EVALUATION OF NATURAL AND ARTIFICIAL AGGREGATES IN HOT MIX ASPHALT PRODUCTION

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Abstract

The world population continue to grow so the demand for more and reliable infrastructure therefore researches into new and innovative materials are continually advancing. This research title Evaluation of natural and artificial aggregates in production of hot mix asphalt with the intention to determine the durability of river gravels (aggregates) as compared to crushed stone (aggregates) in hot mix asphalt production and uses. Samples of the aforementioned materials were obtained and process according to BS 812 for asphalt production and process. Various laboratories test were conducted on the aggregates, the bitumen and the obtained asphalt using standard laboratory equipment in MSSR Julius Berger Nigeria Plc located in Abuja Nigeria. The aggregates were sieved and graded proportionately to obtain the required aggregate gradation in accordance to General Specification of Road and Bridges (1999) for British Standard. Hot Mix Asphalt was produced with each at 150℃, and the optimum bitumen content values for river gravel hot mix asphalt is at 6.0% and has a stability of 1,550(KN) while the hot mix asphalt produced with crushed stone also has it optimum bitumen content at 6.0% and a stability of 1,570 (KN) showing similarity in both bitumen absorption and stability.

Keywords: *Asphalt, Crushed stone, River gravel, Bitumen, Economy and Availability,*

Introduction

Roads are established path over land for the passage of animals and vehicles (Mathew and Rao, 2006). These pathways helped in providing links, movement of people and goods from one place to another. The first footpath originated from animal paths and served as path for early hunters to reach the forest. Paths eventually grew around primitive settlements and as trade grew, longer routes were developed to transport food and other materials. The roads built by the ancient Romans were carefully planned and structurally constructed (Mathew and Rao, 2006). The increasing demand in the provision of better road, decreasing budgetary funds, and the need to provide a safe, efficient and cost effective road system has led to increase in the need to rehabilitate our existing pavement system.

Pavements are made up of several layers of different materials which functions as a structural element configured to support the wheel loads applied to the road and distribute them to the subgrade. There are two major types of road pavements namely flexible and rigid pavement. The following pavements earth, stabilized soil and bituminous surfaces falls under the flexible pavements type (UNESCO-Nigeria Technical and Vocational project, 2008), but the rigid pavement roads are constructed to perform as a slab. It might be reinforced or mass concrete pavement with high modulus of elasticity and adequate rigidity.

While in the design of flexible pavement, the layers comprises of series of granite layer which is usually topped by a relatively high quality bituminous surface. This layers of granular materials helps to distribute and maintain load to the subgrade, the quality of these granite solely depends on the particle friction, interlocking property and strength. In the construction industry, series of granular materials can be used depending on its availability, cost and durability. River gravel is one out of such materials which is alternate materials used in road and asphalt production over the crushed stone due to its low cost effectiveness compared to crushed stone. The following are layers of flexible pavement which the river gravel can be used; the road sub-base, the road base and the wearing surface.

Asphalt is mostly used if heavy traffic is expected at the base layer. The Sub grade strength has the greatest effect in determining pavement thickness (UNESCO-Nigeria Technical and Vocational project, 2008). Generally, weaker sub grades require thicker asphalt layers to adequately bear different loads associated with different uses. The wearing surface receives the traffic and transfers its loads to the base, while at the same time serve as the base's protection material.

In achieving a comprehensive flexible pavement design procedure based on structural analysis, a complication in terms of difficulties in getting a performance model that relate the variety of pavement materials (river gravel) in relation to distress modes due to casual factors and in characterizing the component layers of the pavement structure to reflect stability.

Aggregates are of numerous types, depending on their source and properties, crushed gravel (granite) and river gravel, are the aggregates of major consideration in this study. Crushed aggregates whitish black aggregate obtained from rock blasting (which could be igneous, sedimentary or metamorphic rocks), texture and structural property places some rocks at a higher advantage over others in serving as aggregate materials; it is sourced naturally but becomes artificial after going through some changes in physical and mechanical properties. The relationship between specifications of crushed and river aggregates and its performance is often not well defined due to the fact that most specifications are based on experience with local materials. Density, durability and strength are parameter that plays important role in specification of these materials, because of the structural behaviour of the layers, being sub base and base layer application in pavement structure. Worldwide, fundamental measures such as shear parameters from axial testing are used to satisfy this granular material.

