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Research Paper

Dehydroxylated Kaolin on the Stiffness of Hot Mix Asphalt Mixtures For Medium Traffic Roads

Eme Dennis Budu[1]* and Obazee Anthony Igunma[2]
[1,2]Department of Civil and Environmental Engineering, University of Port Harcourt
**Corresponding Author; Eme, Dennis Budu*

ABSTRACT
Highway pavements are generally faced with two major types of failures; failure due to permanent deformation and failure due to fatigue cracking. These failures arise principally from the use of weak asphalt or use of weak subgrade. This study tends to prevent these failures through deployment of dense HMA mixtures using aggregates prevalent in the Niger Delta region with incorporation of an available and environmentally friendly material called kaolin in dehydroxylated form, as the filler material. Hence, this study is aimed at evaluating the performance of different categories of dense hot mix asphalt mixtures for medium traffic category modified using dehydroxylated kaolin. During development of the preliminary mix design, the linear programming method using excel solver was employed for the dry mix preparation (aggregate combination) while the conventional Marshall mix design procedure was employed during the wet mix design process (optimum bitumen content determination). Initially seven categories of asphalt concretes were considered which later reduced to six categories after evaluation of the preliminary dry mix design. Dehydroxylated white clay (DWC) was added in the proportions of 0-10% by weight of fine aggregatesto the hot mix asphalt mixtures during the main experimental mix design development. In order to determine the effect of DWC on the different categories of dense asphalt concrete selected, simple graphical analysis was employed. Preliminary investigations revealed that angularity and density of the aggregates affect the amount of bitumen required for aggregate coating. The stiffness of the HMA mixtures improved with introduction of DWC. Furthermore, 8.3%, 7.8%, 8%, 6.6%, 7.2% and 6.4% are obtained as the ODWCs' for HMA categories 1, 2, 3, 4, 5 and 6 in that order. For the various HMA categories, the maximum stiffness (MSF) recorded are; 3.6N/mm for category 1, 4.72N/mm for category 2, 4.79N/mm for category 3, 5.6N/mm for category 4, 5.4 N/mm for category 5 and 5.5N/mm for category 6. This indicates that HMA category 4 is the best HMA category because it has the highest stiffness.
Keywords*; Dehydroxylated kaolin, stiffness, Hot mix asphalt, medium traffic roads, white clay*

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I. INTRODUCTION

The two principal modes of failure in pavements are fatigue cracking and permanent deformation. Engineers seek to hold these forms of failure to acceptable limits within a pavement design life. Fatigue resistance of an asphalt mixture is the ability of the mixture to withstand repeated bending without fracture. It is one of the common forms of distress in asphalt pavements and manifests itself in the form of cracking under repeated traffic loading or a series of temperature fluctuations/variation in the pavement. Fatigue cracking initiates at the bottom of asphalt base and appears on the pavement surface as interconnected tracks of different forms and it may also start at the surface and grow downwards as is the case for thermal (fatigue) cracking. Some forms of fatigue cracking include; longitudinal cracking, transverse cracking, and block cracking. The published studies on fatigue resistance indicate that hydrated lime improves the fatigue resistance of asphalt mixtures in 77% of the cases [1].

There are two major causes of permanent deformation, which are the use of weak asphalt and weak subgrade. The focus of this study is on failure resulting from weak asphalt. Rutting resulting from accumulation of permanent deformation in the asphalt layer is now considered to be the principal component of flexible pavement rutting [2]. In Nigeria, the trucks/tankers are relied on for the movement of freight (oil and gas products, finished products, raw materials etc). The increase in truck tyre pressures and axle loads put the asphalt mixtures under increasingly high stresses. Some of the factors that cause weak asphalt mixture include aggregates gradation, aggregate surface texture, voids in the asphalt mixture, air voids and the voids in the aggregate skeleton filled with bitumen, type of binder and temperature. The problems of fatigue cracking and permanent deformation have been addressed using different approaches. These include the use of harder bitumen, better design method like the superpave mix design, the use polymer modified asphalt, the use of grouted asphalt, and the use of lime-modified asphalt. This study seeks to employ the use of a special type of soil being dehydroxylated white clay for modification process.

The properties of asphalt concrete are also dependent on the shape and gradation of coarse aggregates. The two basic types of coarse aggregate used in this region are granite and gravel. Granite are crushed aggregates whose shapes are irregular while gravel are rounded aggregates. The optimum combination of these two aggregates in relationship to sharp and eroded sand in comparison to their individual optimization with sharp and eroded sand is the principal focus of this study.

1.1 Modification of Asphalt Mixtures

Various materials, chemicals and substances have been employed in the modification process of asphalt concrete. Different types and quantities of filler have effect on the performance of asphalt-concrete mixture [3]. Filler provides better resistance to micro cracking so that it can increase the fatigue life of asphalt-concrete mixture [4]. In this study,hydrated lime was more effective in stiffening binders than limestone fillers. Waste cement dust as filler on the asphalt-concrete mixture enhances the mechanical properties of the mix, and the laboratory results indicate that the cement dust can totally replace limestone powder in the asphalt paving mixture [5].Significant improvement in fatigue life of the asphalt-concrete mixtures can be obtained by using fly ash from oil shale [6].Structural characteristics of asphalt-concrete mixture are improved by using hydrated lime and phosphogvypsum as filler material [7].

Muniandy and Aburkaba [8] used four types of industrial by-product wastes filler namely, limestone as reference filler, ceramic waste dust, coal fly ash, and steel slag dust and they discovered that these filler materials increases the stiffness and fatigue life of Stone Mastic Asphalt (SMA) Mixtures .

The temperature susceptibility and durability of the asphalt binder and asphalt-concrete mixture can be improved by using filler materials ([9]; [10]). Using fly ash as filler on asphalt-concrete mixture provides better resistance against low temperature cracking and fatigue cracking [11]. Various conventional materials such as cement, lime, granite powder are normally used as filler in asphalt-concrete mixtures in Bangladesh. Cement, lime and granite powder are expensive and are used for other purposes more effectively. With the economic point of view, the present investigation has been taken in order to study the performance of asphalt-concrete mixtures with nonconventional filler such as, non-plastic sand, brick dust and ash and to compare with the conventional filler materials.

Hassan and Israa [12] carried out an experiment of stone mix asphalt using glass powder as a filler. They varied the bitumen content 4 to 7%. As reference filler material Limestone and Ordinary Portland cement were used and overall results were satisfactory.

Sert and Kütük [13] conducted an experiment on the use of bio gypsum as filler material which is harmful for environment as a waste. They carried out this study for lime stone and bio gypsum filler and found a satisfactory result. It reduces the OBC content and %VFA, %VMA and specific gravity it yields is nearly same. Mix with bio gypsum shows more rigid behavior. Authors found its crucial importance for heavy traffic road hot climate region for it excessive %VFA value.

Kar et al. [14] in their study focused on the use of fly ash (by product from coal based thermal power plant) as a mineral filler for Marshall bituminous mix design to solve the disposal problem and also for cost efficiency of bituminous mix design.

Murana and Sani [15] partially replaced cement by Bagasse Ash (BA) as a mineral filler material for this study to find the influence on the Marshall characteristics. Tests were carried out for different percentage of BA with different percentage of bitumen content to find the optimum one. In this study the mix with 10% BA and 90% OPC satisfy the standard specified by Asphalt institute. 10% of BA yields a good result for all characteristic. They concluded that 10% BA will be optimum to partially replace the OPC.

