules and major chemical in cement forms a chemical bond. Pure water was used in order for the experiment so as to prevent any side effect from occurring which may disrupt the hydration process. Medium quantity of water was used because too much of water will reduces the concrete strength and little quantity of water will make the concrete not workable. In order to achieve both the strength and true workability of concrete, a careful balance between water to cement ratio is required when making the concrete.

In this research study, the various test carried out includes;

Sieve Analysis:

The distribution of different particle sizes in coarse aggregate basalt was determined in accordance to BS 410 and ASTM E11. The digital weighing balance was used to measure 1 kg of the crushed

Website: ijetms.in Issue: 3 Volume No.8May - June – 2024
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sun-dried basalt aggregate which was free from hazardous levels of organic contaminants of unbound aggregate mixtures. The prepared aggregate sample was then passed through the following sieves which was arranged in descending order (60mm, 40mm, 20mm, 10mm, 5mm, 2mm, 1mm, 0.5mm, 0.25mm, 750µmm and the receiving pan). The sieve set up was manually shaken for about 5min, then the mass of particles retained on each sieve were weighed using the digital weighing balance and the result was recorded. The result was expressed as a percentage by weight of materials passing each sieve as shown in Appendix I

Specific Gravity:

The test was conducted in accordance with BS 812:2, EN 12390-7. Specific gravity test is mainly carried out to determine the quality of the basalt aggregate. The apparatus used are; weighing balance, a thermostatically controlled oven, a wire basket of not more than 6.3mm mesh, a container for filling water, a shallow tray and two absorbent clothes. The procedures followed were;

- 2kg of aggregate was measured using by using the weighing balance and was washed thoroughly to remove fines and dirt.
- It was drained and placed in wire basket and immersed in distilled water at a temperature of 22-32^{o}c and a cover of at least 5cm of water above the top basket
- After the water immersion, the entrapped air was removed from the sample by lifting the basket containing it about 25mm above the base of the tank and was allowed to drop at the rate of about one drop per second. The basket and aggregate were completely
- Immersed in water for a period of 24 hour afterwards.
- The basket and the sample are weighed while suspended in water at a temperature of 22^o-32^{o}c. The weight while it was suspended in water was recorded as W_1(g).
- The basket and aggregate were then removed from the water and was drained for a few minutes. The empty basket was returned to the tank of water jolted 25 times and weighed in water and was recorded as W_2(g).
- The aggregates were placed on the absorbent clothes was surface dried till no further moisture could be removed by the clothes. The surface dried aggregates were completely surface dried, the surface dried aggregates were weighed and recorded as W_3(g).
- The aggregate was placed in a shallow tray and was kept in an oven and the temperature was maintained at a temperature of 110^{o}c for 24 hrs. It was removed from the oven, cooled and weighed as W_4(g). The specific gravity was recorded as the weight of the sample to the equal volume of water. The results are shown in chapter four (note that specific gravity of aggregates used for road construction is about 2.5 to 3.0).

Workability (Slump test):

The slump test was conducted in accordance to BS 1881: part 102 (1983). The slump value of concrete is a principle of gravity flow of the surface of the concrete cone that indicates the quantity of water added to it. The apparatus used in this experiment includes; A frustum shape metallic mould cone having a bottom diameter of 200mm, top diameter of 100mm and height of 300mm and a steel tamping rod having 16mm diameter, 0.6m long with bullet end and a trowel. The procedures were;

- The internal surface of the cone was cleaned and was freed from other old sets of concrete.
- The mould was placed on the smooth horizontal, rigid and non-absorbent surface.
- The mould was then filled with fresh concrete in four layers and was tapped each layer 25 times by the taping rod, and was levelled to the surface with the trowel.
- Then the mould was slowly pulled in vertical and was removed from the concrete.
- The free concrete deformed all the surface to subside due to the effect of gravity.

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The subsidence of the concrete is the slump of the concrete. The difference in height of the subsided concrete to the height of the mould cone in mm was the slump value of the concrete and was recorded in chapter four.