Tensile strength, durability, economy, texture and availability of these materials play an important role in their use, which include significant savings, resulting from the use of river gravel instead of crushed aggregates or beauty and readily availability of the crushed aggregates. Environmental issues around the use of non-renewable resources such as weathered gravels are becoming more important in developing economies and have been important for a long time in the developed world (RSDT, 2013). Even the very best calcretes and laterites perform almost as well as graded crushed stone and can be used for heavy traffic. However, River aggregates are always more variable than crushed aggregates (RSDT, 2013). On a general perspective more time and resources are observed to be saved in the application of river aggregates. Hence, this study tends to measure some characteristics stimulating factors influencing the strength of the two separate aggregates

Materials and Methodology

The materials used for this study were river aggregates, crushed aggregates, bitumen, and produced asphalts obtained from the Natural and artificial sources. Method standard stated BS 812 was used to sample the river aggregates from Kuta river in Niger State being a common alternative material for crushed aggregates. The artificial aggregate used was the crushed stone obtained from the blasting of rocks at Julius Berger Quarry site located at Mpape branch in Abuja, Nigeria using same Euro Code sampling method. On the other hand the bitumen used was collected from Kaduna refinery grade 60/70 and subjected to bitumen tests in accordance with Euro Code at the asphalt plant of Mssr Julius Berger Nig Plc located at Mpape branch in Abuja, Nigeria. After sampling of the materials, laboratory tests such as specific gravity, water absorption, aggregate crushing value, grading of aggregates and sieve analysis of the aggregates used for mix-design using Job- Mix Formula method were carried out.

The following were the methods adopted in achieving the desired aims and objectives of this study; Check on material adequacy, Mix design, Asphalt production and Marshall Stability test.

Physical Properties Adequacy of Materials

To ensure the effectiveness of the materials, tests were conducted in accordance to BS 812 on the sampled materials before and after mix. These tests include: Aggregate specific gravity test, Aggregate water absorption test, Aggregate crushing value, Sieve analysis and bitumen tests. Results for the above test are in Table 4 and Table 5 while grading envelope of the two aggregates was also displaced in Figure 1a and Figure 1b

Mix Design

Job mix formula was used to determine the required percentages for each graded aggregates sample as obtained in the sieve analysis which requires different percentages of aggregates and filler. The percentages and weights of the aggregates and filler used in the asphalt production are shown in Table 1. Also provided in Table 2 is the bitumen adding ranges as specified by General Specification Road and Bridges (1999) for wearing course in relation to sample weight.

Table 1: Percentage and weight of aggregates using job mix formula.

S/No	Aggregate sizes (mm)	Percentage of Natural Aggregates (%)	Percentage of Artificial aggregates (%)	Weight of Aggregates (g)	Aggregate weight for Total mix for Extraction, Specific gravity and Marshall Test (g)
1	9.5-19	15	18	180	1080
2	4.75-9.5	20	12	240	1440
3	0-5	50	63	600	3600
4	Filler	15	7	180	1080
Total				1200	

Table 2: Percentage and Weight of Bitumen using Job Mix Formula.

S/No	Percentage of bitumen (%)	Weight of Bitumen (g)	Weight of Bitumen for Total Mix for Extraction, Specific gravity and Marshall Test (g)
1	5.0	60	360
2	5.5	66	396
3	6.0	72	432
4	6.5	78	468
5	7.0	84	504