Joni and Zghair [16] analyzed the Marshall characteristics after using foundry sand as a filler material instead of lime and cement and they compared these three side by side. They used aggregates according to SCRB, R/9 2003 specification, 40-50 grade bitumen accompanied by this three mineral filler and found it's suitability as a filler material. Although the characteristics not more preferable than cement and lime but they are satisfactory enough to be used. The stability for cement, lime and foundry sand is 13.6 KN, 12.5 KN, and 11.25 KN which close to these conventional filler.

Wasilewska, et al. [17] have carried out an advanced experiment on five types of rock that can be used as a filler material. In this study the researchers considered limestone as a reference material to evaluate the results. In this study they had emphasized on the characteristics of the filler set by ASSHTO, ASTM. And they have compared the obtained results with the polish code requirements. They have tested gradation, water content, particle density, Delta R&B temperature, and surface area and Bitumen Number of Five types of rocks that were used as a source of the mineral fillers: gabbro, granite, trashy basalt, quartz sandstone and rocks from postglacial deposits. Performing Scanning Electron Microscopy (SEM) analysis of grain shape and size they observed a significant difference in grain size and shape. They have concluded the study by reporting that binder type plays important role to improve performance not the filler type.

From the reviews above, asphalt concrete has been improved from different dimensions ranging from shape or angularity of aggregates, to the use of conventional and non-conventional materials as fillers. In the quest to satisfy availability and safety this study seeks to optimize the different types of available aggregates in this region in the production of asphalt concrete using a naturally existing, environmental friendly substance which is the dehydroxylated kaolin.

II. MATERIALS AND METHODS

2.1 Study Design

This study is directed towards finding the best performing densely graded asphalt concrete using available aggregates in this part of the country in corporation with an eco-friendly filler material, dehydroxylated white clay (DWC), also present in abundance in this part of the country. Sourced white clay or kaolin was subjected to a temperature of 700^0C and pulverized to obtain the DWC, otherwise called, metakaolin (MK). Before the commencement of experimental investigations, seven (7) possible combinations of materials to obtain a dense graded hot mix asphalt (HMA) mixtures were suggested. Analytical or formula method using linear programming was used in combining the various aggregates selected to obtain different optimum aggregate blends (OAB), which resulted to six possible densely graded HMA categories as against the seven categories initially proposed. In the wet mix design process, the Marshall Mix design procedure was adopted in determining the optimum bitumen content (OBC) for the different HMA categories obtained from the dry process. In the main experimental programme, the OBCs' for the different HMA categories were used in preparation of HMA mixtures with incorporation ofDWC as thefiller material. DWC percentage was limited to the range of 0-10% by weight of fine aggregates for each category.Stiffness, a major property measuring against HMA's permanent deformation, was then determined. Furthermore, the effect of DWC on HMA stiffness was then investigated and the best category selected.

2.2 Materials

Granite and gravel of nominal size 12.5mm sourced from a construction material shop within Port Harcourt were used as the coarse aggregates in this study. Granite are irregular, angular shaped coarse aggregates whereas, gravel are rounded coarse aggregates. The specific gravities and gradation details of both materials are shown in Table 1.

Fine river sand and eroded sand, which are abundantly available in the Niger Delta region of Nigeria were used as fine aggregates during the course of this study.Fine river sand are considered to be angular in shape but eroded sand are considered rounded fine aggregates due to the actions of weathering elements. The properties and particle size distribution details of these two materials are displayed in Table 2.

Dehydroxylated white clay (DWC), due to its environmental friendliness, availability in the Niger Delta region, proven records of pozzolanity and its inert nature was employed as the filler material for the study. The portion of DWC finer than 75µm was used for this purpose. The specific gravity and oxide composition of DWC is shown in Table 3.

Asphalt cement of PEN grade 60/70 was used in this study for the binding or coating of aggregates. Certain properties of the asphalt cement is shown or presented in Table 4.

Table 1. Gradation properties and specific gravities of coarse aggregates

Aggregate/properties	Value	Description
Granite:		
Gradation parameters;		
D_{60}	9.41mm C_u = 2.31	Using the coefficient of uniformity (C_u) and that of curvature (C_c), the granite is therefore a uniformly graded material according to the USCS classification
D_{30}	6.14mm ⇨	
D_{10}	4.073mm C_c =0.983	
Specific gravity	2.64	
Gravel:		
Gradation parameters;		
D_{60}	9.61mm C_u = 2.40	The gravel is also uniformly graded material according to the USCS classification
D_{30}	6.225mm ⇨	
D_{10}	4.012mm C_c =1.00	

Specific gravity	2.43

Table 2. Gradation properties and specific gravities of fine aggregates

Aggregate/properties	Value	Description
Fine river sand:		
Gradation parameters;		
D_{60}	2.815mm C_u = 18.77	Using the coefficient of uniformity (C_u) and that of curvature (C_c), the fine river sand is therefore a uniformly graded material according to the USCS classification
D_{30}	0.68mm ⇨	
D_{10}	0.15mm C_c =1.09	
Specific gravity	1.64	
Eroded sand:		
Gradation parameters;		
D_{60}	2.686mm C_u = 26.86	The eroded sand is also uniformly graded material according to the USCS classification
D_{30}	0.50mm ⇨	
D_{10}	0.10mm C_c =0.931	
Specific gravity	1.55	

Table 3. Properties of DWC

Properties	Value (%)	Description
Basic Oxides;		
CaO	4.67	The combine acidic oxides of (Al_2O_3+ SiO_2+ Fe_2O_3) with a value of 91.34%, met the requirements of ASTMC618 (2017) for a Class N pozzolan.
Al_2O_3	3.54	
Fe_2O_3	2.89	
SiO_2	80.24	
(Al_2O_3+ SiO_2+ Fe_2O_3)	91.34	
Specific gravity	1.83	

Table 4. Asphalt cement properties

Property	Value
Specific gravity	1.09
Softening point	53^0C
Penetration	68
Flash point	250^0C

2.3 Methods

Preliminary dry mix design (optimum aggregate blend determination)

In combining the aggregates in the preliminary dry mix design, the analytical or formula method of aggregate combination using linear programming (excel solver) was employed. Information from the gradation analysis of the different aggregates were used in relation to the standard job mix (Table 5) specified for flexible pavement wearing course to determine the optimum aggregate blend for the different categories of asphalt concrete. Equation (1) represents the general equation used in combining three aggregates.

$$aA + bB + cC = P \quad (1)$$

Where a, b and c represents the optimum proportion of the three different aggregate sizes A, B and C. P represents the gradation resulting from combination of these aggregates which must fall within the specified job mix or be as close as possible to the midrange of job mix. The constraint here is that the summation of the optimum proportions (a, b and c) of these aggregates must be 1 (Equation 2)

$a + b + c = 1$ (2)

For n number of sieve sizes, Equation (1) becomes;

$$\begin{aligned} aA_1 + bB_1 + cC_1 &= P_1 \\ aA_2 + bB_2 + cC_2 &= P_2 \\ aA_3 + bB_3 + cC_3 &= P_3 \\ &\vdots \\ aA_n + bB_n + cC_n &= P_n \end{aligned} \quad (3)$$

The general procedure adopted here using excel solver for optimization of aggregate combination for the different asphalt categories is hereby outlined;

1. The mid-point of the specified job mix for each sieve size was determined
2. Sieve analysis was conducted on the different aggregates to obtain the gradation (percent finer) than each of the considered sieve size
3. An initial or arbitrary value of a, b and c depending on the number of aggregates considered in that category was chosen
4. Equation (1) was then applied to obtain the grading (P) for each of the considered sieve size
5. The difference between P and the mid-point of the job mix was calculated for the different sieve sizes
6. These differences were then squared to obtain the square of differences (SD)
7. The sum of squares of these differences (SSD) was then obtained
8. Then finally excel solver was then employed for the optimization process with;

