MECHANICAL STRENGTH DETERMINATION OF CRUSHED STONE AGGREGATE FRACTION FOR ROAD PAVEMENT CONSTRUCTION (CASE STUDY: SELECTED QUARRIES IN WESTERN NIGERIA)

Ariyo Adanikin
Elizade University

MECHANICAL STRENGTH DETERMINATION OF CRUSHED STONE AGGREGATE FRACTION FOR ROAD PAVEMENT CONSTRUCTION (CASE STUDY: SELECTED QUARRIES IN WESTERN NIGERIA)

Olutaiwo A. O[1]., Ashamo A. A.[2]and Adanikin, A.[3]

1,2 -Department of Civil and Environmental Engineering, University of Lagos, Akoka, Nigeria.
3- Department of Civil & Environmental Engineering, Elizade University, Ilara-Mokin, Nigeria.

Corresponding email: adewaleolutaiwo@gmail.com

Abstract

In this research work, the mechanical strength of crushed stone aggregate fractions for road pavement construction in Western Nigeria was assessed. Samples of crushed stone aggregates were collected from nine (9) representative quarries spread across the states in Western Nigeria.The physical and mechanical properties of the aggregates were evaluated. The results were then compared with the specifications in international standards (BS and ASTM Standards). All the aggregate samples met the required limit for Loose Density, Water Absorption, Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) tests. Aggregates samples from Samchase, Kopek, CCECC and SaliwaYetidipe quarries have flakiness indices exceeding the permissible limit (29.5%, 25.7%, 27.9% and 34.5% respectively). Hi-Tech and Western quarries samples have elongation indices of 44.5% and 40.3% respectively which are higher than the permissible limit. The two samples that failed Aggregate Abrasion Value test (AAV) are Hi-Tech and Western quarries, having 30.8% and 30.4% respectively. These two aggregates samples have AAV less than 35% which means they are still good for pavement construction only if the appropriate guidelines are followed (since any aggregate with AAV more than 35% is deemed weak for pavement construction). The study concluded that aggregates from Julius Berger quarry have the highest mechanical strength.

Keywords: Aggregates;Aggregate Crushing Value (ACV); Road Pavement;MechanicalStrength

1. INTRODUCTION

One of the major road construction materials is crushed stone aggregate. Aggregate is a broad category of coarse particulate materials used in construction, including sand, gravel, unscreened and screened crushed stone, slag, recycled concrete and geosynthetic aggregates (Wikipedia, 2014). Crushed stone or angular rock is a form of construction aggregate, typically produced by mining a suitable rock deposit and breaking the removed rock down to the desired sizes using crushers.It is distinct from gravel which is produced by natural processes of weathering and erosion, and typically has a more rounded shape. By volume, aggregate generally accounts for 92 to 96 percent of bituminous concrete and about 70 to 80 percent of Portland cement concrete (Mathew &Rao, 2007). Flexible road pavement is typically constructed from layers of compacted materials, and generally its strength decreases downwards. For conventional materials, a number of tests are conducted and their acceptability is decided based on the test results and the specifications. This ensures the desirable level of performance of the chosen material, in terms of its permeability, volume stability, strength, hardness, toughness, fatigue, durability, shape, viscosity, specific gravity, purity, safety, temperature, and susceptibility etc., whichever are applicable (Aravind&Animesh, 2005).

Use of low quality materials, especially aggregates in construction, has been identified as one of the causes of road failures in Nigeria (Ndefo, 2012). This invariably means that inappropriate selection of crushed stone aggregates for road pavement construction can cause premature pavement failure. Selecting the right aggregate material is imperative to overcome the frequent problem of pavement failure. In the various ways in which aggregate is used, it is exposed to a variety of stresses, and the response of the structure in which it is used will largely depend upon the properties of the aggregate. Its properties should therefore be tested and assured before the road is built.Shapes of the aggregate and surface texture are vital characteristics in the view of mechanical bonding effect and bond strength in concrete design (Masad, 2002). Crushed aggregates are angular but every crushed aggregate does not have the same angularity (Topal&Sengoz, 2008). Effective properties of aggregates improve when they are processed by cracking natural rocks (Quiroga& Fowler, 2004). The result showed that the higher the Rock Quality Designate (RQD) and Uniaxial Compressive Strength (UCS) values, the lower the Aggregate Crushing Value (ACV) which means that there are strong relationships between the values of RQD, UCS and ACV (Adeyemo&Olaleye, 2012)