Asphalt Production

The samples were prepared using Marshall Design Procedures for asphalt concrete mixes according to General Specifications for Roads and Bridges (1999). The procedures involved the preparation of a series of test specimens for a range of asphalt (bitumen) contents such that test data curves showed well defined optimum values. The tests were conducted on the bases of 0.5 percent increments of bitumen content. In order to provide adequate data, three replicate test samples were prepared for each set of bitumen content used. During the preparation of the asphalt concrete samples, the aggregates were first heated for about 5 minutes to attain a temperature of 80^{o}C bitumen was added to the heated aggregates and allowing proper absorption into the aggregates and properly mix with mixer and attaining a temperature not less than 150^{o}C. Measured samples from the mix were taken for specific gravity and extraction after which the remaining 1200g was poured into mould and compacted on both faces with 75 blows using an automated 4.5kg-rammer falling freely from a height of 450mm. This process was repeated on till last sample was done. The Compacted specimen was subjected to Unit weight – Total Mix, Stability, Flow, Percent Voids – Total Mix and Percent of Total Voids filled with Binder. The results obtained are shown in Table 6 and used to determine the optimum bitumen content of the asphalt concrete.

Marshall Stability Test

This test was carried out to determine the durability of the produced Hot Mix Asphalts (HMA) of the granite and river aggregates. It’s a test that helps to determine the rate of deformation of asphalt to axle load. It can also be used to determine the optimum bitumen content that can provide stability, unit weight (Density), flow, voids and voids filled with Bitumen of the produced Hot Mix Asphalt. The standard requirement of asphaltic material is given in Table 3.

Table 3: Specified properties of compacted Asphalt Concrete according to the BS code:

S/No	Properties	Wearing Course
1	Optimum Bitumen Content	5-8%
2	Stability	≤3.5KN, ≤350Kp
3	Flow	20-40mm
4	Voids in Total Mix	3-5%
5	Voids Filled with Bitumen	72-82%

Results and Discussion

Physical Properties Adequacy

The test conducted on the aggregates material as shown in Table 4 indicates that the major requirement of hardness and durability of a granite aggregates was also met by the river aggregates with crushing values of 26.3 and 27.1 respectively. Also looking at the specific gravity of the two materials it was discovered that both materials are relatively of same weight in quantity and volume. The water absorption rate of the river aggregates though higher than the granite aggregates but still within the recommended range for asphaltic materials. The analyses conducted on granites aggregates was done on about four (4) samples and a blend of them all was needed for the requirement for asphalt production to be meet, resulting to waste of time and resources while only single sieves analysis was required in the case of river aggregates. The grading envelopes of the materials are presented in Figure 1a and Figure 1b.

Table 4: Specified Properties of Aggregate Test and Obtained Result from Kuta river gravel.

S/No	Properties	Specified Standard	Results obtained (River Agg)	Results obtained (Crushed Agg)
1	Specific Gravity	2.4 – 2.9	2.65	2.69
2	Water absorption	0.2 – 1.5	0.947	0.252
3	Aggregate Crushing Value	≤ 30	26.3	27.1

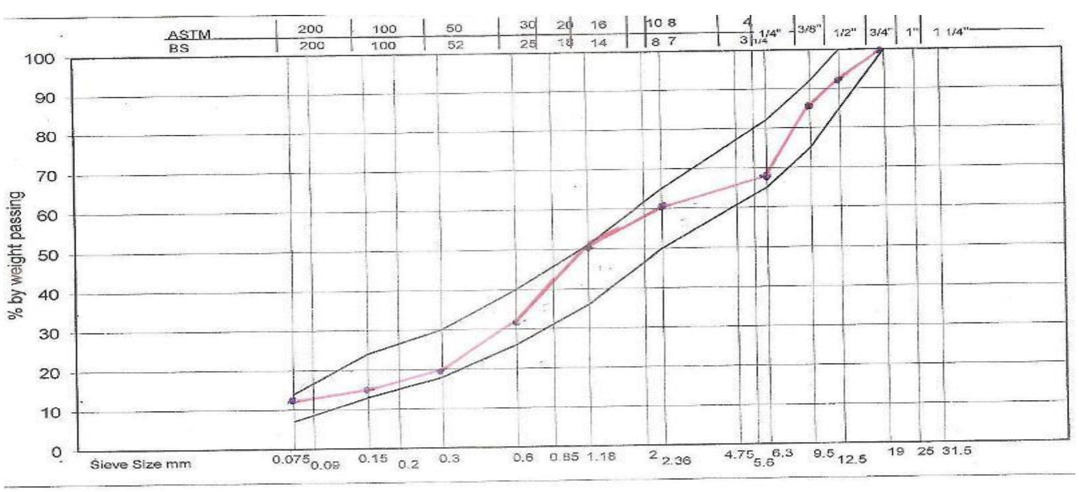

Figure 1a: Obtained from the Combined Gradation of Natural Aggregate.