Objective function; Minimizing (SSD)

By changing variables; A, B and C (depending on the number of aggregates)

Subjecting to constraints; $a + b + c = 1$

a, b, c, A, B, C ≥ 0

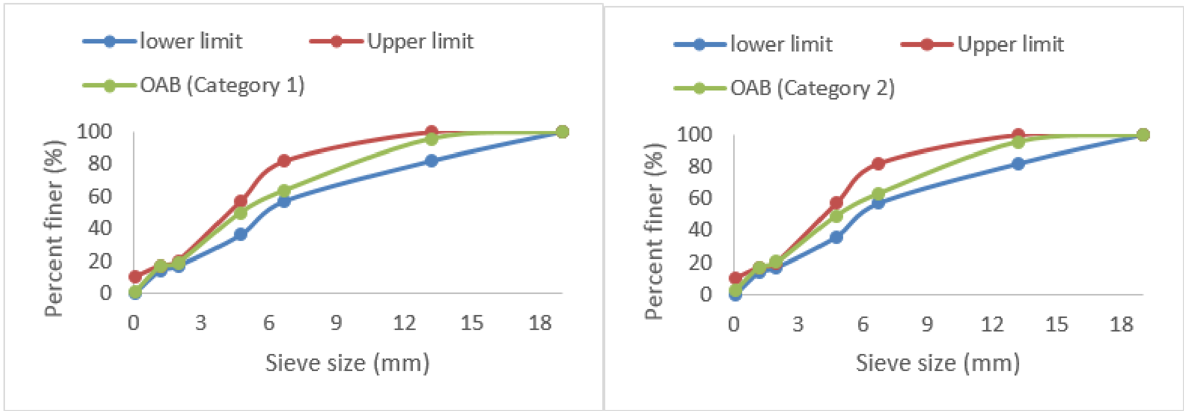
These steps were strictly followed in obtaining the optimum aggregate blends (OAB) for the different categories of dense asphalt concrete considered. This resulted to OAB values displayed in Table 6 with their gradation curves shown in Figure 1.

Table 5. Job Mix Formula Adopted

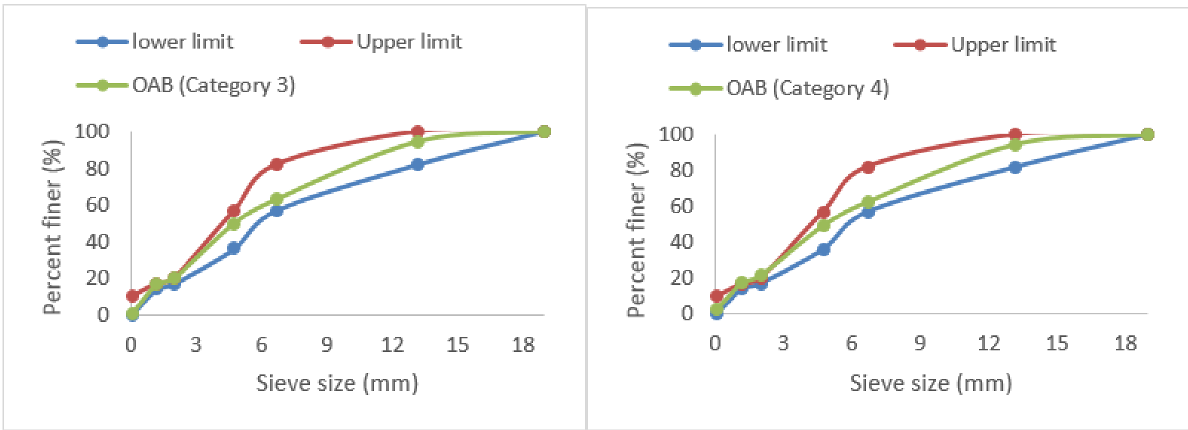
Sieve size (mm)	19	13.2	6.7	4.75	2.00	1.18	0.075
JMF (%)	100	82-100	57-82	36-57	17-20	14-17	0-10

Table 6. Summary of optimum aggregate blends (OAB) for the different categories

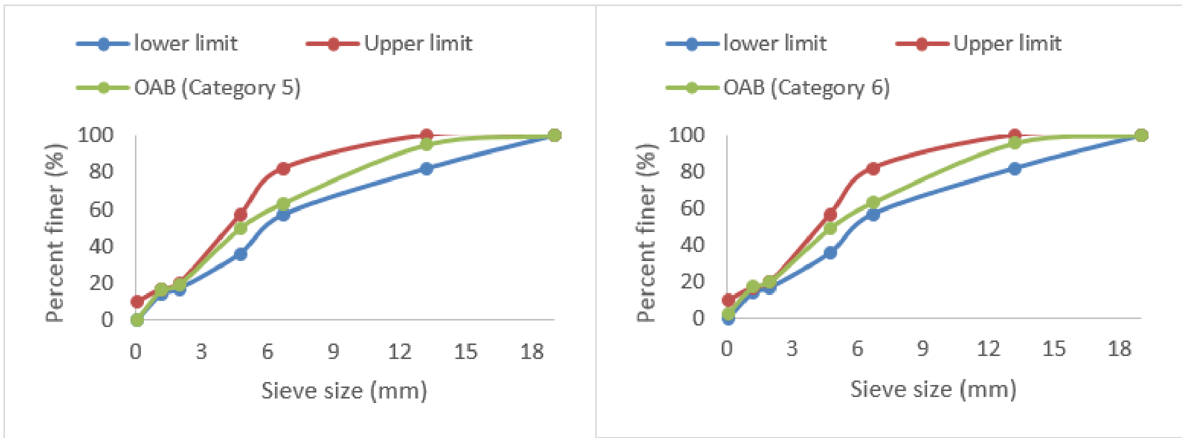
Category	Aggregate type	Optimum Aggregate content (%)
Category 1	Granite	**57.1**
	Granular sand	**42.9**
Category 2	Granite	**57.5**
	Rounded sand	**42.5**
Category 3	Gravel	**57**
	Granular sand	**43**
Category 4	Gravel	**57.4**
	Rounded sand	**42.6**
Category 5	Granite	**22.3**
	Gravel	**34.8**
	Granular sand	**42.9**
Category 6	Granite	**57.5**
	Granular sand	**0.9**
	Rounded sand	**41.6**



a. grading curve for Category 1   b. grading curve for Category 2



c. grading curve for Category 3   d. grading curve for Category 4



e. grading curve for Category 5   f. grading curve for Category 6

Figure 1. Gradation curves for the different asphalt concrete categories

Preliminary wet mix design (optimum bitumen content (OBC) determination)

In determining the optimum bitumen content during the preliminary wet mix design, the Marshall conventional design procedure was adopted.The tests are scheduled on the basis of 0.5% increments of asphalt cement content, with at least two asphalt contents above "optimum" and at least two below "optimum". Bitumen percentage was limited to 4% - 6% by weight of total mix for the different HMA categories. The optimum aggregate blend (OAB) obtained for the different asphalt categories was adjusted in terms of proportion of total mix, resulting to the preliminary mix design shown in Table 7. The specimens are compacted on two faces, with 50 blows considering medium (104 < ESA < 106) traffic category and with the compaction hammer using a free fall of 450mm. The test specimens are made under a standard temperature of 60°C.Each compacted specimen is subjected to the following tests and analysis:

