Characterisation of Saw Dust Ash – Quarry Dust Bituminous Concrete

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ABSTRACT

This study evaluates usefulness of Quarry Dust and Saw Dust Ashas mineral fillers in a bituminous concrete in order to reduce cost and encourage reuse of waste materials in the environment. Bituminous concrete blends were generated with 4% Quarry Dust and 4% Saw Dust Ash replacements of aggregates. The binder contents were 3, 3.5, 4, 4.5 and 5% for a 60/70 penetration grade bituminous binder. Briquette specimens were formed using the five different bituminous concrete blends. Standard laboratory experiments were conducted on the aggregates, Quarry Dust, Saw Dust Ash, bituminous binder and bituminous concrete specimens based on the relevant codes and standards. The Marshall method was used for the bituminous concrete design procedure. The optimum binder content was found to be 4.88% using the standard Marshall curves. At optimum binder content, using 4% design air void for medium traffic and maximum aggregate of 10mm, the Stability, Flow, VMA and VFA were 8.15kN, 8.28(0.25mm), 15.22% and 74.2% respectively. These were found to have passed the Asphalt Institute design criteria.

Keywords– Bituminous Concrete, Saw Dust Ash, Quarry Dust, Waste Materials

I. INTRODUCTION

The main ingredients of bituminous concrete are aggregates and bituminous binder. The aggregates consist mainly of fine and coarse sizes. In peculiar instances, additives such as mineral fillers, Polymer Modified Asphalt (PMA), or extenders could also be added to the bituminous blend. Mineral fillers are materials passing the 75μm sieve which can increase stability, fill the voids in the mix, improve the bond between the binder and the aggregates, as well as reduce the binder content[1]. An overall cost reduction could take place as a result of reduction in binder content. However, [2] argues that too much of filler may reduce the strength of the asphalt concrete mix by increasing the quantity of asphalt required to coat the aggregates. In early practices, Carbonate of Lime was the only mineral filler utilised. Later on, Silica was introduced. There are currently several other mineral fillers such as Portland cement, carbon black, crushed fines (Quarry Dust), and fly ash also used with bituminous concrete.

Several attempts have been made by researchers to utilise industrial waste materials as mineral fillers in bituminous concrete. Most of such attempts have resulted in reduction in cost or reduction in the amount of waste materials in the environment. In some cases, the reduction in cost and environmental waste may take place but the waste material in question be compatible with other ingredients in the bituminous concrete blend. In other cases, the waste materials may render the stability compromised. However, reducing both the cost and waste materials in the environment at the same time using both conventional and non-conventional mineral fillers to satisfy the above research problem is key. In this study, Quarry Dust (QD), being a conventional mineral filler and Saw Dust Ash (SDA), being a non-conventional mineral filler were introduced as additives in the bituminous concrete blends.

II. LITERATURE REVIEW

Asphalt concrete mixtures have different performance characteristics in terms of tire wearing, roadway noise, brake efficiency and durability. When used for road construction, the characteristics of such concrete to possess the ability to resist skid in a wet state, and resist deformation due to traffic loads depends greatly on the mix design [3].

A. Saw Dust Ash and Quarry Dust as Mineral Fillers
Saw Dust Ash

Saw Dust Ash (SDA) is a burnt form of wood that resulted from saw mill, which is supposed to be a waste material. Several studies[4]–[8] have been conducted with the use of SDA in concrete, some of which were on bituminous concrete. In a study by [8], sawdust concrete with a binder such as bitumen to sawdust ratio of 1:1 resulted in an excellent bond strength and was found to be comparable with a conventional concrete. However, the drying shrinkage was found to be very high at almost 10 times as great as in most other lightweight concretes, which greatly limits its usefulness. In spite of the limitations, sawdust-bituminous concrete has a good resiliency, insulation value, and low thermal conductivity.

It has been proven by various studies [4], [6], [7] that CaO is the most dominant compound in SDA. Results from [7]also indicate that high amounts of CaO, SO_3 and loss on ignition (LOI) in concrete reduces pavement ravelling, improves the rutting resistance at high temperature, improves aging resistance, improves bond strength, reduces stripping to moisture attack, and improves resistance of the pavement to deformation due to dynamic shear loading. Results from[6] indicate a 9.04% SO_3,7.3% LOI and49% CaO content in SDA, which also establish and confirm the high dominance of SO_3,LOI and CaO, signifying the excellent bonding capability of SDA.[6]also found that SDA increased the stability of the bituminous concrete.