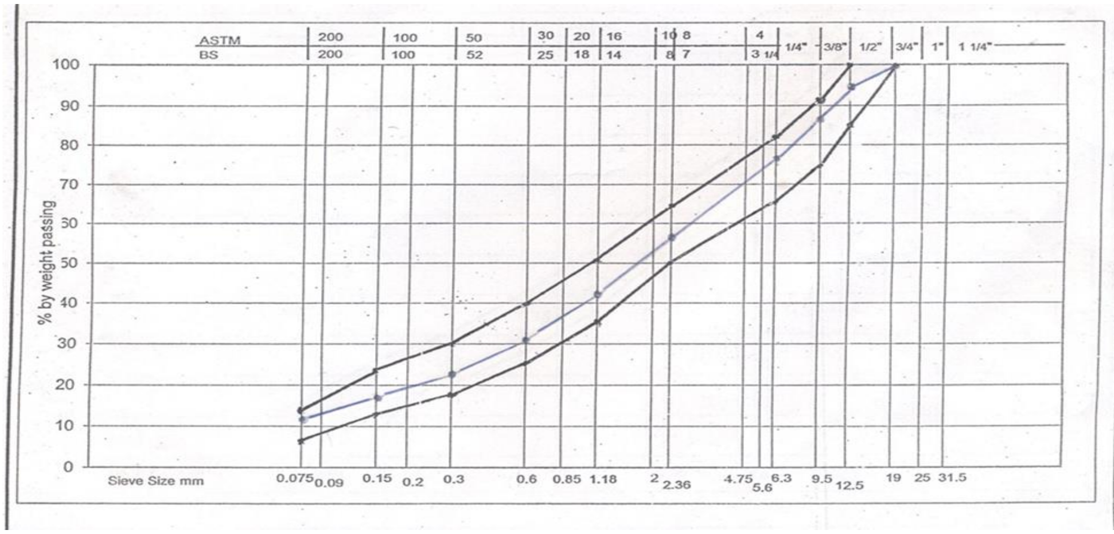

Figure 1b: Obtained From the Combined Gradation of Artificial Aggregate.

Bitumen Properties

The bitumen tests conducted was to check if the binder used was adequate and up to standard as specified for Roads. It was further confirm that the bitumen used was adequate and up to standard and that the bitumen is grade 60/70 penetration.

Table 5: Summary of Bitumen Test Results:

Penetration Test Result	
Trials	Penetration 1/10mm at 25°C
1	65
2	64
3	66
Average	65
Standard	60 – 70

Specific Gravity Test Result	
Trials	Softening Point R+B (°C)
1	305
2	295
3	300
Average	300
Standard	Not less than 230

Flash Point Test Result	
Trials	Specific Gravity (at 25°C)
1	1.037
2	1.044
3	1.042
Average	1.041
Standard	1.02 - 1.06

Trials	**Softening Point R+B (°C)**
1	48.8
2	48.2
3	48.5
Average	48.5
Standard	46 – 54

Marshal stability Results

These are results showing the graphical representation of the data obtained as in the marshal stability table. From the graphs the following parameters can be obtained; maximum unit weight (density), maximum stability, void in mix, void filled with bitumen, and optimum bitumen content.