*Corresponding Author: Eme, Dennis Budu

1. Bulk density determination
2. Density and voids analysis.
3. Stability and Flow tests.

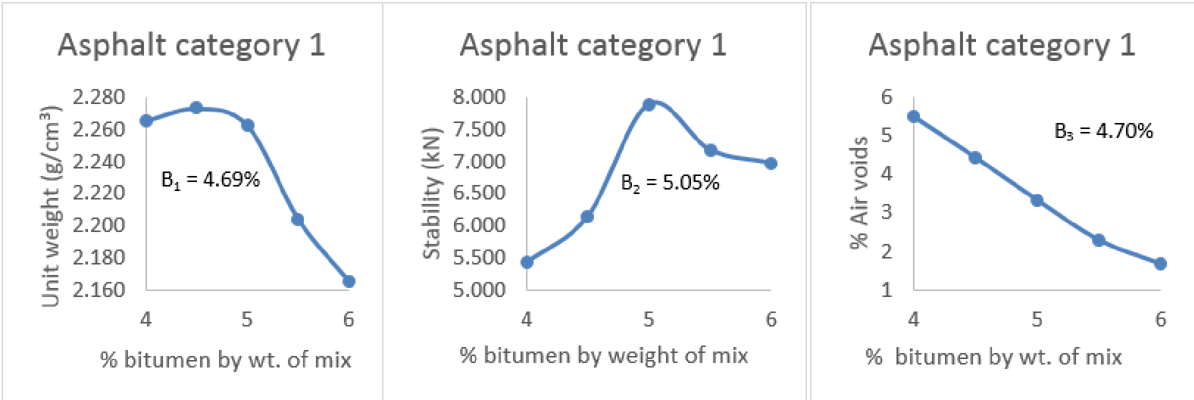
After determination and analysis of the aforementioned, three important plots were prepared in order to determine the optimum bitumen content for the different HMAcategories;unit weight versus percent bitumen content,corrected Marshall stability versus percent bitumen contentand percent of void in the total mix(P_{av}) versus percent bitumen content. These graph plots are presented in Figure 2 for the different asphalt concrete categories. Optimum Bitumen content was then determined from the plotted graphs by the use of Equation (4). On application of Equation (4), the optimum bitumen contents for all HMA categories were obtained as tabulated in Table 8, forming the basis for the main experimental mix design.

$$B_0 = \frac{B_1 + B_2 + B_3}{3} \quad (4)$$

Where;
B_0 = Optimum Bitumen Content,
B_1 = Percent bitumen content at maximum unit weight,
B_2 = Percent bitumen content at maximum stability,
B_3 = Percent bitumen content at 4% air voids in the total mix.

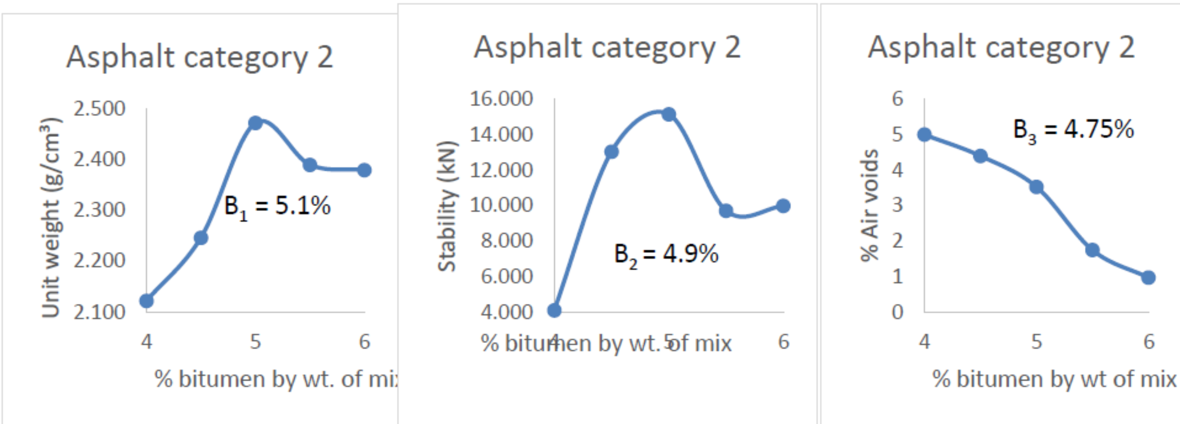
Table 7. Preliminary experimental mix design

Category	**Optimum Aggregate blend (%)**			**Adjusted Aggregate blend (%)**			**Bitumen content (%)**
	Granite	**Granular sand**		**Granite**	**Granular sand**		
	57.1	42.9		54.82	41.18		4
Asphalt Category 1	57.1	42.9		54.53	40.97		4.5
	57.1	42.9		54.25	40.75		5.0
	57.1	42.9		53.96	40.54		5.5
	57.1	42.9		53.67	40.33		6.0
	Granite	**Rounded sand**		**Granite**	**Rounded sand**		
Asphalt Category 2	57.5	42.5		55.2	40.8		4
	57.5	42.5		54.91	40.59		4.5
	57.5	42.5		54.63	40.37		5.0
	57.5	42.5		54.34	40.16		5.5
	57.5	42.5		54.05	39.95		6.0
	Gravel	**Granular sand**		**Gravel**	**Granular sand**		
	57	43		54.72	41.28		4
	57	43		54.44	41.06		4.5
Asphalt Category 3	57	43		54.15	40.85		5.0
	57	43		53.87	40.63		5.5
	57	43		53.58	40.42		6.0
	Gravel	**Rounded sand**		**Gravel**	**Rounded sand**		
	57.4	42.6		55.1	40.9		4
Asphalt Category 4	57.4	42.6		54.82	40.68		4.5
	57.4	42.6		54.53	40.47		5.0
	57.4	42.6		54.24	40.26		5.5
	57.4	42.6		53.96	40.04		6.0
	Granite	**Gravel**	**G.sand**	**Granite**	**Gravel**	**G.sand**	
	22.3	34.8	42.9	21.41	33.41	41.18	4
Asphalt Category 5	22.3	34.8	42.9	21.30	33.23	40.97	4.5
	22.3	34.8	42.9	21.18	33.06	40.76	5.0
	22.3	34.8	42.9	21.07	32.89	40.54	5.5
	22.3	34.8	42.9	20.96	32.71	40.33	6.0
	Granite	**G.sand**	**R.sand**	**Granite**	**G.sand**	**R.sand**	
	57.5	0.9	41.6	55.2	0.86	39.94	4
Asphalt Category 6	57.5	0.9	41.6	54.91	0.86	39.73	4.5
	57.5	0.9	41.6	54.63	0.86	39.52	5.0
	57.5	0.9	41.6	54.34	0.85	39.31	5.5
	57.5	0.9	41.6	54.05	0.85	39.10	6.0