The principal mechanical properties required in road stones are (i) satisfactory resistance to crushing under the roller during construction and (ii) adequate resistance to surface abrasion under traffic and (iii) high surface stresses to withstand tyre rims of heavily loaded vehicles(Verwaal& Mulder, 2000). All these have made the crushing strength of aggregates an essential requirement for road construction in Nigeria. Similarly, after the initial trafficking and removal of any surface bituminous coating, vehicle will be travelling on the actual aggregate used in the mixture for the bulk of the life of the road surface. Thus,aggregates undergo substantial wear and tear throughout their life (Ndukauba&Akaha, 2012). In general, aggregates should be hard and tough enough to resist crushing, degradation, and disintegration from any associated activities. Furthermore, they must be able to adequately transmit loads from the pavement surface to the underlying layers, and eventually the sub-grade, otherwise premature structural failure could occur. Therefore, selecting aggregates with the necessary characteristics for a particular site is imperative.

This research work aims to determine the mechanical strength of crushed stone aggregate fraction for road pavement construction with case study of crushed stone samples from some selected quarry sites in western part of Nigeria.

1.1 Location of The Study Areas

The quarries for the production of crushed stone aggregates in the western states of Nigeria are mostly located near the parent rock material. Out of all the states in the western part of Nigeria (Ondo, Ogun, Osun, Oyo, Ekiti and Lagos) only Lagos state has no rock outcrop sufficient for commercial quarry operation and therefore depend solely on the importation of various sizes of rock fragment / aggregates from neighboring states. Quarries that are operational in each state were identified and presented. Figure 1.1 shows the map of Nigeria and the location of the sample quarries.

Figure 1.1: The Map of Nigeria Showing the Location Sample Quarries

1.2 Brief Geology of The Study Area

The three major rock types - igneous, metamorphic and sedimentary - abound in Nigeria. Igneous and metamorphic rocks constitute the Pre-cambrian basement complex which is the oldest, crystalline, solid physical foundation of the country. Sedimentary rocks fill up the basins which are vast depressions between basement landmass. The Basement Complex and the sedimentary basins are equally dispersed in Nigeria, with basement most extensive in Northern Nigeria; less so in the south-western part of the country; and least along the eastern margin (GSDA, 2006. Bitumen or tar occurs in Cretaceous sediments extending from Ogun to Ondo State. The Geological map of Nigeria is as shown in Figure 1.2.

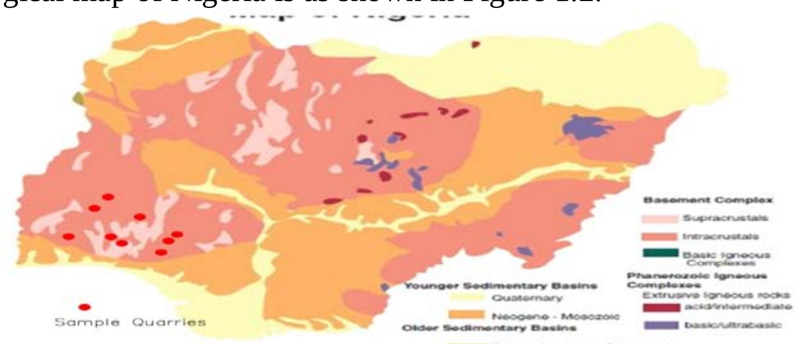


Figure 1.2: Geological Map of Nigeria(GSDA, 2006)

2. METHODS

For the purpose of this research work, samples of crushed stones from nine (9) selected quarries within the Western part of Nigeria were investigated. The nine (9) selected quarries among many others presents a good representation of the type of rock that is obtainable in the area. The selections were made based on the extent of patronage and rate of production of aggregates from the quarries as compared to others within the same state and sampled opinion. The details of the selected quarry are listed in Table 1.0.