Table 6: Marshall Test result

Percent Binder content	5.0	5.5	6.0	6.5	7.0
Unit weight – Total Mix	2.335	2.340	2.360	2.366	2.350
Stability	1350	1380	1550	1540	1500
Flow	26.0	34.0	36.0	40.0	46.0
Percent Voids – Total Mix	4.1	4.5	3.3	2.6	2.1
Percent of Total Voids filled with Binder	73.4	73.5	80.6	85.1	88.4

Table 6b: Marshall Test result Artificial Aggregate

Percent Binder content	5.0	5.5	6.0	6.5	7.0
Unit weight – Total Mix	2.351	2.353	2.355	2.355	2.350
Stability	1410	1610	1570	1460	1410
Flow	30.0	32.0	34.0	37.0	40.0
Percent Voids – Total Mix	4.9	4.5	3.2	3.2	2.7
Percent of Total Voids filled with Binder	69.9	73.7	81.1	82.3	85.6

Apparent density (Unit Weight)
This is the weight of the sample after a certain amount of bitumen and compaction has been given to that sample; it's shown how closely packed the aggregates are in a particular sample with the presence of the binder. Presented in Figure 2 and Figure 3 are the graphs showing the relation between the unit weight and percentage binder content of the samples. The graph shows an increase in weight with increase bitumen content until it reaches the optimum unit weight, then decreases and the maximum densities occurs at 2.360 and 2.355 respectively for river gravel and crushed stone. The figure further shows that at binder content of 6.0% for the river gravel has a weight of 2.360, but that of crushed stone has a weight of 2.355, showing that both materials are suitable.

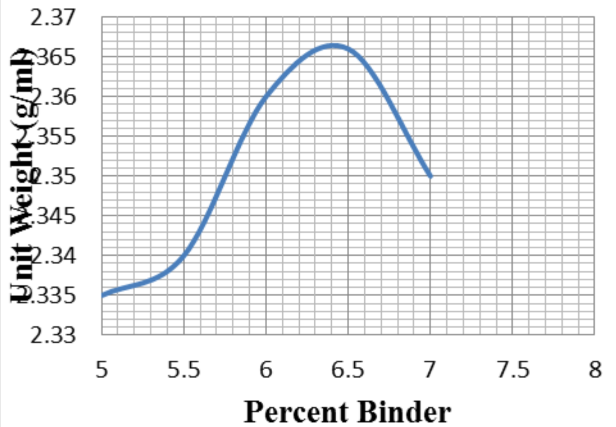

Fig 2:Unit Weight fo River Gravel

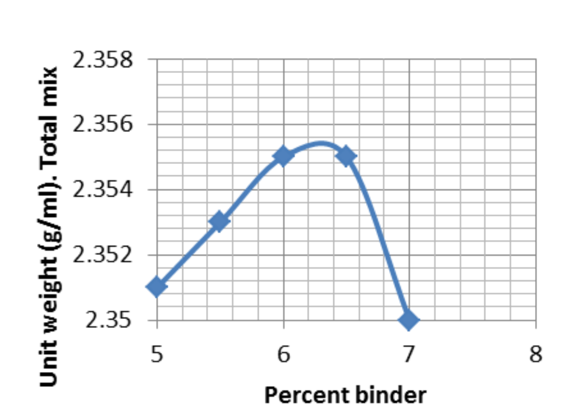

Fig 3:Unit weight of crushed Stone

Figure 2 and 3: Graphs of Unit Weight against Binder Content

Stability: this is a graph showing the relationship between the corrected stability and the bitumen content of the sample. This graphs shows an increase in stability as the bitumen content increases, reaches its peak and then decreases. The figure also shows that at binder content of 6.25%, the river gravel as a stability of 1560(N) while that of the crushed stone at 5.5% of bitumen as a stability of 1610(N). The bearing capacity and the binder content lie perfectly within the specified standard (see Table 3) which confirms the reasonnableness of the determined optimum binder content.