1.Unit weight vs bitumen *2. Stability vs bitumen* *3. Air voids vs bitumen*

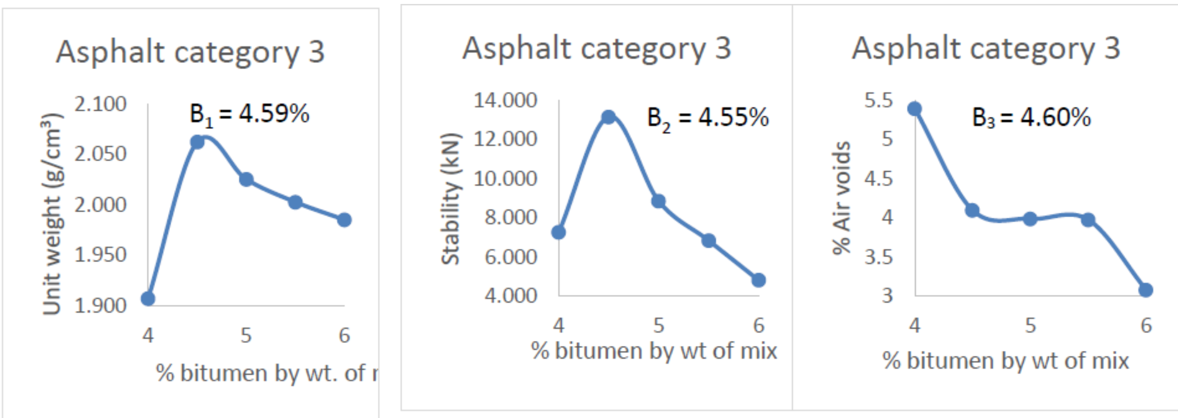
a. **HMA parameters versus percent bitumen content (Category 1)**



1.Unit weight vs bitumen *2. Stability vs bitumen* *3. Air voids vs bitumen*

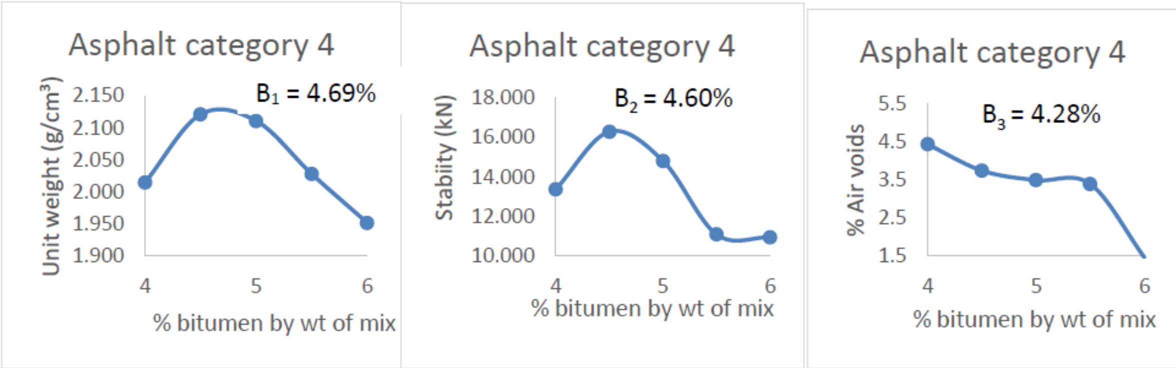
b. HMA parameters versus percent bitumen content (Category 2)

c.



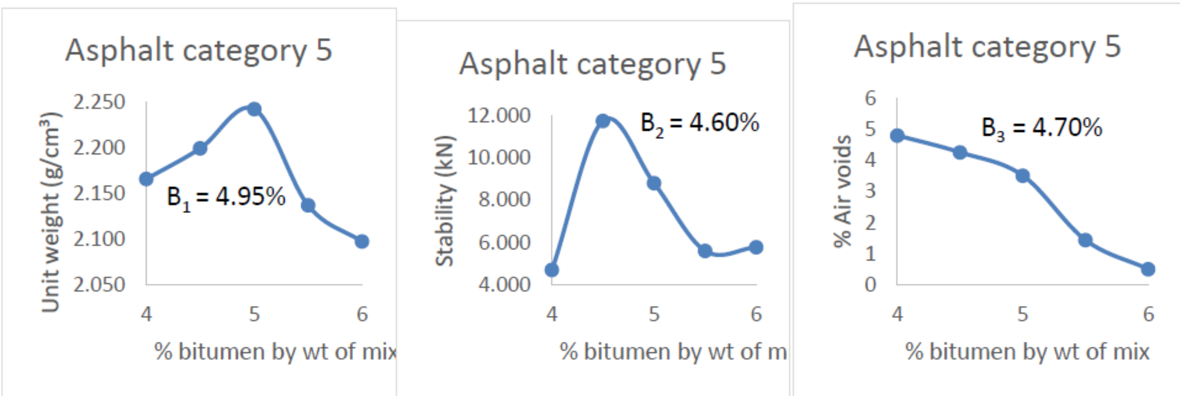
1.Unit weight vs bitumen *2. Stability vs bitumen* *3. Air voids vs bitumen*

c. **HMA parameters versus percent bitumen content (Category 3)**

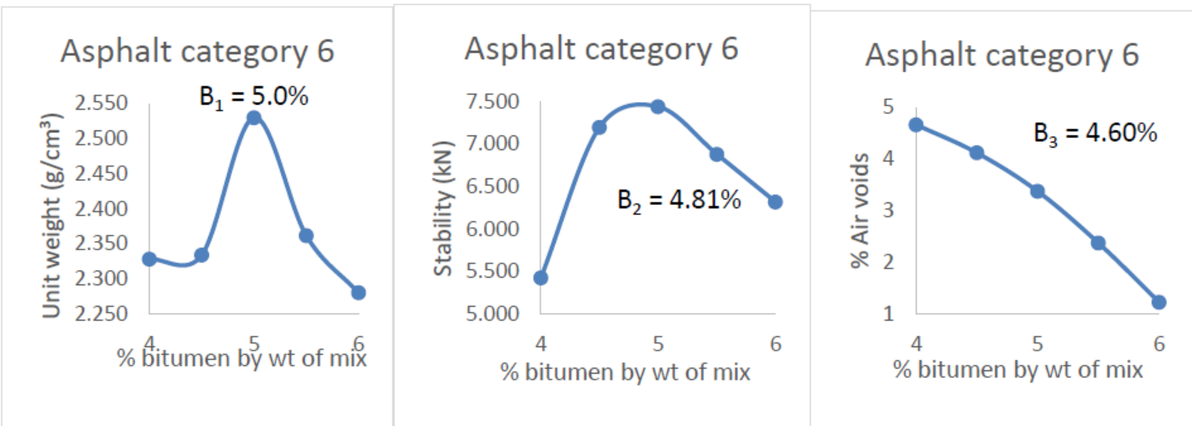


1.Unit weight vs bitumen *2. Stability vs bitumen* *3. Air voids vs bitumen*

d. **HMA parameters versus percent bitumen content (Category 4)**



e. **HMA parameters versus percent bitumen content (Category 5)**



1.Unit weight vs bitumen *2. Stability vs bitumen* *3. Air voids vs bitumen*

f. **HMA parameters versus percent bitumen content (Category 6)**

Figure 2. HMA Parameters for OBC Determination

Table 8. Optimum bitumen content for all HMA categories

Category	**Bitumen content**			
	B_1 (%)	**B_2 (%)**	**B_3 (%)**	**OBC (%)**
1	4.69	5.05	4.70	4.81
2	5.1	4.90	4.75	4.92
3	4.59	4.55	4.60	4.58
4	4.69	4.60	4.28	4.52

5	4.95	4.60	4.70	4.75
6	5.00	4.81	4.60	4.80

Experimental mix design

Information obtained from the preliminary mix design (OABs' and OBCs') was used in building the experimental mix design for the different HMA categories. The DWC percent by weight of total fine aggregates was limited to 0 – 10% with a 2% increment between experimental runs. This results to six (6) experimental runs per HMA category. Table 9 presents the experimental mix design adopted in the preparation of HMA mixtures.