Quarry Dust

Quarry Dust (QD) is a by-product of the crushed aggregates in a rock quarry, resulting in fines. The dust generated in the quarrying process is known as QD. This material with particle sizes between 0 and 4.75mmis considered a waste material. It is however used in road construction as a surface finishing material in the form of a filler in the bituminous concrete blend. It is cheap, and can also be used for moulding of hollow or solid blocks. A study[9]proved that, between 20% and 40% of sand replacement with QD, there was a significant increase in compressive strength of concrete at the 7 and 28 days curing periods. This had a direct positive environmental effect, as it reduced the quantity of sand to be mined. However, [10]posits that fillers from SDA have higher air voids of about 60 to 70% than the fillers from QD which are about 30 to 40%. In another study [11]QD was used to replace 9%, 11%, 13%, 15%, 17%, 19%, 21%, 23% and 25% of asphalt binder by weight. It was found that, at an optimum binder content of 5%, the 21% bitumen replacement with QD resulted in a maximum stability.

III. MATERIALS AND METHODS

Bituminous binder, sand, granite, SDA and QD were the ingredients used to produce the bituminous concrete. The bituminous binder contents were3%, 3.5%, 4%, 4.5% and 5% of the total weight of the specimens. The binder was a 60/70 penetration grade, obtained from Port Harcourt refinery. The sand was obtained from a nearby sand vendor who mines sand from a salt water river in Port Harcourt. The granite and QD were obtained from a nearby vendor who supplies crushed stone materials from Akamkpa quarry in Cross river state. The granite is 10mm in size. The saw dust was obtained free of charge from Iluabuchi saw mill in Port Harcourt and burnt to ashes in the laboratory. All experiments were carried out in the Civil engineering laboratory of the Rivers State University, Port Harcourt. Standard experiments in line with relevant codes were conducted in two parts: part 1 was for each of the ingredients (bituminous binder, sand, granite, SDA and QD); while part 2 was for the bituminous concrete specimen. Two replicates were made for the bituminous compacted specimen with cylindrical diameter of 10.16cm and height of 6.35cm, using 3% binder content, after which the part 2 experimental procedure was carried out. The procedure was repeated for 3.5%, 4%, 4.5% and 5% binder contents.

Mix Design

The mix proportions for the ingredients of the bituminous concrete are shown in table 1. [1] described three methods of bituminous concrete mix design being the Marshall method (ASTM D 1559), Hveem method (ASTM D1560), and Super pave method[12]. The Marshall method of bituminous concrete mix design was adopted in this study. It has the following steps[1], [13]:

- Aggregate evaluation
- Asphalt cement evaluation
- Specimen preparation
- Marshall Stability and flow measurement
- Density and voids analysis
- Design asphalt content determination

Table 1: Mix Proportions for Bituminous Concrete Ingredients

Description	Binder	Fine	Coarse	SDA Filler	QD filler
% aggregate		40	52	4	4
% weight of compacted specimen	3			97	
	3.5			96.5	
	4			96	
	4.5			95.5	
	5			95	

The volume of specimen was determined by eq. 1 below:

$$V_m = \pi d^2 h / 4 \qquad (1)$$

While the volume of each constituent material is given by

$$V_i = m_i / S.G_i \qquad (2)$$

$$V_m = \sum V_i \qquad (3)$$

The voids were determined using eq. 4 to eq. 6.

$$VTM = \frac{V_v}{V_m} X100 \qquad (4)$$

$$VMA = \frac{V_v + V_{be}}{V_m} X100 \qquad (5)$$

$$VFA = \frac{V_{be}}{V_{be} + V_v} X100 \qquad (6)$$

or $\quad VFA = \frac{V_{be}}{V_{be} + V_v} X100 \qquad (7)$

Where,

The diameter of the compacted bituminous concrete specimen and its height are d and h respectively, while π is a constant equivalent to 22/7. VTM, VMA and VFA are voids in total mixture, voids in the mineral aggregates and voids filled with asphalt respectively. V_i, m_i and $S.G_i$ are the volume, mass and specific gravity of each ingredient respectively. Similarly, V_m, V_v and V_{be} are volumes of total mixture, air voids and effective asphalt binder respectively.

IV. RESULTS AND DISCUSSIONS

The results of the experiments conducted on each ingredient and on the bituminous concrete are shown in tables 2 to 5.

Table 2: Physical Properties of Bitumen

Test	Unit	Test Methods	60/70 Grade	Result (60/70)
Penetration, 100gm, 25°C	0.1mm	ASTM D946	60 – 70	67.7
Ductility, 5cm/min, 25°C	cm	ASTM D 113	> 100	105
Specific Gravity at 25°C	-	ASTM D70	1.01 – 1.05	1.02
Softening point test	°C	ASTM D3461	47-54	49.5
Dynamic Viscosity test	Sec	ASTM D4402	< 100	69.5

As shown in table 2, the results of all the properties investigated satisfy the respective standard testing methods.