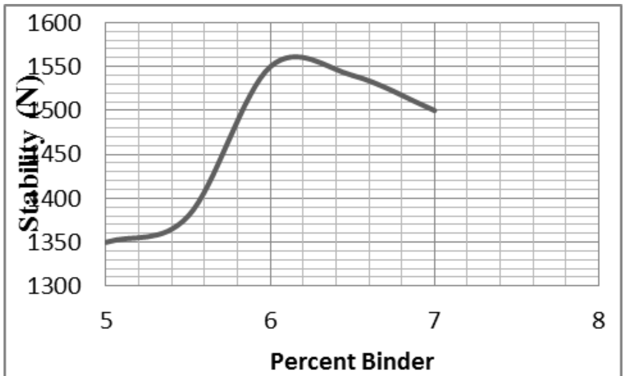

Fig 4:River gravel

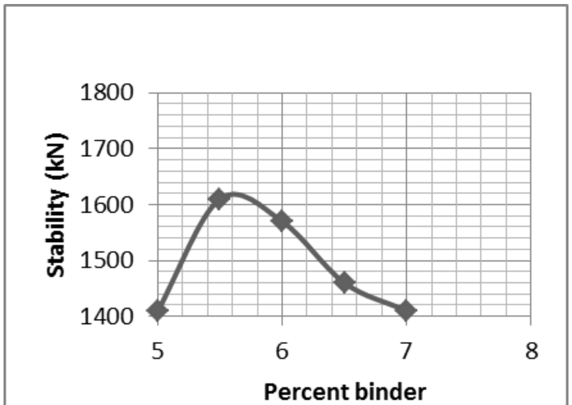

Fig 5:Crushed stone

Figure 4 and 5: Graph of Stability against Binder Content

Flow: This is the measure of the deformation of the sample or the total movement of strain in unit (mm) occurring in the sample of no load occurring at stability. The graph shows the relation between the flow of the sample and the bitumen composition. It determines the bitumen content that correspond with the required air void. The figure also shows that at binder content of 6.0%, the river gravel has a flow of 36mm while that of the crushed stone at 6.0% of bitumen as a flow of 34mm.

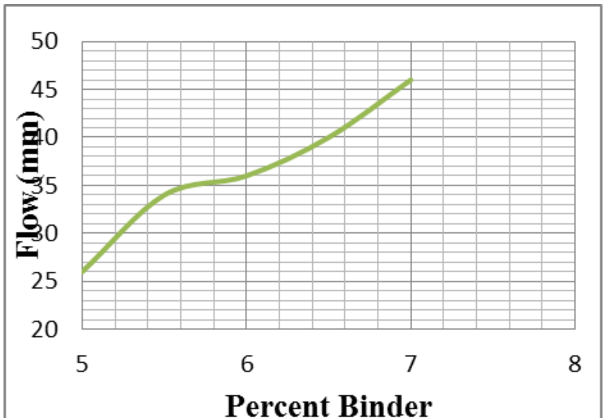

Fig 6:River Gravel

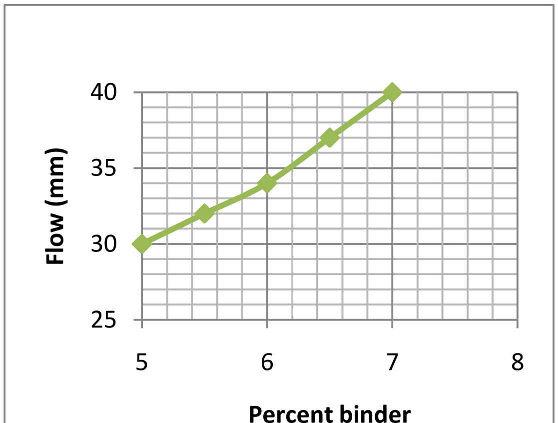

Fig 7:Crushed stone

Figure 6 and 7: Graph of Flow against Binder Content

Percent Voids - Total Mix: this is a graph showing the relationship between the percent voids in total mix and the binder content. This graph shows an increasing percentage air void with decreasing bitumen content till the maximum obtainable void value is reached then shows a decrease. The figure also shows that at binder content of 6.0%, the river gravel as a void of 3.3% while that of the crushed stone at 6.0% of bitumen as a void of 3.2%.