Stiffness of HMA mixtures

The stiffness of the asphalt concrete specimens for the different categories was computed in accordance to Equation (5). Stiffness property of a HMA mixture gives an insight into how resilient such HMA mixture is to permanent deformation. It's a parameter sometimes used interchangeably with resilient or dynamic modulus. It is mathematically represented as the ratio of load/force causing failure to the deformation (flow) recorded by a compacted HMA sample.

$$S = \frac{P\ (in\ N)}{d\ (in\ mm)} \qquad (5)$$

Where, P is equivalent to the failure load which in this case was taken as the corrected Marshall stability value in N and d is the recorded deformation (flow in mm) of the HMA sample at failure. During the course of the experiments, the dimensions of produced samples varied from the standard specifications. Therefore, the measured stability values were corrected to those which would have been obtained if the specimen was exactly 63.5mm thick. This is done by multiplying the measured stability values by the appropriate correction factor as provided in Table 10 (Emesiobi, 2000).

Table 9. Experimental mix design

Category	Optimum Aggregate blend (%)			Adjusted Aggregate blend (%)				OBC (%)
	Granite	**G. sand**		**G.nite**	**G. sand**		**DWC**	
	57.1	42.9		54.35	40.84		0.00 (0%)	4.81
Asphalt Category 1	57.1	42.9		54.35	40.02		0.82 (2%)	4.81
	57.1	42.9		54.35	39.21		1.63 (4%)	4.81
	57.1	42.9		54.35	38.39		2.45 (6%)	4.81
	57.1	42.9		54.35	37.57		3.27 (8%)	4.81
	57.1	42.9		54.35	36.76		4.08 (10%)	4.81
	Granite	**R. sand**		**G.nite**	**R. sand**		**DWC**	
Asphalt Category 2	57.5	42.5		54.67	40.41		0.00 (0%)	4.92
	57.5	42.5		54.67	39.60		0.81 (2%)	4.92
	57.5	42.5		54.67	38.79		1.62 (4%)	4.92
	57.5	42.5		54.67	37.99		2.42 (6%)	4.92
	57.5	42.5		54.67	37.18		3.23 (8%)	4.92
	57.5	42.5		54.67	36.37		4.04 (10%)	4.92
	Gravel	**G. sand**		**Gravel**	**Granular sand**		**DWC**	
	57	43		54.39	41.03		0.00 (0%)	4.58
	57	43		54.39	40.21		0.82 (2%)	4.58
Asphalt Category 3	57	43		54.39	39.39		1.64 (4%)	4.58
	57	43		54.39	38.57		2.46 (6%)	4.58
	57	43		54.39	37.75		3.28 (8%)	4.58
	57	43		54.39	36.93		4.10 (10%)	4.58
	Gravel	**R. sand**		**Gravel**	**Rounded sand**		**DWC**	
	57.4	42.6		54.81	40.67		0.00 (0%)	4.52
Asphalt Category 4	57.4	42.6		54.81	39.86		0.81 (2%)	4.52
	57.4	42.6		54.81	39.04		1.63 (4%)	4.52
	57.4	42.6		54.81	38.23		2.44 (6%)	4.52
	57.4	42.6		54.81	37.42		3.25 (8%)	4.52
	57.4	42.6		54.81	36.60		4.07 (10%)	4.52
	Granite	**Gravel**	**G.sand**	**G.nite**	**G.vel**	**G.sand**	**DWC**	
Asphalt Category 5	22.3	34.8	42.9	21.24	33.15	40.86	0.00 (0%)	4.75
	22.3	34.8	42.9	21.24	33.15	40.04	0.82 (2%)	4.75
	22.3	34.8	42.9	21.24	33.15	39.23	1.63 (4%)	4.75
	22.3	34.8	42.9	21.24	33.15	38.41	2.45 (6%)	4.75
	22.3	34.8	42.9	21.24	33.15	37.59	3.27 (8%)	4.75

	22.3	34.8	42.9	21.24	33.15	36.77	4.09 (10%)	4.75
	Granite	**G.sand**	**R.sand**	**G.nite**	**G.sand**	**R.sand**	**DWC**	
Asphalt Category 6	57.5	0.9	41.6	54.74	0.86	39.60	0.00 (0%)	4.80
	57.5	0.9	41.6	54.74	0.84	38.81	0.81 (2%)	4.80
	57.5	0.9	41.6	54.74	0.83	38.02	1.63 (4%)	4.80
	57.5	0.9	41.6	54.74	0.81	37.22	2.45 (6%)	4.80
	57.5	0.9	41.6	54.74	0.79	36.43	3.27 (8%)	4.80
	57.5	0.9	41.6	54.74	0.77	35.64	4.09 (10%)	4.80

Table 10. Marshall Stability Correlation values (Emesiobi, 2000)

Volume of Specimen (cm^3)	Thickness of specimen (mm)	Correction Factor
457-470	57.2	1.19
471-482	58.8	1.14
483-495	60.3	1.09
496-508	61.9	1.04
509-522	63.5	1.00
523-535	65.1	0.96
536-546	66.7	0.93
547-559	68.3	0.89
560-573	69.9	0.86
574-585	71.5	0.83
586-596	73.0	0.81
599-610	74.6	0.78
611-625	76.2	0.76

III. RESULTS AND DISCUSSION

Effect of Aggregate Type on the OBC of unmodified HMA mixtures

Table 11 presents in summary, the optimum combination of aggregates and bitumen for the different HMA categories which was used in analyzing the consequential effect of the aggregate type on the amount of bitumen required for effective coating of aggregates.

From Table 11, it can be inferred that the lesser the density or specific gravity of the aggregate type in a particular aggregate composition, the higher the optimum bitumen content. In comparing HMA categories 1 and 2, category 2 has higher bitumen content. This can be attributed to the difference in specific gravities of the sharp sand and eroded sand. Because the eroded sand is less dense, it occupies a higher volume per given mass, thus requiring a higher amount of bitumen content to completely coat the aggregates. Same thing cannot be said of categories 3 and 4, as the bitumen content of category 3 is higher than that of category 4 despite the eroded sand having a lower specific gravity than the sharp sand. The reversal here can be hinged on the relatively high difference in percentage composition between the sharp sand and the eroded sand. Another reason for this can also be deduced from their angularity difference, because the difference in percentage composition is high, more bitumen is being consumed by the sharp sand which is angular as compared to the eroded sand that is rounded.

Furthermore, in comparing categories 1 and 3 on the basis of coarse aggregate type, it can be observed that category 1 required a higher bitumen content than category 3. This can also be attributed to the issue of angularity difference as granite is angular while gravel is rounded. Less bitumen is required to completely coat rounded aggregates as against angular aggregates. Same information can be inferred from comparison of categories 2 and 4.

In addition, in comparing categories 5 and 6, category 6 require a higher bitumen content. The difference in aggregate composition here, is the gravel in category 5 and the eroded sand in category 6. Although both aggregates are angular, eroded sand is finer than gravel thus occupying more volume at any given mass. As a result, more bitumen is required by category 6 to completely coat the aggregates present.

Effect of DWC on the stiffness of HMA mixtures

Table 12 present the stiffness test results of modified HMA mixtures. Figure 3 show pictorially how DWC addition as a filler material affects the stiffness. From Figure 3, it can be observed that the stiffness of all categories of HMA increases as the DWC content increases up to an optimum percentage addition. This increment can be attributed to the difference in densities or specific gravities of fine aggregate and the DWC. Beyond the optimum DWC dosage, decrease in HMAstiffness can be observed. This decrease can be placed on the DWC content being too much causing a noticeable reduction in the coarse nature of the mix thereby reducing the adhesion between the aggregates.

