International Journal of World Policy and Development Studies
ISSN(e): 2415-2331, ISSN(p): 2415-5241
Vol. 4, Issue. 3, pp: 20-29, 2018
URL: http://arpgweb.com/?ic=journal&journal=13&info=aims

Academic Research Publishing Group

Original Research Open Access

Appraisal of Different Production Methods on Coarse Aggregate Performance in Concrete

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Abstract

Properties of concrete have been reported to depend mainly on cement and coarse aggregates. Coarse aggregates, in turn, depend on the type of the parent rock from which aggregates has been obtained as well as the methods of aggregates production. Suitability of coarse aggregates obtained from three different methods of production namely; machined crushed stone from the quarry (MCSQ), manually crushed stone by application of fire (MCSF) and manually crushed stone with hammer after blasting (MCSH) was investigated. A total number of 216 concrete cubes were cast, in order to determine the compressive strength of the various concrete made with MCSQ, MCSF and MCSH; with varied mix ratios of 1: 1½: 3, 1: 2: 4 and 1: 3: 6. The results of aggregate crushing value (ACV) and aggregate impact value (AIV) for MCSH are 28.4 % and 15.06 % respectively, for MCSF are 30.7 % and 19.5 % respectively, and for MCSQ are 29.8 % and 18.07 % respectively. Furthermore, the compressive strength of concrete cubes obtained from MCSQ, MCSF and MCSH respectively at the end of 28 days were: 22.07 N/mm2, 19.04 N/mm2 and 28.15 N/mm2 respectively for the mix 1: 11/2: 3; 22.00 N/mm2, 20.96 N/mm2 and 23.33 N/mm2 respectively for the mix 1: 2: 4 and 17.04 N/mm2, 12.52 N/mm2 and 17.48 N/mm2 respectively for the mix 1: 3: 6. . The compressive strength values obtained for the various mixes and aggregates fall within 15 to 30 N/mm2 as specified in BS EN 1992-1-1:2004 except the concrete obtained from MCSF for the mix 1:3:6 at 28 days curing. The statistical analysis was done and reported for the various results.

Keywords: Coarse aggregates; Aggregate crushing value; Aggregate impact value; Compressive strength.

1. Introduction

The most commonly material used today is concrete (Barritt, 1984). Its content includes coarse aggregates (crushed stone or gravel), fine aggregates (river sand or stone dust), cement, water and additional admixtures if necessary, i.e. It is a material that consists of a binding medium in which are embedded particles or fragments of aggregates (Zongjin, 2011). Concrete is the most widely used constructional material on earth. This is because it is used for many different structures, such as dams, pavements, building frames, or bridges, much more than any other construction material.

Kishore (1995) classified concrete in term of compressive strength at 28 days into low grade (up to 15 N/mm^2), medium grade (between 16 N/mm^2 and 50 N/mm^2), high grade concrete (between 50 N/mm^2 and 100 N/mm^2) and ultra - high strength concrete (beyond 100 N/mm^2). In addition, the strength of concrete mainly depends on the amount of water used, aggregate gradation, and aggregate size and shape, cement quality, mixing time, mixing ratios, curing, etc. (Kabir, 2006). However, facts reveal that fine and coarse aggregates make up 70 % which is about three-quarter of the volume of normal weight of concrete (Neville, 2003).

Crushed stone is a form of coarse aggregate which is in high demand for the production of concrete. It is characterized by its high volume and remarkable strength which in turn improves the strength of the concrete produced for construction purposes. Aginam *et al.* (2013) investigated the effect of coarse aggregates types (crushed granite, washed gravel and unwashed gravel) on the compressive strength of concrete. It was discovered that the compressive strength from the unwashed granite gave the least strength and that the strength of concrete depends greatly on the internal structure, surface nature and shape of aggregates. This also followed (Jimoh and Awe, 2007) where they studied the influence of aggregate types and sizes on the compressive strength of concrete. They realised that as the size of coarse aggregates increases, concrete strength decreases and the rate of fall in strength is highest with concrete containing granite and quarry dust. This implies that the strength, durability and structural performance of concrete are greatly affected by the properties of fine and coarse aggregates (Ayub *et al.*, 2012).

The construction industries in the developing world seeks the use of alternative means of crushed stone production, which can replace the demand for crushed stone from the quarry, thereby reducing environmental load on crushed stone from the quarry, reduction of production and transportation cost as well as augmenting the quality of concrete (Lohani *et al.*, 2012). This is why (Siddiqi *et al.*, 2013) investigated the suitability of using locally available coarse aggregates in Azad Kashmir to make concrete. The result from their investigations showed that the concrete made using locally available aggregates in Azad Kashmir performed satisfactorily in terms of mechanical properties and their performance was found to be quite similar to those aggregates gotten from the quarries. In

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Nigeria, the cost of coarse aggregates from quarry is expensive because the siting of quarries is usually very far from built-up areas due to both environmental and geological factors. The focus of this research is to determine and statistically compare the strength properties of crushed stone obtained from various sources and the concrete produced from them.