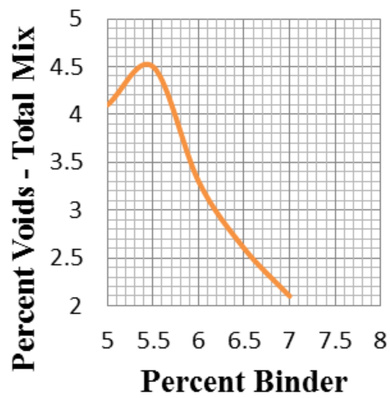

Fig 8:River Gravel

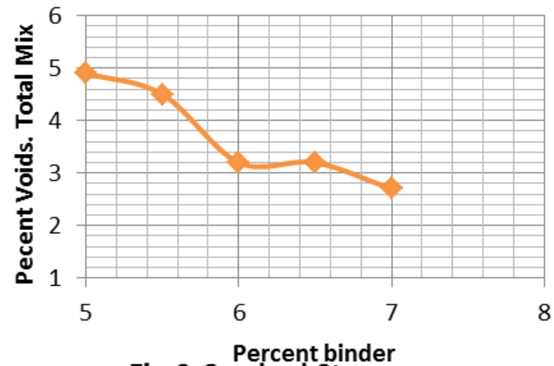

Fig 9:Crushed Stone

Figure 8 and 9: Graph of Percent Voids – Total Mix against Binder Content

Void Filled with Bitumen: this graph shows the relation between the percentages of the total mixture filled with bitumen at relative bitumen content. The graph shows a curve of steady increase as the bitumen content increases. The more you increase the bitumen, the higher the void filled with bitumen. The figure also shows that at binder content of 6.0%, the river gravel as a void filled with bitumen of 80.6% while that of the crushed stone at 6.0% of bitumen has a void of 81.1%.

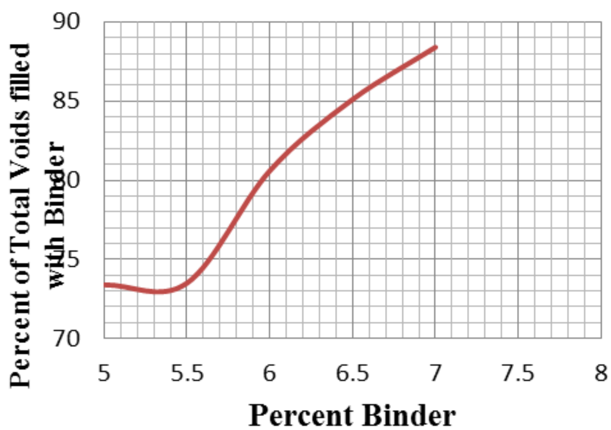

Fig 10:River Gravel

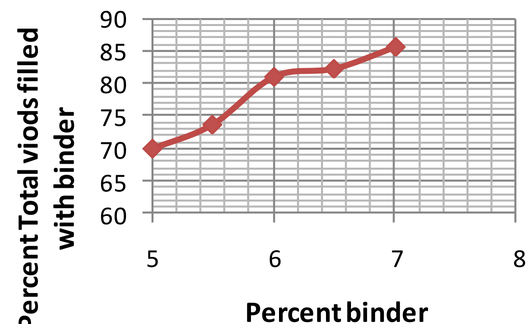

Fig 11:Crushed Stone

Figure 10 and 11: Graph of Percent of Total Voids filled with Binder against Binder Content

Conclusion

This research work on the Strength comparison of the properties of River Gravel in Asphalt production compared to crushed aggregates as an alternative material for hot mix asphalt in civil Engineering (highway engineering) was focused on verifying the performance of river gravel in asphalt production and meant to check its potentials and possibilities for use in highway engineering. From the result obtained, it can be concluded that the properties of the produced asphalt such as unit weight, stability, flow, percent voids in total mix and percent of total voids filled with bitumen met the standard specification for hot mix asphalt. Also from the graph, at optimum binder content of 6.0% for both production, the stability of that produced with river gravel having a value of 1560(N) is lower than that produced with crushed stone which has a value of 1610(N), meaning that the asphalt produced with crushed stone has a relative strength compare to the asphalt produced using river gravel.

Recommendation

It is therefore recommended from the test results and conclusion, that River gravel asphalt can be recommended for use in road construction and maintenance of work in Nigeria and beyond where this natural material abound because of the advantages it possesses over the crushed stone such as durability, less expensive, availability from natural source (rivers) and its minimal environmental hazards such as dust emission during blasting as in crushed stone which increases energy savings.

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