The sampling of aggregates for tests were done at the selected quarries following the appropriate sampling procedure in the BS, as described. The samples were investigated in a specialized laboratory to determine the physical and mechanical properties of the aggregates. The knowledge of the physical properties was used in addition to evaluate the result of the mechanical properties of the aggregates.

Table 1.0: Selected Quarries for Test Samples

L/ Id	State	Name of Company	Description of Location
1	Ondo State	Hi-Tech Quarry	Ore, Ondo state
2	Ondo State	Samchase Quarry	Ore, Ondo State
3	Ondo State	Stone Works Quarry	Owo Road, Akure, Ondo State
4	Oyo State	KOPEK Quarry	Olonde, Oyo State
5	Oyo State	RATCON Nigeria limited	Lagos - Ibadan expressway, Ibadan, Oyo state.
6	Ogun State	Western Quarry Limited	Odeda, Ogun State
7	Ogun State	CCECC quarry	Ago-Iwoye in Ogun state, Nigeria
8	Ogun State	Julius Berger Quarry	Ogere, Ogun State
9	Osun State	SaliwaYetidipe Quarry	Oshogbo, Osun State.

Figure 2.1: Aggregate Samples from the Nine Selected Quarries

The following tests were conducted on all the samples: (i) Aggregates Loose Density Test (BS 812: 102), (ii) Water Absorption Test (BS 812-102: 1989), (iii) Flakiness Index Test (clause 5 of BS 812-102: 1989); (iv) Elongation Index Test (clause 5 of BS 812-102: 1989); (v) Aggregate Crushing Value (ACV) Test (clause 5 of BS 812-102: 1989); (vi) Aggregate Impact Value (AIV) Test (clause 5 of BS 812-102: 1989) and (vii) Aggregate Abrasion Value (AAV) - Los Angeles Test (clause 5 of BS 812-102: 1989).

3. RESULTS AND DISCUSSION

The results of all the laboratory tests carried out on each of the nine quarries aggregates samples (Q1 to Q9) are tabulated in Table 3.2 while the corresponding graph and charts are represented in Figures 3.1 to 3.7 and Figure 3.1a to 3.7a respectively.

3.1 Aggregate Loose Density Test

Samples with higher values of the aggregate loose density are likely to possess higher strength if the other requirements of properties that enhance strength are equally met. Any aggregate with loose density less than 0.75Kg/dm^3(750Kg/m^3) as specified by the BS 812 Part 2: 1995 is not good for road pavement construction.The summary of the tests (Figure 3.1) revealed that all the samples from different quarries tested passed the loose density test with Sample Q8 being the highest with 1.46Kg/dm^3(1460Kg/m^3) while Q2 has the lowest value of 1.37Kg/dm^3(1370Kg/m^3).and this is as shown in.

Figure 3.1: Graphical Representation ofSampled Aggregates Loose Density

3.2 Water Absorption Test

Strong aggregate will have a very low water absorption value that is below 1.0 %, according to BS 812 Part 109: 1990, andis good enough for road pavement construction. The amount of water an aggregate can absorb tends to be an excellent indicator of the strength/weakness of the aggregate. Therefore, the aggregate moisture content will affect the water content (and thus the water-cement ratio also) and the water content affects aggregate proportioning because it contributes to aggregate weight. Samples with higher values of the aggregate water absorption values are likely to possess a weaker/lower strength compared to other samples with lower water absorption values.

The test results, as shown in Figure 3.2, reveal that sample Q8 has the lowest water absorption while sample Q6 has the highest. All the samples passed the test very well.