Density of cube before absorption:
The density of each cube after 24 hours of casting for each sample is to be measured in order determine the change in density which is to be calculated as mass(kg) for each sample divided by the volume of the cube.

Density of cube after absorption:
The density of each cube after 28 days of curing for each sample is to be measured in order determine the change in density which is to be calculated as mass(kg) for each sample divided by the volume of the cube. The result is shown in chapter four.

Water absorption test:
Water absorption test was conducted in accordance with BS 1881 part 122 (1983). The specimens were dried in an oven for a specified period of time and was placed in the desiccators to cool. Immediately after the cooling of the specimens, it was weighed and the result was recorded. Then, after weighing, the specimens were emerged in water at a temperature of 23^{o}C for 24hours. The specimen was removed, patted dry with a lint free cloth, and weighed. Finally, the percentage in weight between the ovens dried and saturated surface condition (SSD). The result of this test was presented in detailed in chapter four.
Percent Water Absorption = [(wet weight-Dry weight)]/Dry weight ×100 ………………… (1)

Concrete Mix Design:
implies for one cubic meter of concrete contains; 1 part of cement, 1part of sand/fine aggregate and 2 parts of the concrete mix designed is based on minimum design of 25N/mm^2. The concrete ratio = 1:1:2, which coarse aggregate. The design is in accordance to the British method which is that of the Department of Environment (DOE) revised in 1988 similar to the ACI approach design calculation are shown in the Appendix.

Concrete Specimen
The cube size of 150mm × 150mm × 150mm is used to conduct the comprehensive test of the sample at 0%, 10%, 20%, 30%, 40%, 50%, 60%, 80% and 100% of aggregate content. The specimens are differentiating with respect to the aspect of the aggregate quantity.

Batching
The constituent materials were weighed using the weighing balance, and the quantity of the concrete materials in each batch was made at least 10% more than that of the proposed test (BS 1881, Part 125C).

Mixing
The materials (cement, sand, crushed aggregate and water) were weighed correctly and mixed on non-absorbent surface using a trowel and a shovel. Fine and coarse aggregate were used; cement was added and thoroughly mixed with the fine aggregate (sand) and then the crushed basalt (aggregates) was added. Finally, the mixing water was added, then the mixing continued until the whole mixed become homogenous.

Compressive Strength
The compressive test is to be conducted using the compressive test machine at the Laboratory in accordance to BS 1881 – part 116, 1983. An increasing compressive load is applied to the specimen

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until it failed in order to obtain the maximum compressive load. Basalt cube of 150mm in length, 150mm in width and 150mm in height are used to determine the compressive strength. The samples were demoded after 24 hours of casting and cured in water until the testing ages. The compressive strengths of concrete were determined at the ages 28days. Where;

Compressive strength = P/A

Where:

P: Ultimate compressive load of the concrete (KN)

A: Surface area in contact with the platens (mm^2)

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RESULTS

SIEVE ANALYSIS RESULT

Table 1. shows the result for fine aggregate used for the experiment.

Total weight of sample = 1000g

IS Sieve Size (mm)	Percentage Finer (%)
9.50	99.5
4.75	97.6
2.36	84.7
1.18	66.2
0.60	31.8
0.30	11.3
0.15	1.5
0	0

Al Fineness Modulus of Aggregate =

$$\frac{\text{summation of cumulative \% retained on sieve 4.75- 0.15}}{100}$$

Fineness Modulus of Aggregate = 3.07

The fineness modulus of the fine aggregates used is within the range of 2.3 to 3.1 which conforms to BS 812-103.1: 1985.It signifies that the sand is workable, strong and very suitable for concrete production.