2. Materials and Methods

2.1. Materials

The materials used for the production of the concrete are: fine aggregate (River Sand), Coarse aggregate, Cement and Water. They were sourced locally from Akure, Ondo State, Nigeria. The coarse aggregates used were obtained through three different means of the same parent rock. The first was obtained through machine crushed from quarry (A), the second was obtained through manually crushed by fire (B) (Plate 1) and the third one was obtained by manually crushing the rock with hammer and with the use of explosive (C) (Plate 2) as shown in Table 1. Three different mix ratios were used ($1:1\frac{1}{2}:3$; 1: 2: 4 and 1: 3: 6) using 0.55 water-cement ratio to produce two hundred and sixteen 150 mm × 150 mm × 150 mm concrete cubes.

Table-1. Names of sources of crushed stone obtained for the research work

Samples	Sources	Well Graded (1)	All-in Aggregates (2)
A	Crushed stone from the quarry	A_1	A_2
B	Crushed stone by fire	B_1	B_2
C	Crushed stone by hammer	C_1	C_2

Plate-1. Process of obtaining granite by blasting with fire

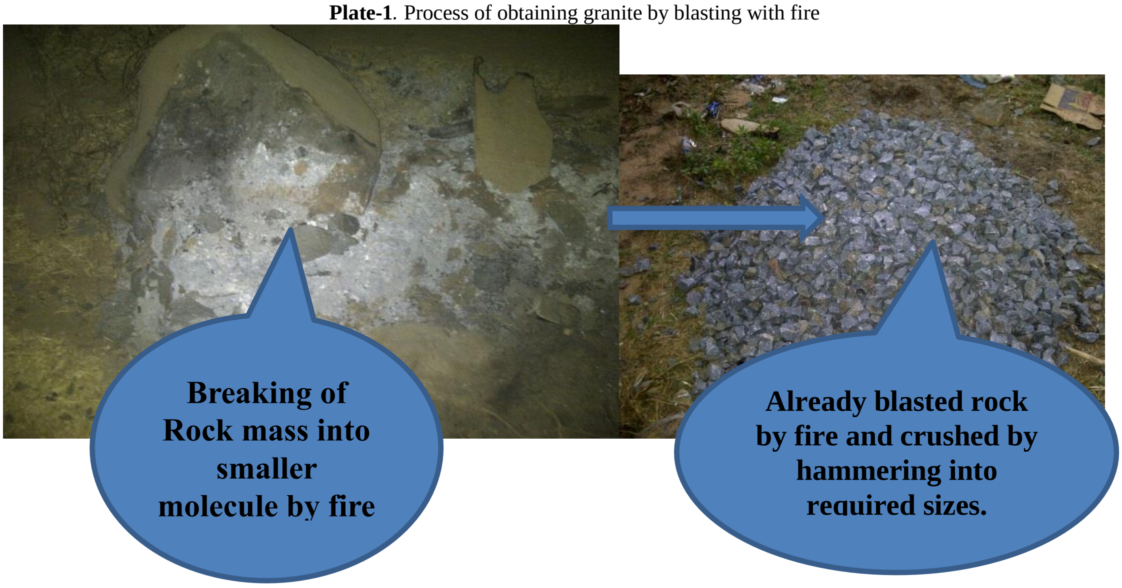


Plate-2. Process of obtaining granite manually with the use of explosive

2.2. Methods

The experiments were carried out at the Structural and the Geotechnical Laboratories of the Federal University of Technology, Akure, Ondo State. The batching of the materials was done accordingly. Mixing of the already batched materials with water followed. To ensure that the wet concrete is to the standard, workability tests (slump test and compaction test) were conducted. The concrete cubes produced were cured in a curing tank filled with water in order to prevent the loss of moisture and to keep them within the room temperature (Plate 3). At 7, 14, 21, and 28 days, crushing tests were conducted so as to determine their respective compressive strengths.

Plate-3. Curing of concrete cubes in water

4. Results and Discussions

The results of the various tests conducted on the materials are presented in Table 2

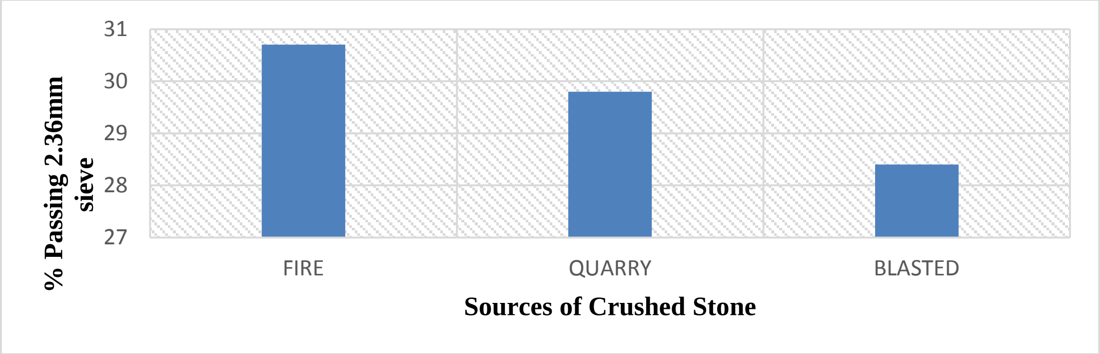
Table-2. Tests on Aggregates, Fresh concrete and hardened concrete