Table 3: Physical Properties of Fillers

Sieve sizes (µm)	QD	SDA	AASHTO M17
No.52 (300µm)	100	100	100
No.100 (150µm)	100	100	95 – 100
No.200 (75µm)	86.86	81.67	70 – 100
Plasticity Index	-	1.13	≤4
Specific Gravity	2.64	2.06	-

The properties in table 3 satisfy the requirements by AASHTO M17 for filler materials, hence both QD and SDA are suitable filler materials.

Table 4: Physical Properties of Aggregates

Type of Aggregate	Specific Gravity	Aggregate gradation		
		Fineness Modulus	Coefficient of Uniformity	Coefficient of Curvature
Course (10mm)	2.68	3.37	1.48	0.93
Fine aggregate	2.67	2.64	2.52	0.92

Table 4 shows the physical properties of the aggregates in accordance with [14].The uniformity coefficient indicates a uniformly graded aggregate for both the fine and coarse aggregates [15]. The fineness modulus for the fine aggregate is between 2.3 and 3.1, hence it is a suitable fine aggregate [1]. This is also the case for the coarse aggregate as it is greater than 3.1.
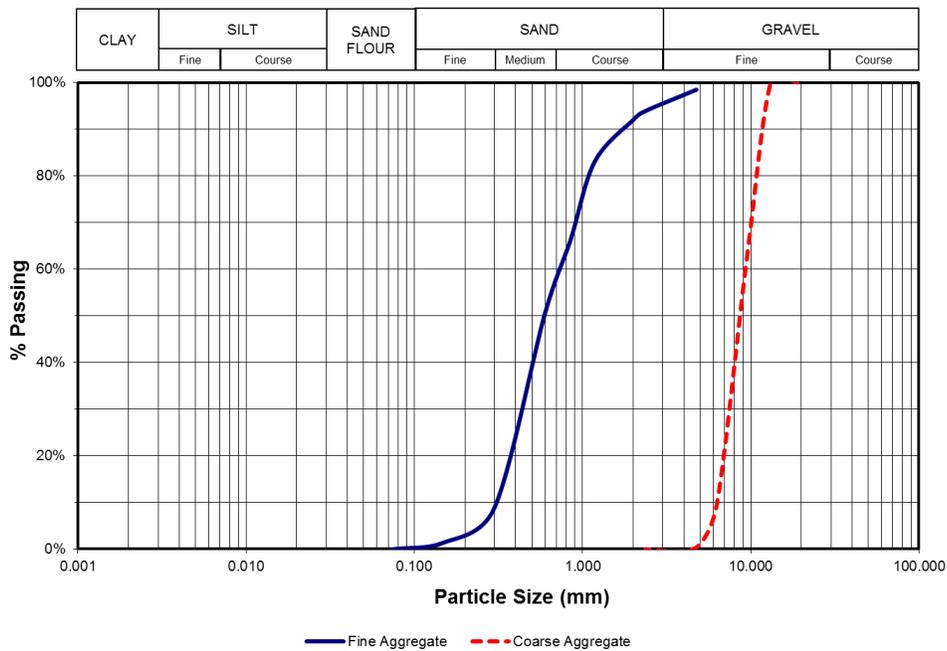
Figure 1: Particle Size Distribution of Aggregates

Figure 1 is the Particle Size Distribution (PSD) for the fine and coarse aggregates determined from the sieve analysis in accordance with ASTM C136.

Table 5: Physical Properties of compacted specimen

P_b(%)	3	3.5	4	4.5	5
Bulk Density G_{mb} (g/cm^3)	2.183	2.237	2.266	2.293	2.380

Table 5 shows the bulk density of the compacted Asphalt specimen with different binder contents. Table 6shows the results for the voids in the specimen with 3% binder content.

Table 6: Results of voids for 3% P_b

Description	Binder	Absorbed binder	Effective binder	Fine	Coarse	SDA	QD	Void
% aggregate				40	52	4	4	0
% weight of compacted specimen	3	0			97			
Bulk density of compacted specimen (g/cm^3)				2.183				
Volume of compacted specimen (cm^3)				514.815				
Total weight (g)	33.708	0.000			1089.889			
Weight of ingredient (g)	33.708	0.000		435.956	566.742	43.596	43.596	0

Specific gravity	1.02	0		2.67	2.68	2.06	2.64	
Volume (cm³)	33.127	0.000	33.127	163.224	211.585	21.175	16.491	69.215
VTM (%)				13.44				
VMA (%)				19.88				
VFA (%)				32.37				

The results in table 6 were based on the results from tables 2 to 5 coupled with eqs. (1) to (7). The same procedure from table 6 was repeated for 3.5%, 4%, 4.5% and 5% binder contents and the summary of the results given in table 7 below. Experimental results from the stability, flow and bulk specific gravity were also included in table 7.