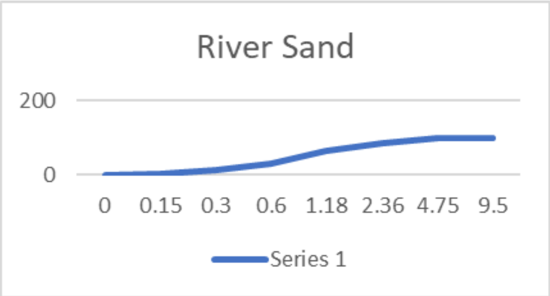

Fig 1: Fine aggregate graph

Table 2. shows the Result for Basalt Aggregate

IS Sieve Size (mm)	Percentage Finer (%)
26.5	200
19	47.4
16	47.4

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13.2	1.8
9.5	1.2
6.4	0.7
2.8	0.4
1.25	0.3
0.6	0.2
0.3	0.1
1.15	0.1
0.075	0
75μm	0

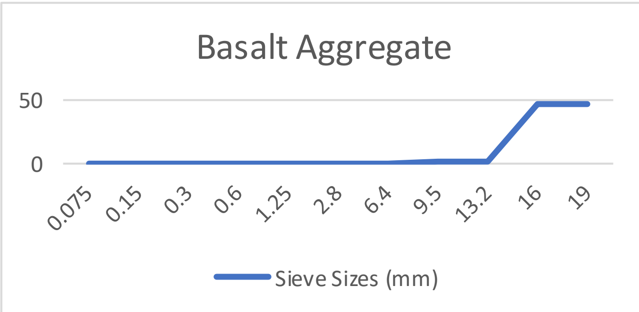

Fig 2: Basalt aggregate graph

FRESH CONCRETE TESTING

The concrete mix was tested to define its workability and consistency. Slump test was the fresh concrete testing that was carried out to determine the workability of fresh concrete. Fresh concrete is defined as workable and consistent when the concrete can be transported, placed, handled, compacted and finished efficiently without any segregation. It can also be defined as concrete that has been recently mixed and has plasticity.

Workability (Slump test):

The slump test is prescribed by BS 1881: Part 102: 1983. The slump was measured in millimetres unit and the result of the test is shown on table 3 below

Table 3: The Slump Value of the Fresh Concrete

% of Basalt Replaced	Slum Height (mm)
0	205
10	218
20	230
30	241
40	255
50	255
60	260
70	263
90	268
100	270

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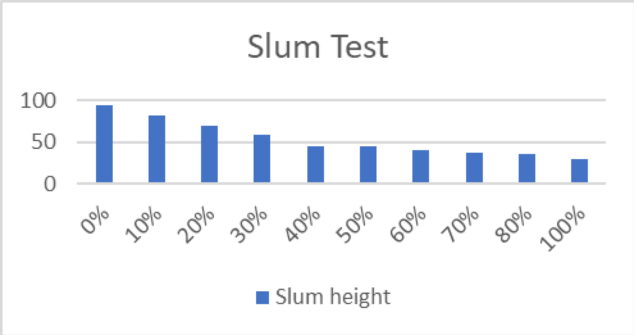

Fig 3: Slump height

The result shows that as the percentage of basalt increases, the slump height increases. It indicates that the concrete mix is becoming less fluid and it is workable to be adopted for construction works. The increase in slump height indicates that there is tendency of higher compressive strength and reduces the tendency of bleeding and segregation which helps to maintain the homogeneity of the concrete mix so as to maintain consistent properties of materials throughout the construction. Also, increase in slump height tends to experience less plastic shrinkage most especially during the curing process which contributes to reduced cracks and durability of the concrete. Meanwhile, increase in slump height provides quicker setting time of the concrete.

CONRETE DENSITY

Table 4 and table 5 below shows the average density of the specimens before and after absorption respectively. The density was performed according to BS 1881-114 density of concrete.