Coarse Aggregates			
	Quarry	Manual	Fire
Specific Gravity	2.59	2.61	2.60
ACV	29.8 %	28.4 %	30.7 %
AIV	19.5 %	15.06 %	18.07 %
Fine Aggregates			
Specific Gravity	2.65		
Moisture Content	9.45 %		
Silty/Clay Content	9.3 %		
Bulk Density	1.73 g/cm^3		
Cement			
Initial Setting Time	50 mins		
Final Setting Time	510 mins		
Fineness	8.55 %		
Consistency	27 %		
Soundness	4 mm		
Slump (mm)			
Grade	Slump (mm)	Compacting Factor	
1:3:6	29	0.87	
1:2:4	40	0.95	
$1:1\frac{1}{2}:3$	35	0.93	

4.1. Coarse Aggregates

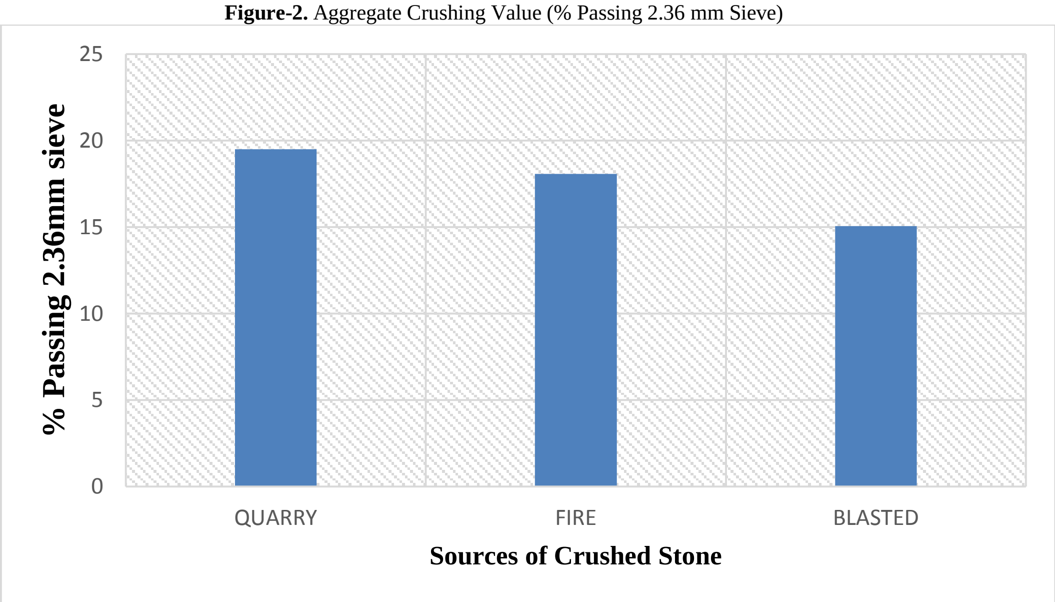
The aggregate crushing values (ACV) for all the three sources of aggregates are shown in Figure 1. It was observed that the percentage of ACV for the blasted material was the least (28.4 %) while that of the fire source gives the highest value (30.7 %). This shows that they are suitable for engineering work according to IS: 2386 (Part IV) – 1963 and BS 882 (1992)

Figure-1. Aggregate Crushing Value (% Passing 2.36 mm Sieve)



However, Figure 2 shows the result of the aggregate impact value (AIV) for all the three sources of coarse aggregates:

Figure-2. Aggregate Crushing Value (% Passing 2.36 mm Sieve)



It was also observed that the percentage of AIV for the blasted material was the least, which informs that the blasted material source proved to be the material with the greatest strength. Hence, for strong aggregate, AIV value should be low, it should also be between 10 % and 25 % in order for the granite to be suitable for civil engineering construction. This implies that the granites from all the sources are suitable for civil engineering construction.

However, the specific gravity for the coarse aggregate is 2.6 which is within the acceptable limit of 2.55 – 2.80, and therefore suitable for civil engineering construction.

4.2. Fine Aggregates

It could be observed from Table 2 that the specific gravity for the fine aggregates is 2.65 which falls within the standard. Also, the value of moisture content is 9.45 % which also falls within the limit of 6 – 12 % specified by BS 1377 (1975) and hence suitable for construction purpose. As well, the value of silty/clay content (9.3 %) and bulk density (1.73 g/cm^3) fall within the standard.

4.3. Cement

The value of soundness is 4 mm which is less than 10 mm standard specification. The expansion of the cement is less and hence less prone to cracking. Also, the value of fineness is 8.55 % which satisfied the requirement by BS 4550 (1978), while that of initial and final setting time (50 minutes and 510 minutes respectively) also comply to the standard of BS 882 (1978).

4.4. Compressive Strength Tests Results

Figures 3, 4 and 5 show the bar chart presentations of the average compressive strength values for all the mix ratios adopted in the research.