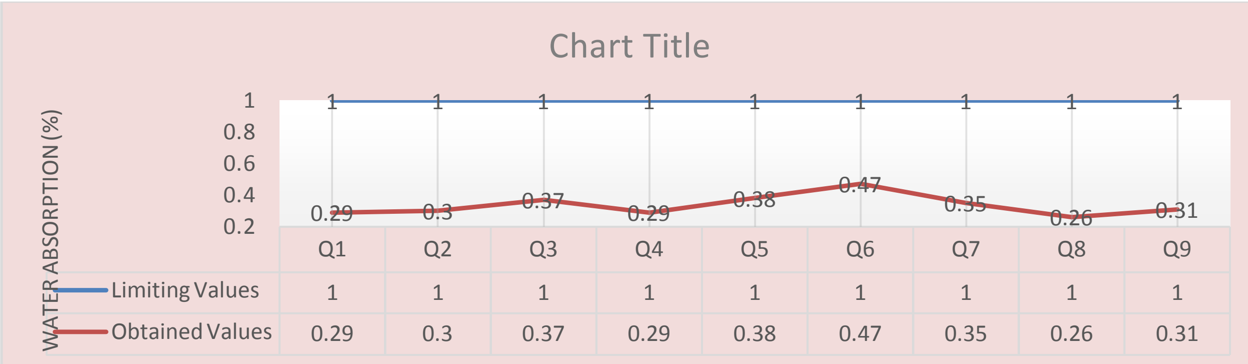


Figure 3.2: Graphical Representation of the Sampled Aggregates Water Absorption

3.3 Flakiness Index Test

Aggregates are classified as flaky when they have a thickness of less than 60% of their mean sieve size. The particle shape determines how aggregates are packed into a dense configuration. Generally, high values of flakiness and elongation index indicate that the aggregate sample is poorly shaped and consists of a high proportion of flaky, elongated and irregular shaped particles. Lower flakiness index indicates better shaped particle. The flakiness index must be less than 25% (BS 812Section 105.1 – 1989). Specimens with a high flaky index are likely to have lower strength and can easily undergo wear and tear with traffic and environmental effects. Changes in flaky value are related to the crusher type, an improvement of aggregate property and as a result, improve the asphalt wearing properties. Unexpectedly, the geometrically cubical aggregates in this study exhibited low values of flakiness index.

From the test results, as shown in Figure 3.3,samples Q1, Q3, Q5, Q6 and Q8 are likely to pass other strength tests because of the low flakiness index obtained. Q3 and Q8 are most likely to exhibit higher strength than other samples because of their very low flakiness index obtained. Samples Q2, Q4, Q7 and Q9 have flakiness indices above 25% and this is likely to affect their strength eventually.