Table 4: Cube density before absorption

Basalt content %	Cube volume (m^3)	Weight (kg)	Density (kg/ m^3)	Average density (kg/m^3)
0	3.375×10^{-3}	6.940	2056.29	2077.03
		7.030	2082.96	
		7.060	2091.85	
10	3.375×10^{-3}	7.440	2204.44	2208.89
		7.400	2192.59	
		7.525	2229,63	
20	3.375×10^{-3}	7.720	2287.41	2280.37
		7.630	2260.74	
		7.743	2294.22	
30	3.375×10^{-3}	7.895	2339.26	2325.43
		7.865	2330.37	
		7.785	2306.67	
40	3.375×10^{-3}	8.005	2371.85	2384.69
		8.135	2410.37	
		8.005	2371.85	
50	3.375×10^{-3}	8.135	2340.00	2353.33
		8.125	2407.41	
		8.865	2312.59	
60	3.375×10^{-3}	8.235	2440.00	2440.49
		8.270	2450.37	
		8.205	2431.11	

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80	3.375×10^{-3}	8.480	2512.59	2520.99
		8.525	2525.93	
		8.520	2524.44	
100	3.375×10^{-3}	8.580	2542.22	2556.54
		8.625	2555.56	
		8.680	2571.85	

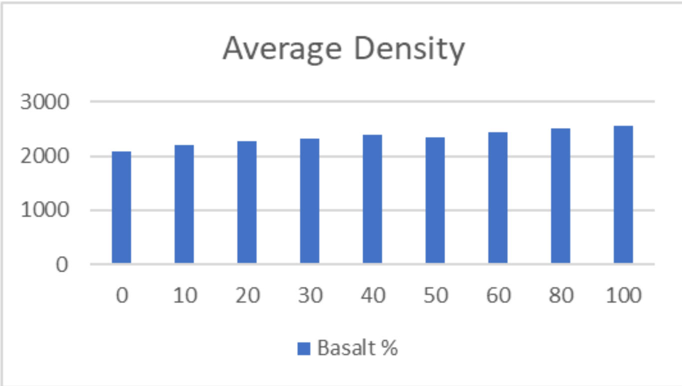

Fig 4: Average density before absorption result

From figure 4 above, each bar represents the average density of the basalt increment as calculated in table 3 above. The density of the cubes increases as the percentage of basalt increases and percentage of limestone decreases. This is due to the effect of basalt content, such that basalt aggregate is denser than limestone. Gradual increase in density of concrete cubes before absorption helps to prevent sudden change in the moisture content that can lead into cracks due to internal stress developed in the concrete cube. Also, gradual increase in the density of the cubes after 24 hours of casting helps to prevent spalling which might occur if the concrete sets quickly.

Table 5: Cube density after absorption

Basalt content %	Cube volume (m^3)	Weight (kg)	Density (kg/ m^3)	Average density (kg/m^3)
0	3.375×10^{-3}	7.385	2188.15	2182.22
		7.410	2195.56	
		7.300	2162.96	
10	3.375×10^{-3}	7.705	2282.96	2290.86
		7.800	2311.11	
		7.890	2278.52	
20	3.375×10^{-3}	7.965	2360.00	2343.70
		7.955	2357.04	
		7.810	2314.07	
30	3.375×10^{-3}	8.045	2383.70	2402.96
		8.135	2410.37	
		8.150	2414.81	
40	3.375×10^{-3}	8.300	2459.26	2442.62
		8.415	2409.33	
		8.300	2459.26	
50	3.375×10^{-3}	8.330	2468.15	2470.62
		8.390	2485.93	
		8.295	2457.78	

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60	3.375×10^{-3}	8.475	2511.11	2499.26
		8.425	2496.30	
		8.405	2490.37	
80	3.375×10^{-3}	8.660	2565.93	2567.90
		8.655	2564.44	
		8.685	2573.33	
100	3.375×10^{-3}	8.680	2571.85	2579.26
		8.750	2592.59	
		8.685	2573.33	