Figure-3. Compressive strength of concrete cubes from different crushed stone source-(Well graded aggregate) – 1: $1^1/_2$: 3

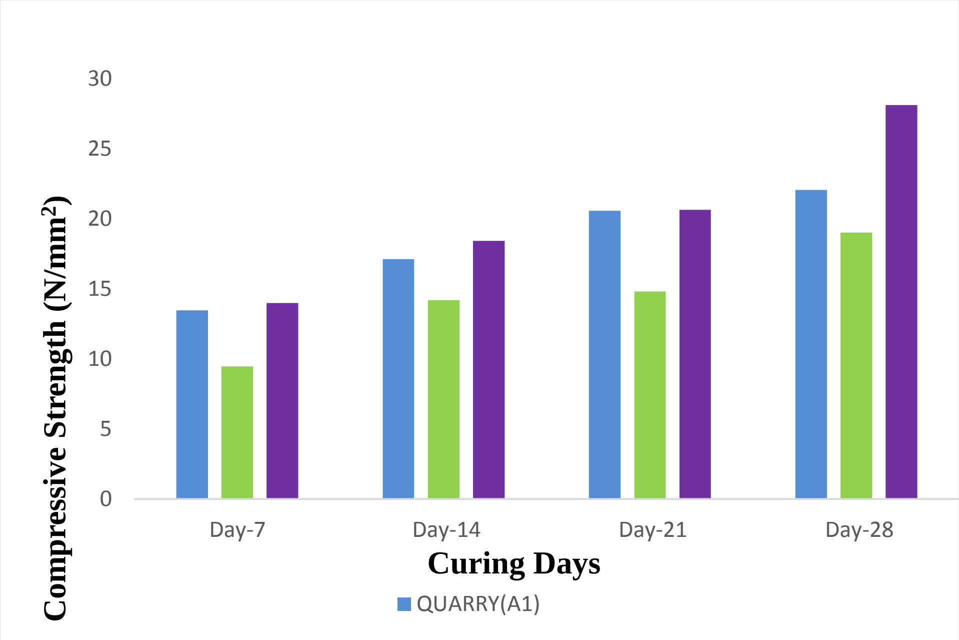


Figure-4. Compressive strength of concrete cubes from different crushed stone source- (all-in aggregate) – 1: $1^1/_2$: 3

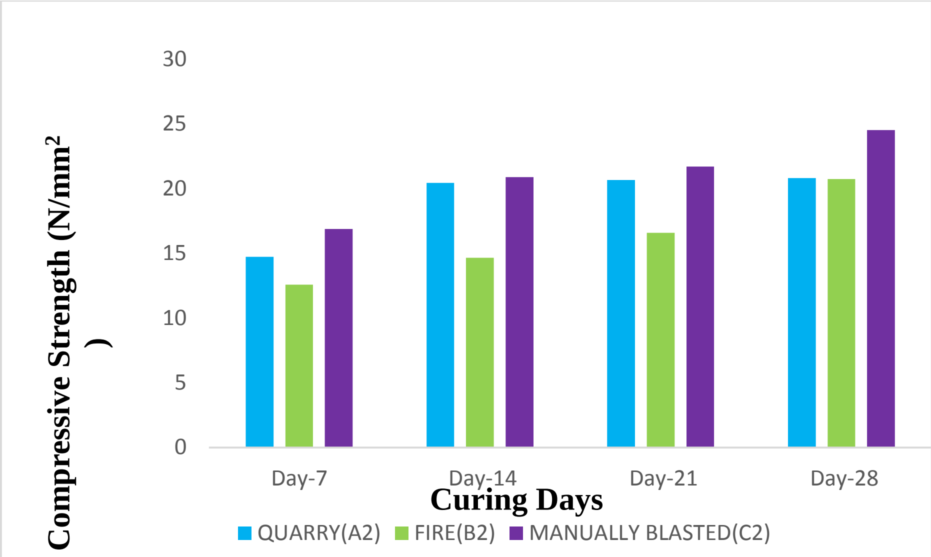


Figure-5. Compressive strength of concrete cubes from different crushed stone source-(well graded aggregate) – 1: 2: 4

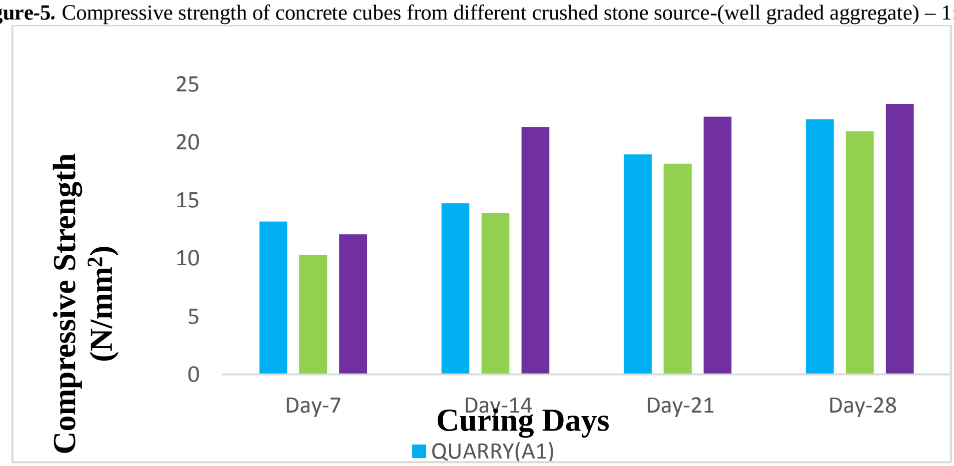


Figure-6. Compressive strength of concrete cubes from different crushed stone source- (all-in aggregate) – 1: 2: 4