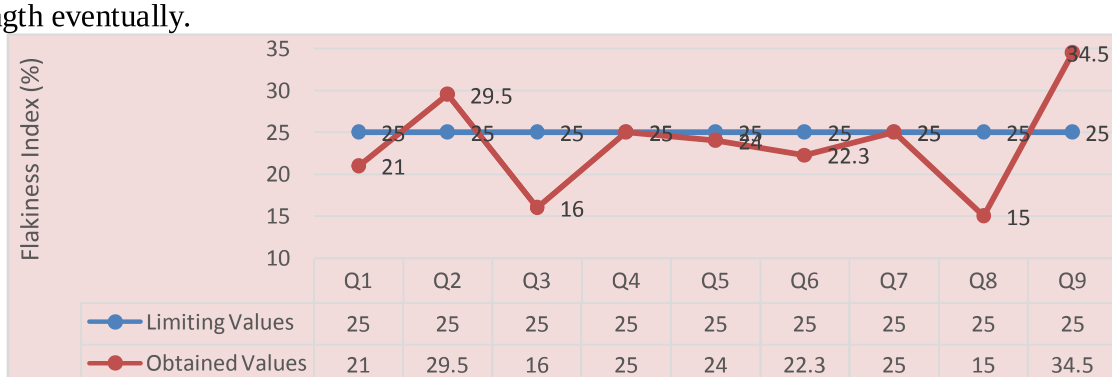
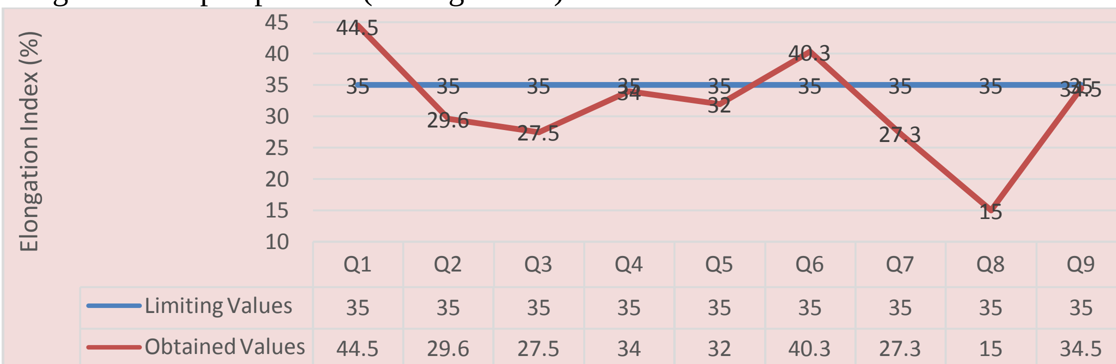


Figure 3.3: Graphical Representation of the Sampled Aggregates Flakiness Index

3.4 Elongation Index Test

Aggregate particles are classified as elongated when they have a length (greatest dimension) of more than 1.8 of the mean sieve size. The particle shape determines how aggregates are packed into a dense configuration. Generally, high values of elongation index indicate that the aggregate sample is poorly shaped and consists of a high proportion of elongated and irregular shaped particles. Lower elongation index indicate better shaped particle. Unexpectedly, the

geometrically cubical aggregates in this study exhibit low values of elongation index. BS 812Section 105.2 – 1990 specified that a maximum 35% elongation is desirable while elongation index above this will affect the strength of the aggregate.
Samples Q1 and Q6 have elongation indices above 35% and this is likely to affect their strength eventually. Other samples passed the test, with Q8 having the best value of elongation at 15%, indicating better shaped particles(see Figure 3.4).



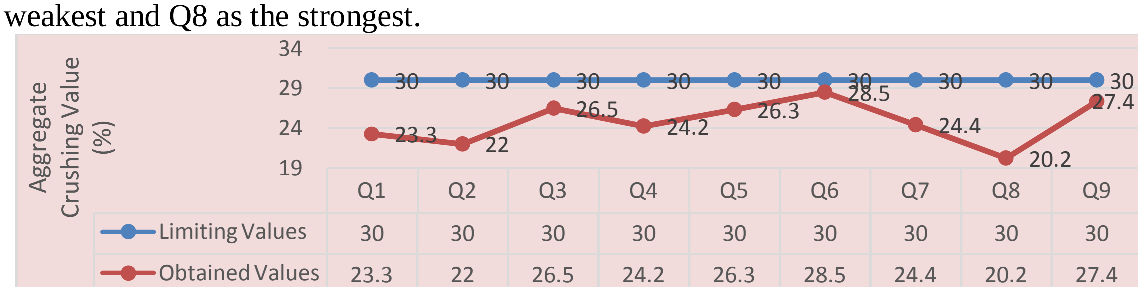
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Limiting Values	35	35	35	35	35	35	35	35	35
Obtained Values	44.5	29.6	27.5	34	32	40.3	27.3	15	34.5