Using simple regression and graphical analysis, the optimum DWC contents (ODWC) are being displayed in Figure 3. ODWC for category 1 modified HMA is 8.3% (Figure 3a). Applying same analogy to the other categories, 7.8%, 8%, 6.6%, 7.2% and 6.4% are obtained as the ODWCs' for categories 2, 3, 4, 5 and 6 in that order. For the various HMA categories, the maximum stiffness (MSF) recorded are; 3.6N/mm for category 1, 4.72N/mm for category 2, 4.79N/mm for category 3, 5.6N/mm for category 4, 5.4 N/mm for category 5 and 5.5N/mm for category 5. This is shown summarily in Table 13.

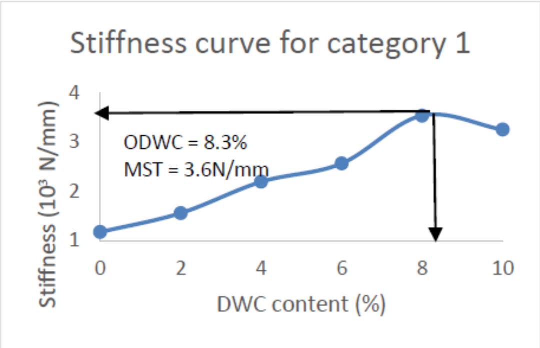
Table 11. Optimum bitumen content for the different asphalt concrete categories

Asphalt Category	Aggregate composition		OBC (%)
	Type	**OAB (%)**	
Category 1	Granite	**54.35**	
	Sharp/angular sand	**40.84**	**4.81**
Category 2	Granite	**54.67**	**4.92**
	Eroded/rounded sand	**40.41**	
Category 3	Gravel	**54.39**	**4.58**
	Sharp/angular sand	**41.03**	
Category 4	Gravel	**54.81**	**4.52**
	Eroded/rounded sand	**40.67**	
Category 5	Granite	**21.24**	**4.75**
	Gravel	**33.15**	
	Sharp/angular sand	**40.86**	
Category 6	Granite	**54.74**	**4.80**
	Sharp/angular sand	**0.86**	
	Eroded/rounded sand	**39.60**	

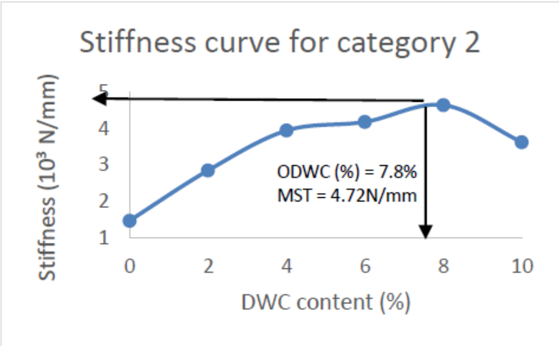
Table 12. Stiffness test results of modified HMA

Category	Adjusted Aggregate blend (%)			OBC (%)	Av. P (kN)	Deformation, d (mm)	Stiffness (10^3N/mm)
	Granite	**Granular sand**	**DWC**				
	54.35	40.84	0.00 (0%)		8.545	7.3	1.171
Asphalt	54.35	40.02	0.82 (2%)		9.726	6.25	1.556
Category 1	54.35	39.21	1.63 (4%)		12.940	5.9	2.193
	54.35	38.39	2.45 (6%)	**4.81**	14.116	5.5	2.567
	54.35	37.57	3.27 (8%)		16.293	4.6	3.542
	54.35	36.76	4.08 (10%)		13.024	4	3.256
	Granite	**Rounded sand**	**DWC**				
Asphalt	54.67	40.41	0.00 (0%)		10.067	6.85	1.500
Category 2	54.67	39.60	0.81 (2%)		17.253	6.05	2.852
	54.67	38.79	1.62 (4%)		21.848	5.53	3.951
	54.67	37.99	2.42 (6%)	**4.92**	20.864	4.98	4.189
	54.67	37.18	3.23 (8%)		19.727	4.24	4.652
	54.67	36.37	4.04 (10%)		14.444	3.98	3.629
	Gravel	**Granular sand**	**DWC**				
	54.39	41.03	0.00 (0%)		6.403	5.55	1.154
	54.39	40.21	0.82 (2%)		13.981	5.21	2.683
Asphalt	54.39	39.39	1.64 (4%)		13.824	4.19	3.299
Category 3	54.39	38.57	2.46 (6%)	**4.58**	17.390	4.26	4.082
	54.39	37.75	3.28 (8%)		19.151	4.01	4.776
	54.39	36.93	4.10 (10%)		13.614	3.64	3.740
	Gravel	**Rounded sand**	**DWC**				
	54.81	40.67	0.00 (0%)		18.463	5	3.693
Asphalt	54.81	39.86	0.81 (2%)		19.173	4.84	3.961
Category 4	54.81	39.04	1.63 (4%)		18.725	4.33	4.324
	54.81	38.23	2.44 (6%)	**4.52**	21.418	3.88	5.520
	54.81	37.42	3.25 (8%)		19.428	3.65	5.323

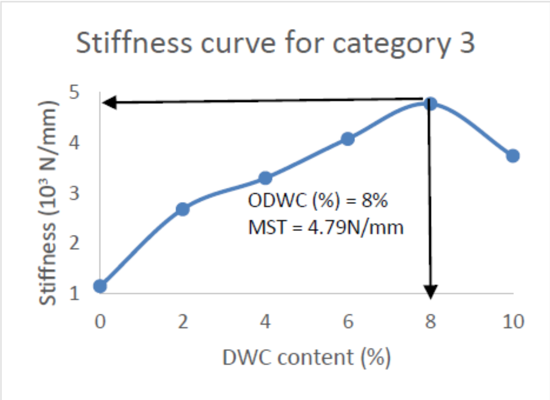
	54.81	36.60		4.07 (10%)		16.353	3.61	4.530
	G.nite	**G.vel**	**G.sand**	**DWC**				
	21.24	33.15	40.86	0.00 (0%)		11.668	5.37	2.173
Asphalt Category 5	21.24	33.15	40.04	0.82 (2%)		12.987	4.96	2.618
	21.24	33.15	39.23	1.63 (4%)		16.005	4.68	3.420
	21.24	33.15	38.41	2.45 (6%)	**4.75**	20.503	4	5.126
	21.24	33.15	37.59	3.27 (8%)		20.064	3.82	5.252
	21.24	33.15	36.77	4.09 (10%)		11.707	3.31	3.537
	G.nite	**G.sand**	**R.sand**	**DWC**				
	54.74	0.86	39.60	0.00 (0%)		8.505	4.34	1.960
Asphalt Category 6	54.74	0.84	38.81	0.81 (2%)		12.385	4.3	2.880
	54.74	0.83	38.02	1.63 (4%)		16.808	4.17	4.031
	54.74	0.81	37.22	2.45 (6%)	**4.80**	17.426	3.21	5.429
	54.74	0.79	36.43	3.27 (8%)		15.821	3.09	5.120
	54.74	0.77	35.64	4.09 (10%)		12.727	2.91	4.373



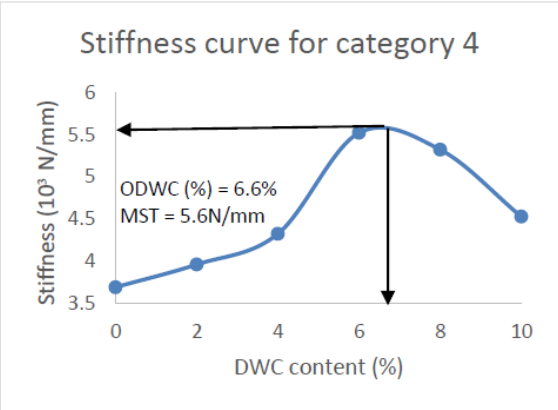
a. Stiffness vs DWC(category 1)