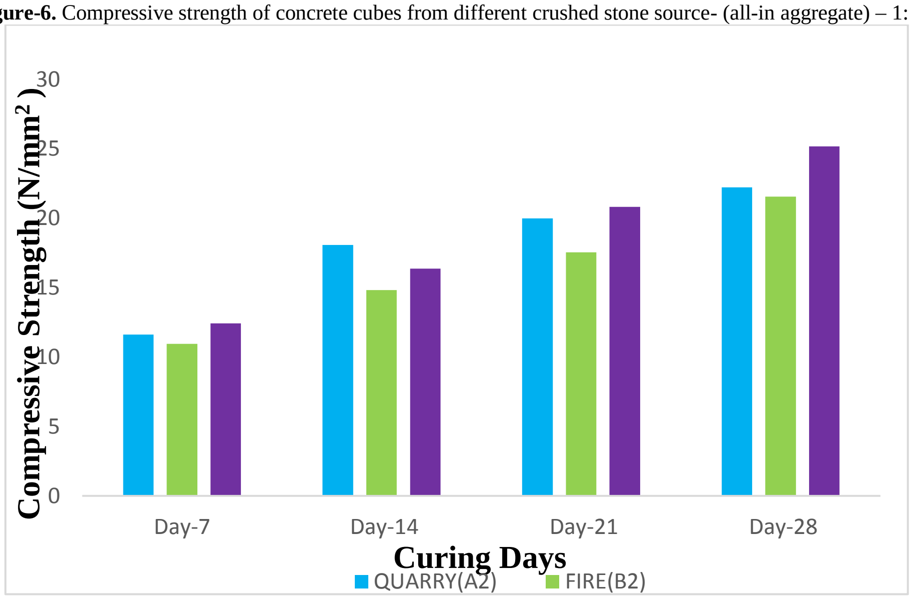


Figure-7. Compressive strength of concrete cubes from different crushed stone source-(well graded aggregate) – 1: 3: 6

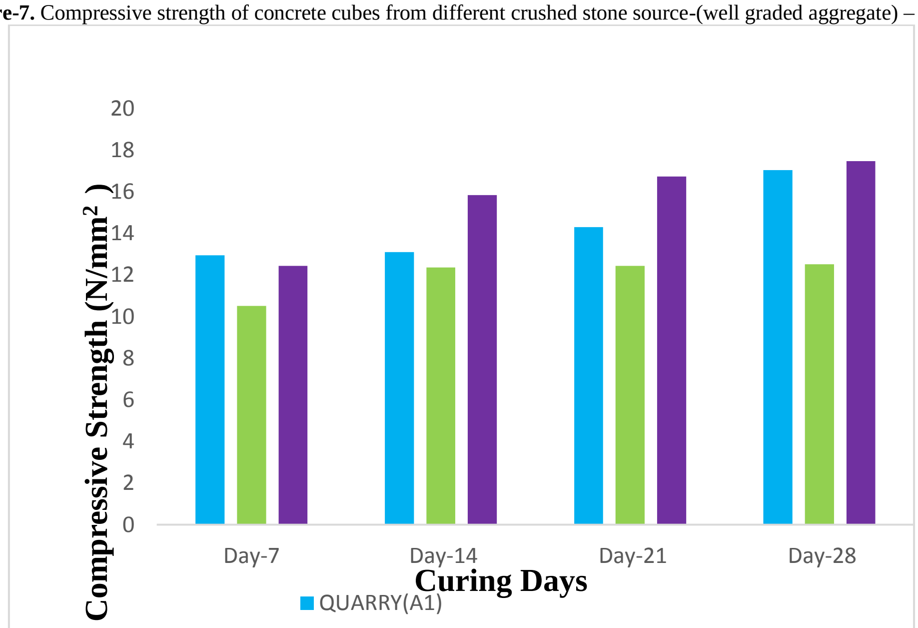
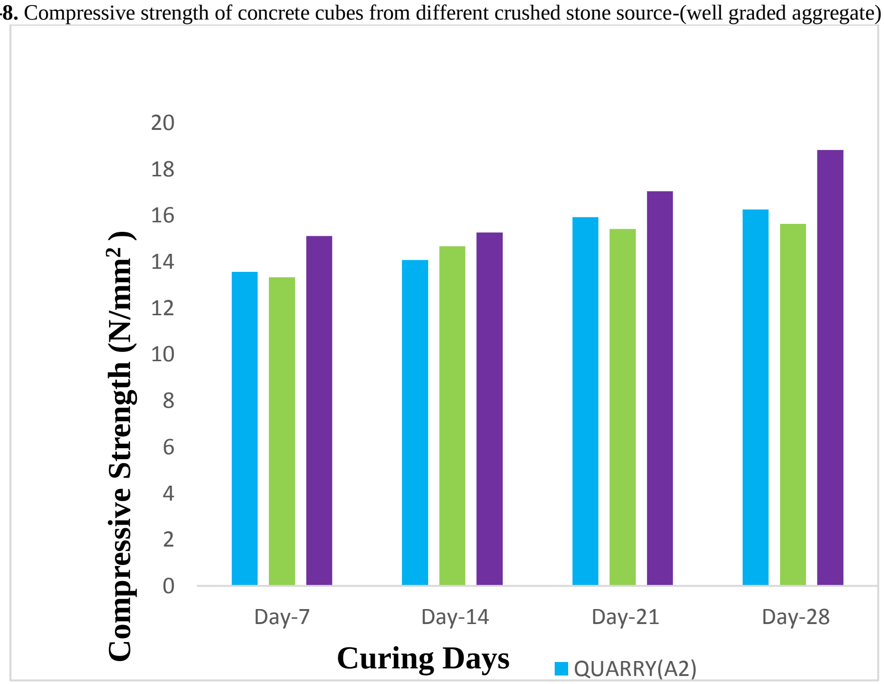


Figure-8. Compressive strength of concrete cubes from different crushed stone source-(well graded aggregate) – 1: 3: 6



Based on the results, it could be deduced that the average compressive strength from where the source of aggregate was fire has the least value for all the mix ratios as well as for both all-in aggregates and well-graded aggregates. The values for manually blasted source aggregates has the highest value for all the mix ratios and for both well-graded aggregates and all-in aggregates.