Figure 3.4: Graphical Representation ofthe Sampled Aggregates Elongation Index

3.5 Aggregate Crushing Value (ACV) Test

After compression, the fine materials (materials passing through sieve # 8 or 2.36mm) produced, expressed as a percentage of the original mass is the aggregate crushing value (ACV). The lower the value (finer particles), the stronger the aggregate, that is, the greater its ability to resist crushing. Crushing value of 30 percent and above is not good for road construction. Aggregate used in road construction, should be strong enough to resist crushing under traffic wheels loads. If the aggregate are weak, the stability of pavement structure is likely to be adversely effected. The aggregate crushing value provides a relative measure of resistance to crushing under a gradually applied compressive load. In order to achieve a high quality pavement, aggregate possessing low aggregate crushing value should be preferred. BS 812 - 110: 1990suggested standard Aggregate Crushing Value of less than 30% for granites in road construction.

From the test results as shown in Figure 3.5, the study reveals that the aggregate crushing values of sampled materials from locations Q1 to Q9 have their values within the permissible. Therefore, materials from all the locations are suitable for road construction with location Q6 as the weakest and Q8 as the strongest.



	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Limiting Values	30	30	30	30	30	30	30	30	30
Obtained Values	23.3	22	26.5	24.2	26.3	28.5	24.4	20.2	27.4

Figure 3.5: Graphical Representation ofthe Sampled Aggregates Crushing Value (ACV)

3.6 Aggregate Impact Value Determination (AIV) Test

Resistance of an aggregate to sudden shock impact is crucial in road construction. The percentage mass of fines (materials passing through sieve 2.80mm BS sieve) formed in the test is known as the Aggregate Impact Value (AIV). Aggregate Impact Value (AIV) below 10 percent is regarded as very strong and AIV above 35 percent would normally be regarded as too weak for use in road surface. Toughness is the property of a material to resist impact. Due to traffic loads, the roads aggregates are subjected to the pounding action or impact and there is possibility of stones breaking into smaller pieces. The road stones should therefore be tough enough to resist fracture under impact.

The Aggregate Impact Values obtained for all the samples Q1 to Q9 (Figure 3.6) passed the test with values less than the maximum 30% standard permissible and are therefore suitable for road construction and other engineering works. Acceptable values for AIV for base course and sub base course are less than 30% according to ASTM: C33 (ASTM 1994) and BS 812 - 112: 1990.

Figure 3.6: Graphical Representation of the Sampled Aggregates Impact Value (AIV)

3.7 Aggregate Abrasion Value (AAV) Test

This gives a measure of the resistance of the aggregate to surface wear by abrasion. Rock materials with Aggregate Abrasion Values below 30 percent are regarded as strong, while those above 35 percent would normally be regarded as too weak for use in road surface.From the test results, two samples Q1 and Q6, narrowly failed the test, having 30.8% and 30.4% respectively (Figure 3.7). It is advisable that when these aggregates with AAV between 30 - 35% are used in road construction, more bitumen should be used and the quantity of such additional bitumen determined from mix design exercise to prevent bleeding of the asphaltic concrete.