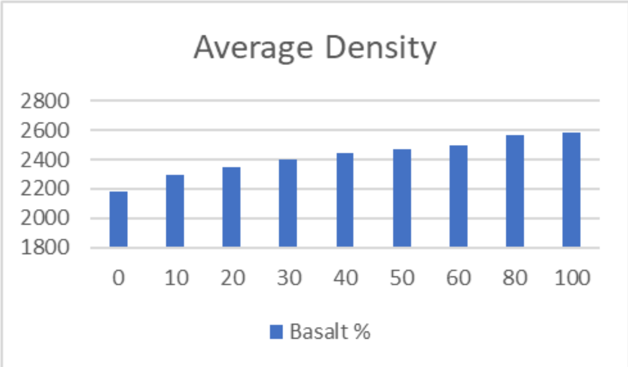

Fig 5: Average density after absorption result

From the fig 5 above, the charts show increase in the density of cubes after 28 days of curing which is higher than the density of the same cubes before absorption. This is due to hydration of which the cubes had undergone within the period of 28 days. Since concrete consist of cement, sand and aggregates, the cement particles react water in a chemical particle called hydration. As a result of hydration, the sand and aggregates a stronger bond with the cements. Higher density of the concrete cubes after 28 days curing in curing tank signifies that the compressive strength will increase with respect to increase in percentage of basalt used therefore offering high bearing capacity of the concrete. Also, denser concrete is more resistant to wear, impact load, liquids penetration and weathering therefore enhancing the durability and life span of the concrete when used in construction especially in harsh weather condition. Increase density of the hardened concrete especially at 100% basalt aggregates provide better insulation to change in temperature which cannot be neglected during civil construction application.

WATER ABSORPTION:

Table 5 below shows the water absorption of the hardened concrete as the percentage of basalt is increase.

Table 6: Water absorption result

% of Basalt Replaced	% Decrease
0	5.01
10	3.71
20	2.76
30	3.33
40	3.60
50	3.66

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60	2.41
70	1.46
100	0.8

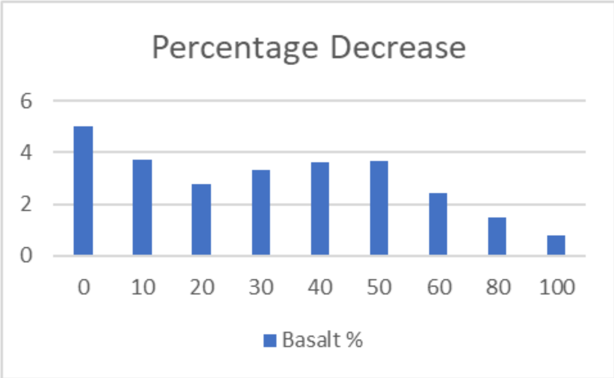

Fig 6.: Water absorption result

The fig 6 shows the gradual decrease in the water absorption of the hardened concrete as the percentage of basalt increases in the homogeneous mix. The decrease in water absorption signifies that the hardened concrete is less porous to water as limestone is replaced with basalt in the mix sample. At 100% of limestone, 5.01% of water is absorbed which conforms to BS EN 12390-7:2019. Meanwhile at 100% of basalt aggregate, the water absorption of the concrete is 0.89% which is due very low permeability of basaltic rock. Therefore, the reduced water absorption of water in 100% basalt of concrete cube means that it is more resistance to chemical attack, deterioration due to moisture or harmful substances into the concrete. Also, due to the reduced moisture content of the cubes, it contributes to the structural integrity and load bearing capacity of structures most especially in hydraulic structures and as a result of the reduced moisture content of the cubes, the structure tends to have longer life span due to its ability to resist fluid.
Concrete compressive strength is the most essential property in concrete, as it gives an idea on the overall quality and characteristics of the concrete. It is defined as the maximum compressive load the concrete can withstand before it fails. The hardened concrete tests conducted was the compressive test of the cubes after 28 days curing.
Compressive Strength:
The test was performed according to the British Standard (B.S. 1881, part 3). The important property in concrete is the concrete compressive strength of the concrete cubes which is an important criterion in defining the overall quality of the concrete strength which is in relationship to the hydrated cement paste. Table 4.6 below shows the compressive strength of the cube specimens corresponding to the varying percentage of limestone and basalt at 7 days curing.