4.5. Statistical Analysis

The statistical analysis of the compressive strength for all the concrete made with their different mix ratios are shown in Table 3 to 7 and Figures 9 to 11 showed the mean plot for each of the mixes. The ANOVA (Analysis of variance test) result for mix $1{:}1^1/_2$; 3 in Table 3 show that the different in the compressive strength between groups is greater than that within group. This is an indication that the result is not by chance. The LSD (lease significant difference) test for this mix in Table 4 shows that there is significant difference between the quarry produced granite well graded and the manually produced granite. There was no significant difference obtained between the quarry produced granite and the other source of production in all in aggregates. This results indicate that production method affects aggregates performance base on the type of aggregate grading. For 1:2:4 mix ratio there was no significant difference for either the granite grading or the method of production. There was a significant difference between the quarry produced granite and fire blasted granite in well graded aggregates for mix 1:3:6. This is also an indication that different aggregates perform differently at different mix ratios.

Table-3. ANOVA Descriptive Table for compressive strength of concrete in ratio $1{:}1^1/_2$; 3 mixes at 28 day curing using the different aggregates prepared

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	169.396	5	33.879	3.771	.028
Within Groups	107.820	12	8.985		
Total	277.216	17			

Table-4. LSD test for compressive strength of concrete in ratio $1{:}1^1/_2$; 3 mixes at 28 day curing using the different aggregates prepared , 1-A1WG, 2-B1WG, 3-C1WG, 4-A2AG), 5-B2AG, 6-C2AG

i (factor)	J(factor)	MD (i-j)	P(Sig.)	Remark
1.00	2.00	1.8267	.470	NS
	3.00	-7.2833	.012	*
	4.00	.05667	.982	NS
	5.00	.13000	.959	NS
	6.00	-3.6500	.162	NS
2.00	3.00	-9.1100	.003	*
	4.00	-1.7700	.483	NS
	5.00	-1.6967	.501	NS
	6.00	-5.4767	.045	*
3.00	4.00	7.3400	.011	*
	5.00	7.4133	.010	*
	6.00	3.6333	.163	NS
4.00	5.00	0.0733	.977	NS
	6.00	-3.7067	.156	NS
5.00	6.00	-3.7800	.148	NS

* Mean Difference (MD) is significant at $p < 0.05$, NS= Not Significant, A1WG-machined crushed quarry granite well graded, B1WG-Fire blasted granite well graded, C1WG-manually produced granite well graded, A2AG-machined crushed quarry granite all in all graded, B2AG-fire blasted granite all in all graded, C2AG- manually produced granite all in all graded.

Figure-9. Mean plot for compressive strength of concrete in ratio $1{:}1^1/_2$; 3 mixes at 28 day curing using the different aggregates prepared

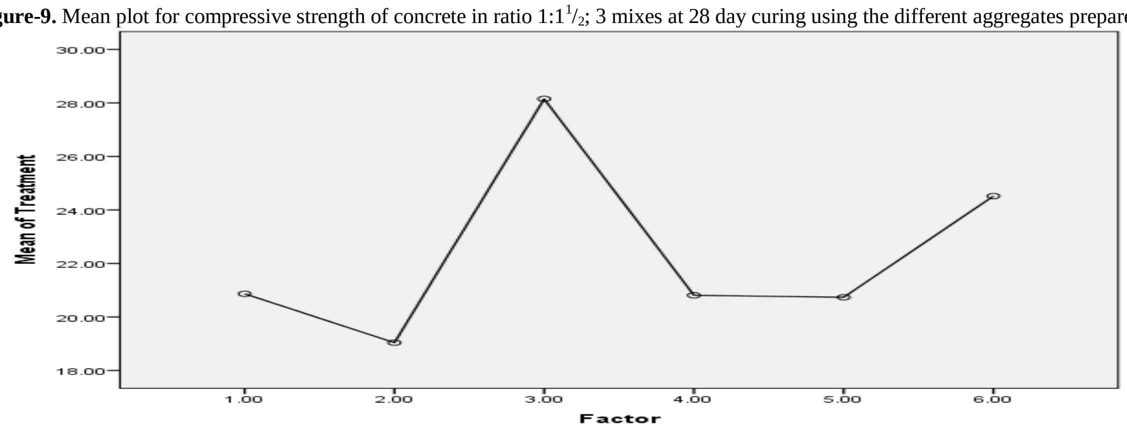


Table-5. ANOVA Descriptive Table for compressive strength of concrete in ratio 1:2: 4 mixes at 28 day curing using the different aggregates prepared

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	34.506	5	6.901	1.355	.307
Within Groups	61.134	12	5.094		
Total	95.639	17			