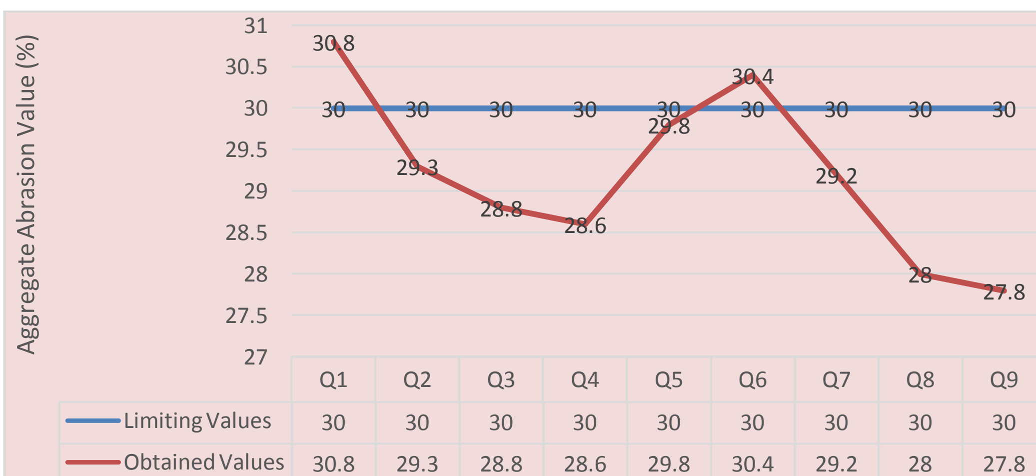


Figure 3.7: Graphical Representation of the Sampled Aggregates Abrasion Value (AAV)

Table 3.2: Summary of all the Test Results

Sample ID	Source of Aggregates (Quarry)	Loose Density of Aggregates (Kg/dm^3)	Water Absorp -tion (%)	Flakines s Index (%)	Elongation Index (%)	ACV Test (%)	AIV Test (%)	AAV Test (%)
Q1	Hi-Tech	1.42	0.29	21	44.5	23.3	10.64	30.8

	Quarry, Ore							
Q2	Samchase Quarry, Ore	1.37	0.30	29.5	29.6	22	12.02	29.3
Q3	Stone Works Quarry, Akure	1.38	0.37	16	27.5	26.5	15.93	28.8
Q4	KOPEK Quarry, Olonde, Ibadan	1.43	0.29	25.7	34	24.2	9.68	28.6
Q5	RATCON Nigeria Limited, Ibadan	1.41	0.38	24	32	26.3	9.10	29.8
Q6	Western Quarry Limited, Abeokuta	1.42	0.47	22.3	40.3	28.5	16.46	30.4
Q7	CCECC quarry, Ago-Iwoye	1.40	0.35	27.9	27.3	24.4	7.53	29.2
Q8	Julius Berger Quarry, Ogbere	1.46	0.26	15	15	20.2	7.12	28.0
Q9	SaliwaYetidipe Quarry, Oshogbo	1.42	0.31	34.5	34.5	23.3	8.47	27.8
	Permissible limit (Standard Specification)	Min is 0.75kg/dm^3 Max is 1.867kg/dm^3	≤1.0% BS 812-109: 1990	≤25% BS 812-105.1: 1989	≤35% BS 812-105.2: 1990	≤30% BS 812-110: 1990.	≤35% BS 812-112: 1990	≤30% BS 812-113: 1990

4. CONCLUSION

The results of the investigation showthatthe values of all the parameters determined on Q1 to Q9 locations of crushed rock aggregates in the south-west Nigeria falls within the specified ranges of the globally accepted BS, AASHTO and ASTM standards of aggregate stone production for road pavement construction. The values of the crushing test, impact test and abrasion test depict good quality and high durability of the aggregates from the nine locations. All the samples passed the ACV and AIV tests but samples Q1 (Hi-Tech Quarry) and Q6 (Western Quarry) have little deviation from the permissible limit of the AAV test (30.8% and 30.4% respectively). For any AAV more than 35%, the aggregate is termed to be weak. Taking a critical look at the results of flakiness and elongation indices, it was deduced that aggregates Samples from Q2 (Samchase), Q4 (Kopeks), Q7 (CCECC) and Q9 (SaliwaYetidipe) quarries have flakiness indices exceeding the permissible limit (29.5%, 25.7%, 27.9% and 34.5% respectively) but passed the elongation test. Similarly, Q1 (Hi-Tech Quarry) and Q6 (Western Quarry) have elongation indices higher than the permissible (failed) but passed flakiness test. It is therefore obvious that out of all the aggregates that failed either elongation or flakiness tests, only Q1 and Q6 failed one of the mechanical strength test (Abrasion tests) and from record. aggregates of this nature with AAV though more than 30% but less than 35% can be improved upon with the use of more bituminous material properly determined from the mix design. Also, an improvement in elongation and flakiness will improve the abrasion resistance property. Consequently, granite aggregates from the studied locations are suitable for road construction, water retaining structures, bridges and culverts, construction of ditching and building etc. Considering all the tests results from different tests conducted, aggregate sample Q8 (Julius Berger quarry) has the aggregate crushing value of 20.2%, aggregate Impact value of 7.12% and aggregate abrasion value of 28.0% making it the most suitable of all the samples tested with the highest strength whileaggregate sample Q6 is the least suitable for use in road construction. Results of this work will be useful in selecting the rock aggregates for optimum use in sustainable road pavement construction and also shows the need for relevant tests on crushed stone aggregates to confirm its suitability for pavement construction.