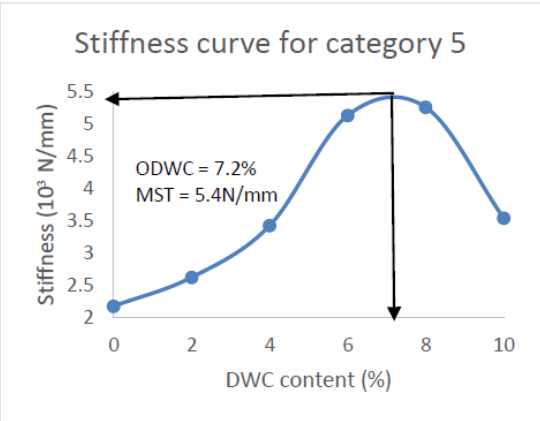
b. Stiffness vs DWC (category 2)



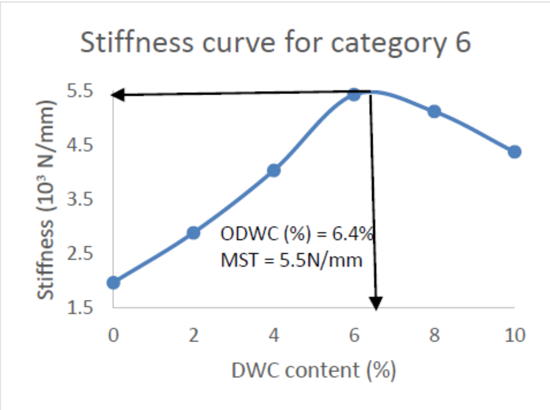
c.Stiffness vs DWC (category 3)



d. Stiffness vs DWC (category 4)



e.Stiffness vs DWC (category 5)



f. Stiffness vs DWC (category 6)

Figure 3. Stiffness against DWC content

Table 13. Rating and ranking of HMA categories

Category	ODWC (%)	MSF (10^3N/mm)	Rank
1	8.3	3.60	**6th**
2	7.8	4.72	**5th**
3	8.0	4.79	**4th**
4	6.6	5.60	**1st**
5	7.2	5.40	**3rd**
6	6.4	5.50	**2nd**

IV. CONCLUSIONS

Angularity or shape of aggregate affects the asphalt cement required for coating. The more angular the aggregate, the more asphalt cement it requires. In terms of density, the less dense the aggregate, the higher the asphalt cement required. Although both density and angularity affect the amount of asphalt cement required, the angularity effect is more significant.

The stiffness of HMA improved with introduction of dehydroxylated kaolin (DWC). This increase is noticeable to an optimum value of DWC addition. On the determination of the optimum DWC(ODWC) content for the different HMA categories using simple regression or graphical analysis, 8.3%, 7.8%, 8%, 6.6%, 7.2% and 6.4% are obtained as the ODWCs' for HMA categories 1, 2, 3, 4, 5 and 6 in that order. For the various HMA categories, the maximum stiffness (MSF) recorded are; 3.6N/mm for category 1, 4.72N/mm for category 2, 4.79N/mm for category 3, 5.6N/mm for category 4, 5.4 N/mm for category 5 and 5.5N/mm for category 6. This indicates that HMA category 4 is the best category because it has the highest stiffness.

REFERENCES

[1]. EuLA, (2010). Hydrated Lime: A Proven Additive for Durable Asphalt Pavements. European Lime Association

[2]. Garba, R.I . H. (2002). Prediction of Rutting Resistance of Asphalt Mixtures . Materials Science DOI:10.1201/9781003078821-7.

[3]. Sharrour A. M. and Saloukeh G. B., (1992). Effect of quality and quantity of locally produced filler (passing sieve no. 200) on asphaltic mixtures in Dubai. Effect of aggregates and mineral fillers on asphalt mixtures performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing and Material, Philadelphia

[4]. Kim, Little and Song, (2003) "Mechanistic evaluation of mineral fillers on fatigue resistance and fundamental material characteristics," TRB Annual Meeting, Paper no. 03-3454

[5]. Ahmed H. Y. and Othman, (2006). "Effect of using waste cement dust as mineral filler on the mechanical properties of hot mix asphalt," Assoc. Univ. Bull Environ Res, vol. 9, no. 1, pp. 51-59.

[6]. Asi I. and Assaad, A. (2005). "Effect of Jordanian oil shale fly ash on asphalt mixes," J. Mater. Civ. Eng., vol. 17, no. 5, pp. 553–559.

[7]. Sudhakaran S. T., Chandran R. S. and Satyakumar, M. (2011). "Study on structural characteristics of bituminous mix with added hydrated lime and phosphogvypsum," International Journal of Emerging trends and Engineering and Development, vol. 2, no.4, pp. 73-83.

[8]. Muniandy R. and E. Aburkaba, (2011). "The effect of type and particle size of industrial wastes filler on Indirect Tensile Stiffness and Fatigue performance of Stone Mastic Asphalt Mixtures," Australian Journal of Basic and Applied Sciences, vol. 5, no. 11, pp. 297-308.

[9]. Bahia H. U., H. Zhai, K. Bonnetti and S. Kose, (1999). "Non-linear viscoelastic and fatigue properties of asphalt binders," J. Asso. Asphalt Paving Technol., vol. 68, pp. 1–34

[10]. Wu S., J. Zhu, J. Zhong and D. Wang, (2011) "Experimental investigation on related properties of asphalt mastic containing recycled brick powder," Constr. Build. Mater., vol. 25, no. 6, pp. 2883–2887

[11]. Kumar P., H. C. Mehndiratta, and V. Singh, (2008). "Use of fly ash in bituminous layer of pavement," Indian Highways, New Delhi, India, pp. 41–50.

[12]. Hassan H. J., and Israa Y. J. (2010). The Effect of Using Glass Powder Filler on Hot Asphalt Concrete Mixtures Properties. Eng. & Tech. Journal ,Vol.29, No.1.

[13]. Sert T. K. andKutuk S. (2013). Physical and Marshall Properties of Borogypsum Used as Filler Aggregate in Asphalt Concrete. Journal of Materials in Civil Engineering 25(2):266-273. 10.1061/(ASCE)MT.1943-5533.0000580

[14]. Kar D., M. Panda, and J. P. Giri, (2014). "Influence of fly ash as a filler in bituminous mixes," Journal of Engineering and Applied Science, vol. 9, no. 6, pp. 895–900.

[15]. Murana A. A. and Sani l. (2015) Partial Replacement of Cement With Bagasse Ash In Hot Mix Asphalt Asphalt. Nigerian Journal of Technology (NIJOTECH) Vol. 34 No. 4, pp.699 – 704

[16]. Joni H. H and Zghair H. H. (2016). Effect of Adding Used-Foundry Sand on Hot Asphalt Mixtures Performance. Eng. &Tech.Journal, Vol.34,Part (A), No.6

[17]. Wasilewska, M., Małaszkiewicz, D. and Ignatiuk, N. (2017), October, Evaluation of Different Mineral Filler Aggregates for Asphalt Mixtures, IOP Conference Series: Materials Science and Engineering, Vol. 245, No. 2, p. 022042, IOP Publishing.