Table-6. LSD test for compressive strength of concrete in ratio 1:2:4 mixes at 28 day curing using the different aggregates prepared , 1-A1WG, 2-B1WG, 3-C1WG, 4-A2AG), 5-B2AG, 6-C2AG

i (factor)	J(factor)	MD (i-j)	P (Sig.)	Remark
1.00	2.00	1.04000	.583	NS
	3.00	-1.33000	.484	NS
	4.00	-.22000	.907	NS
	5.00	.43333	.818	NS
	6.00	-3.19333	.109	NS
2.00	3.00	-2.37000	.223	NS
	4.00	-1.26000	.507	NS
	5.00	-.60667	.748	NS
	6.00	-4.23333*	.040	*
3.00	4.00	1.11000	.558	NS
	5.00	1.76333	.358	NS
	6.00	-1.86333	.332	NS
4.00	5.00	.65333	.729	NS
	6.00	-2.97333	.133	NS
5.00	6.00	-3.62667	.073	NS

Figure-10. Mean plot for compressive strength of concrete in ratio 1:2: 4 mixes at 28 day curing using the different aggregates prepared

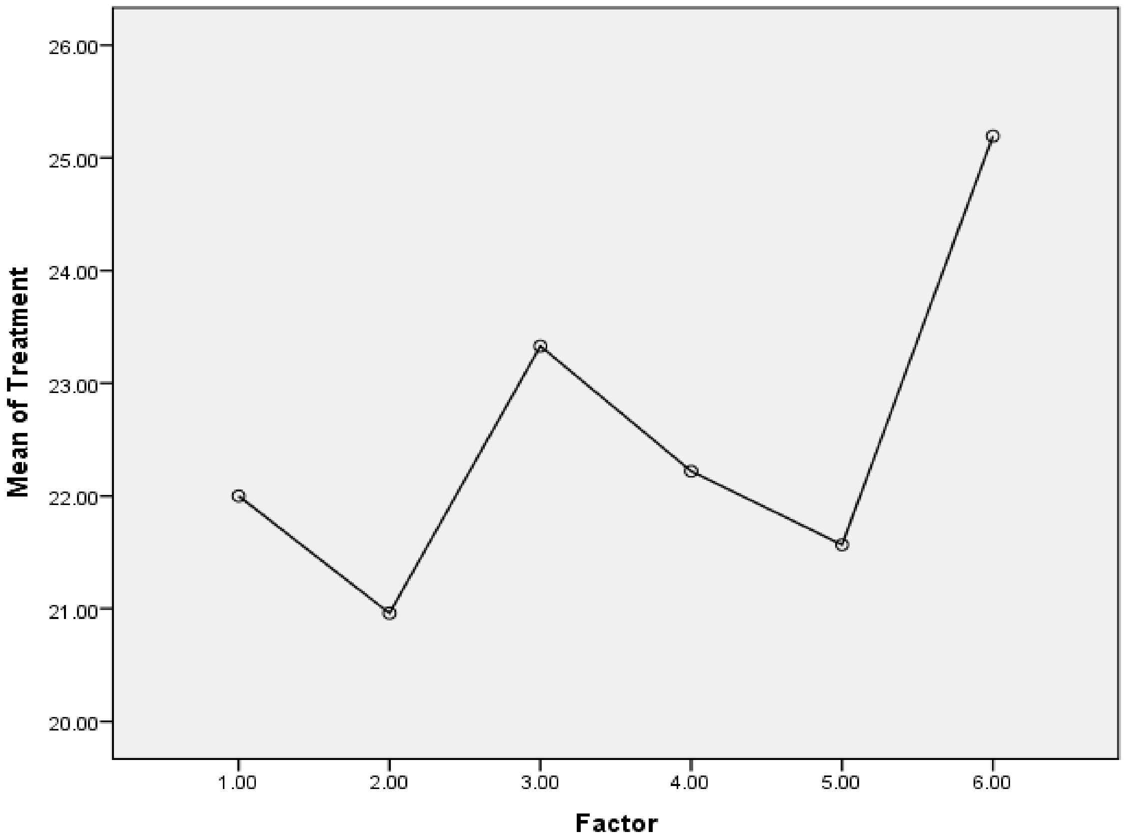


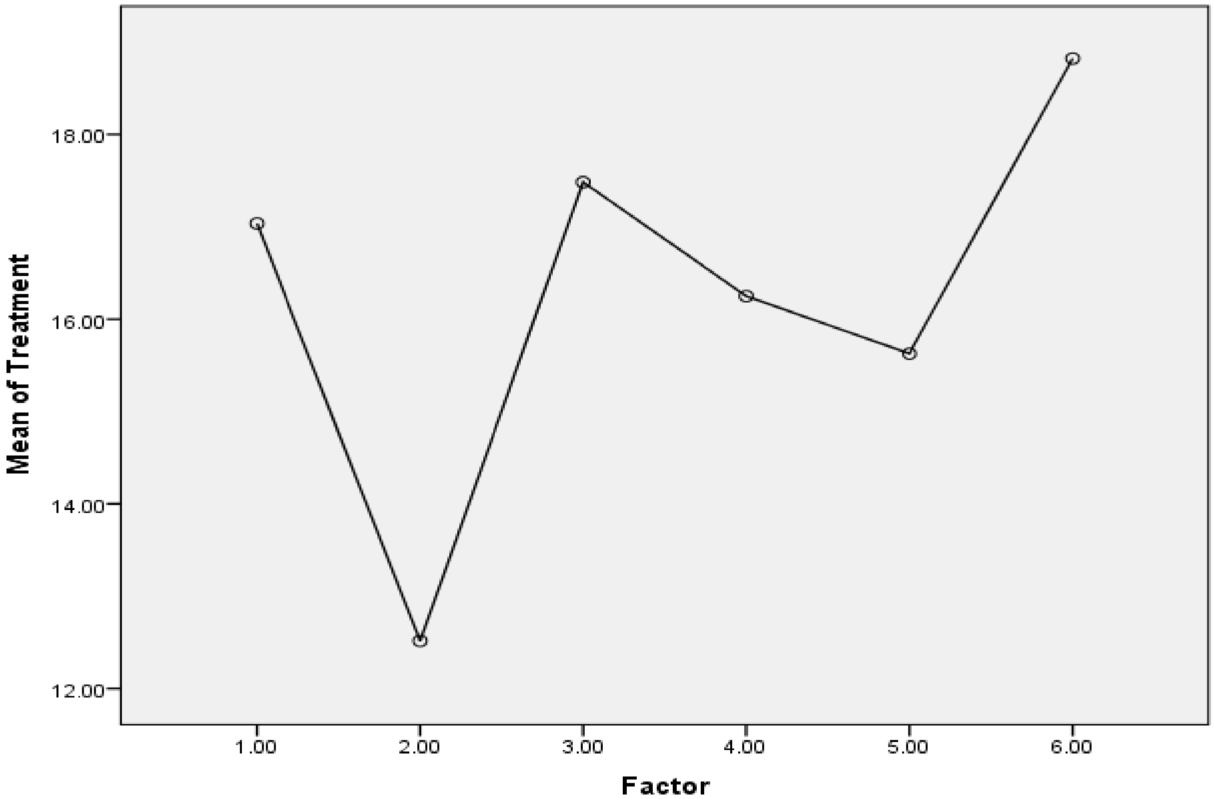
Table-7. ANOVA Descriptive Table for compressive strength of concrete in ratio 1:3: 6 mixes at 28 day curing using the different aggregates prepared

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	69.237	5	13.847	4.778	.012
Within Groups	34.775	12	2.898		
Total	104.012	17			

Table-8. LSD test for compressive strength of concrete in ratio 1:3:6 mixes at 28 day curing using the different aggregates prepared , 1-A1WG, 2-B1WG, 3-C1WG, 4-A2AG), 5-B2AG, 6-C2AG

i (factor)	J(factor)	MD (i-j)	P (Sig.)	Remark
1.00	2.00	4.5200	.007	*
	3.00	-.4467	.753	NS
	4.00	.7867	.582	NS
	5.00	1.4100	.330	NS
	6.00	-1.7867	.223	NS
2.00	3.00	-4.9667	.004	*
	4.00	-3.7333	.020	*
	5.00	-3.1100	.045	*
	6.00	-6.3066	.001	*
3.00	4.00	1.2333	.392	NS
	5.00	1.8567	.206	NS
	6.00	-1.3400	.354	NS
4.00	5.00	0.6233	.662	NS
	6.00	-2.5733	.089	NS
5.00	6.00	-3.1967	.040	*

Figure-11. Mean plot for compressive strength of concrete in ratio 1:3:6 mixes at 28 day curing using the different aggregates prepared



5. Conclusions and Recommendations

5.1. Conclusions

With this research, the following conclusions were drawn:

i. The Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) of manually blasted crushed stone source showed the highest strength, followed by the quarry crushed stone and the fire crushed stone source gave the least strength.

ii. Concrete cubes with manually blasted crushed stone showed the greatest compressive strength both for the "well graded" and "all-in" aggregates at the end of 28 days for each mix ratios, followed by the quarry crushed stone and fire with the least compressive strength.

iii. From the results of ACV and AIV, it can be concluded that heat application on the rock adversely affected the strength of the crushed stone judging from the values obtained from the ACV and AIV.

iv. The research work reveals that the compressive strength is proportional or dependent on the mix ratios. The mix ratio 1: $1^1/_2$: 3 gave the highest compressive strength for all the sources of crushed stone compared to other mix ratios used.

v. Based on the statistical analysis of data carried out using ANOVA as a tool, it can be concluded that for mix ratio 1: $1^1/_2$: 3 (Well-Graded aggregates) and 1: 3: 6 (All-In aggregates), the difference in the compressive strength of concrete cubes is due to the strength variation (ACV and AIV) of each source of crushed stone, at 5% level of significance, while for mix ratio 1: 2: 4 (Well-Graded and All-In aggregates), the difference in the compressive strength of concrete cubes by chance, at 5% level of significance.

vi. Generally the performance of aggregates in concrete production depends on the type and grade of aggregates which also depends on the mix ratio of the concrete components.

5.2. Recommendations

Based on the findings,

i. Aggregates made through fire should be discouraged in concrete with mix ratio 1:3:6 but welcome in the other mix ratio based on the result obtained.

ii. The use of manually blasted aggregates should be encouraged locally because it is relatively cheaper than the one from quarry and also give relative strength and durability properties of both fresh and hardened concrete.

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