References

Adeyemo, A. T.,Olaleye, B. M., 2012. Establishing Relationships between Some Engineering Properties of Granitic Rock Types in Selected Quarries in South-West, Nigeria.*Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)*, Volume 3(6), pp. 934-937

Aravind, K.,Animesh, D., 2005. *Industrial Waste in Highway Construction*.Department of Civil Engineering, IIT Kanpur. 1-4. http://home.iitk.ac.in/~adas/article07.pdf

Ali U. O., Tugrul, E. R., Celal, K., 2012.Investigation of Crushing Type of Concrete Aggregates on Mechanical Properties of Concrete. *International Journal of Materials Engineering,*Volume2(2), pp. 6-9

British Standard Institute BS 812-110: 1990. "*Methods for determination of aggregate crushing value (ACV)*

British Standard Institute BS 812-112: 1990. *Methods for determination of aggregate impact value (AIV)*

British Standard Institute BS 812-113: 1990. *Method for determination of aggregate abrasion value (AAV)*

British Standard Institute BS 812: Part 2: 1995 page 9. *Methods of determination of density*

British Standard Institute BS 812-105.1: 1989. *Methods for determination of particle shape — Section 105.1 Flakiness index*

British Standard Institute BS 812-105.2: 1990. *Methods for Determination of Particle Shape — Section 105.2 Elongation Index of Coarse Aggregate*

British Standard Institute BS 812-109: 1990. *Methods for determination of moisture content*

GSDA, Geological Survey of Nigeria (2006), now Nigeria Geological Survey Agency.*Geological Map of Nigeria*

Masad, E., 2002. Aggregate Imaging System (AIMS).*The Transportation Research Board*, Superpave Mixture/Aggregate Expert Task Group, August 28-29, Minneapolis, MN.

Ndefo, O., 2012. *Causes of Highway Failures in Nigeria: from the Departmentof Civil Engineering*, the Federal Polytechnic Bida, Nigeria

Ndukauba, E., Akaha, T., 2012.Engineering-Geological Evaluation of Rock Materials from Bansara, Bamenda Massif Southeastern Nigeria, as Aggregates for Pavement Construction.*International Journals of Geosciences*, Volume 2(5), pp. 107 – 111

Quiroga, P.N., Fowler, D.W., 2004. *The Effect of the Aggregate Characteristics on the Performance of Portland Cement Concrete*, ICAR Research Report 104-1F

Mathew, T.V.,Rao, K.V., 2007. *Introduction to Transportation Engineering*.Chapter 22. Pavement Materials: Aggregates

Topal, A., Sengoz, B., 2008.Evaluation of Compacted Aggregate Resistance Test Compared with the Fine Aggregate Angularity Standards.*Construction and Building Materials*, Volume22, 993-998

Verwaal, W., Mulder, A., 2000.*Rock and aggregate tests procedures*, Geotechnical Laboratory DGM, Thimphu Bhutan, pp. 75

Wikipedia (2014). Construction Aggregate – Wikipedia, the free encyclopedia.pdf. http://en.wikipedia.org/w/index.php?title=Construction_aggregate&oldid=636773075

Wikipedia (2014).Crushed stone – Wikipedia, the free encyclopedia,pdf. http://en.wikipedia.org/w/index.php?title=Crushed_stone&oldid=615819768