Table 7: Marshall Mix Design Results

P_b(%)	G_{mb}(g/cm³)	VTM (%)	VMA (%)	VFA (%)	STABILITY (kN)	FLOW (0.25mm)
3	2.183	13.44	19.88	32.37	7.49	10.26
3.5	2.237	10.61	18.30	42.04	8.83	9.54
4	2.266	8.75	17.66	50.45	9.675	9.16
4.5	2.293	6.97	17.11	59.27	10.445	8.62
5	2.380	2.73	14.43	81.05	7.075	8.14

The usual six graphs were plotted as shown in figure 2 and the optimum binder content determined to be 4.88% using 4% design air void for medium traffic. The maximum aggregate is 10mm, but according to [13] the nearest to this value is 9.5mm.
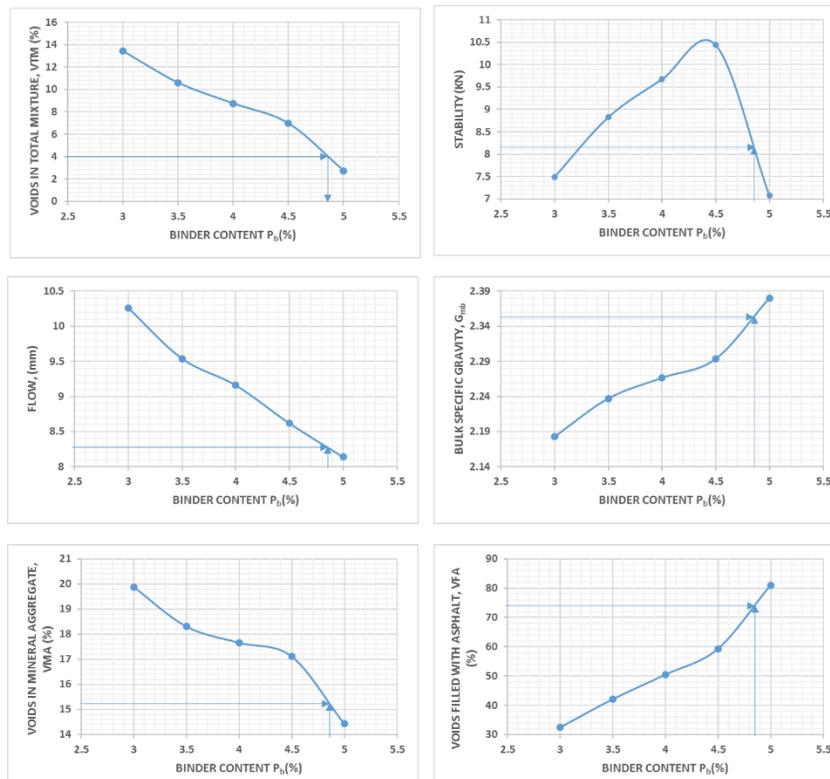
Figure2: Marshall Mix Design Graphs

Table 8 shows the design performance based on Asphalt Institute design criteria as outlined in [13]. The optimum binder content also falls within the acceptable range of binder content as specified by [13].

Table 8: Design performance based on Asphalt Institute criteria

	P_{opt}(%)	Stability (kN)	Flow (0.25mm)	Bulk Specific gravity (g/cm^3)	V.M.A (%)	V.F.A (%)
Graph	4.88	8.15	8.28	2.352	15.22	74.2
Design criteria		5.34 (min)	8 to 16	N/A	15 (min)	65 to 78
Remark	Passed	Passed	Passed	N/A	Passed	Passed

V.   CONCLUSION

The quantities of the conventional aggregates were reduced by 4% QD and 4% SDA for 60/70 penetration grade binder contents of 3, 3.5, 4, 4.5 and 5% by total weight of specimen. This indicates that the cost of aggregate will be reduced. It also indicates that a considerable amount of waste will be reused productively. From the experimental results on the ingredients and on the asphalt concrete specimen with an optimum binder content of 4.88%, the study indicated that QD and SDA are suitable mineral fillers in accordance with AASHTO M17, and that the physical properties of the bituminous concrete were within the Asphalt institute design criteria. SDA can be used in similar research for construction purposes with 4% replacement as well as other percentages. Other filler materials can also be combined with SDA in further studies to expand the knowledge area and close up the research gaps that may arise from this study.

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