Table 6 Compressive strength of concrete cube at 7, 14 and 28days

% of basalt content	Compressive strength at 7 days (N/mm²)	Compressive strength at 14 days (N/mm²)	Compressive strength at 28 days (N/mm²)
0	15.62	21.62	24.03
10	16.10	22.30	24.77
20	16.77	23.21	26.09

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30	18.87	26.12	29.03
40	20.87	28.90	32.11
50	22.49	31.15	34.61
60	24.65	34.13	37.92
70	25.54	35.36	39.29
100	26.36	36.49	40.55

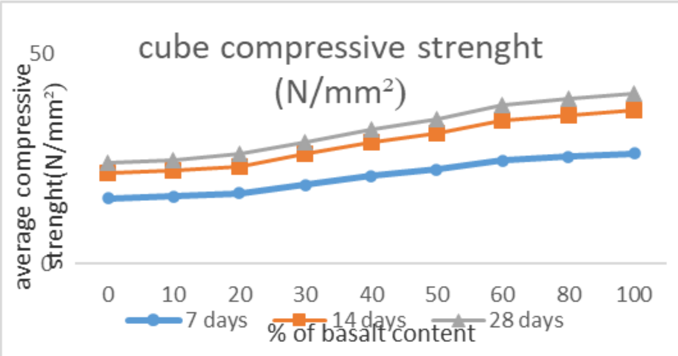

Fig 6: Compressive strength of concrete cubes

From the figure 6 above shows the compressive strength of the concrete cubes at 7 days, 14 days and 28 days of curing, which increases as the percentage of basalt in the cubes increases. This is expected as the basalt is denser than limestone. At 0% basalt of which the limestone quantity is 100%, the compressive strength is lower compared to when the quantity of basalt in the cube is 100% and 0% of limestone in the specimen which is shown in figure 7.0 above. The compressive strength of the concrete cubes increases as the percentage of basalt increases due to better basalt particle packing within the concrete mix. Meanwhile, the improved particle packing of basalt in the concrete reduces void and brings the particles more in contact with each other which leads to stronger interlocking connection of basalt particles. Also, increase in compressive strength of concrete cubes as shown in figure 7.0 above shows lower percentage of water cement ratio and better hydration of cement particles. Between 0% of basalt and 10% of basalt content in the concrete, the compressive strength increases by 0.71 N/mm² which is less than 1.0 N/mm² which is due to poor compaction of concrete in the concrete mould. This cause low increase in compressive strength of concrete cubes as the basalt content is increased. The compressive strength of the specimen at 100% limestone increases by 16.52 N/mm² by 100% of basalt is used. This shows basalt aggregates is more preferable to be used for high load bearing structure. It is noted that the compressive strength of the concrete cubes reached its optimum strength at 28 days of curing which correspond to the engineering standard.

CONCLUSIONS

The use of basalt aggregate in concrete increased the compressive strength of the concrete compared to the widely used limestone aggregate. The conclusions are based on the objectives of the research and observation done throughout the whole course of this study. The conclusions are:

I. The research proves that when basalt aggregate is used in fresh concrete mix, the concrete mix is workable and its slump height decreases as the percentage of basalt is increased gradually.

II.In this study when the percentage of basalt and limestone at 0%,10%, 20%, 30%, 40%, 50%, 60%, 80%, and 100% percentage of specimens for three cubes each was varied and crushed by compressive machine after being cured for 28 days in the curing tank, the compressive strength of the cubes increases gradually with respect to percentage increase in basalt. The optimum compressive strength of the cube was attained at 100% of basalt aggregate. At 100% percentage of basalt, the concrete can be used for the design of high load bearing capacity structure.

DOI:10.46647/ijetms.2024.v08i03.071 ISSN: 2581-4621

III. Basalt aggregates conforms to the standard gradation of coarse aggregate required for concrete work.

IV. From the results, the density of the cubes increases gradually before absorption in water and after water absorption in curing tank which was due to increase in percentage of basalt aggregate in the mix. Also, the rate of water absorption of the specimens decreases as the percentage of basalt aggregates increase. Therefore, it can be used in the design of hydraulic structures.

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