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Suitability of Saw Dust Ash and Quarry Dust as Mineral fillers in Asphalt Concrete

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ABSTRACT

This study attempts to justify how suitable a conventional mineral filler and a non-conventional mineral filler can replace fractions of the aggregates in an asphalt concrete in order to reduce cost and encourage reuse of waste materials. Asphalt concrete mix proportions were generated with 3% Quarry Dust and 3% Saw Dust Ash replacements of aggregates. The binder contents were 3, 4, 5, 6 and 7% for a 60/70 penetration grade asphalt binder. Briquette specimens were formed using the asphalt concrete mix proportions carried out. Standard laboratory experiments were carried out on the aggregates, Quarry Dust, Saw Dust Ash, bituminous binder and asphalt concrete specimens based on the relevant codes and standards. The Marshall method was used for the asphalt concrete design procedure. The optimum binder content was found to be 4.85% 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 5.83kN, 15.73(0.25mm), 15.28% and 73.25% respectively. These were within the Asphalt Institute design criteria

Keywords-- Asphalt Concrete, Filler, Quarry Dust, Saw Dust Ash

I. INTRODUCTION

Asphalt or Bituminous concrete consists mainly of aggregates and bituminous binder. The aggregates may be of fine and coarse grains. In some cases, additives such as mineral fillers, Polymer Modified Asphalt (PMA), or extenders could also be added to the asphalt mix. According to [1] mineral fillers are materials passing the 75µm sieve and could be used to increase stability, improve the bond between the binder and the aggregates, fill the voids in the mix, and reduce the binder content. The reduction in binder content could result in an overall reduction in cost. However, too much of filler may weaken the asphalt concrete mix by increasing the amount of bitumen required to coat the aggregates [2]. Carbonate of Lime was the only mineral filler used in earlier practices. Later on, Silica was introduced. Currently, several other mineral fillers such as Portland cement, crushed fines (Quarry Dust), carbon black and fly ash have also been used with asphalt concrete.

Several researchers have made attempts to use industrial waste materials as fillers. These attempts have in one way or the other, reduced cost or reduced the amount of such wastes in the environment. In some cases, such waste materials may be good at reducing cost or waste, but not compatible with other constituent materials in the mix. In other cases, the waste materials may reduce the stability to an unacceptable limit. However, there is need to reduce both cost and waste at the same time using both a conventional filler and a non-conventional filler to satisfy the above research concerns. In this study, Quarry Dust (QD), a conventional mineral filler and Saw Dust Ash (SDA), a non-conventional filler have been adopted as the additives in asphalt concrete mixes.

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 pulverised form of saw dust from wood saw mill. Several authors [4]–[8] have carried out research with the use of SDA in concrete, especially asphalt concrete. A study by [8] found that sawdust concrete with a binder such as asphalt to sawdust ratio of 1:1 has good bond strength and comparable to a conventional concrete. The drying shrinkage, however, is very high at almost 10 times as great as in most other lightweight concretes, which greatly limits its usefulness. In spite of the limitations, asphalt concrete with sawdust has a good insulation value, resiliency, and low thermal conductivity. It has been established 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,

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SO_3 and loss on ignition (LOI) in the concrete minimises pavement ravelling, improves the rutting resistance at high temperature, improves bond strength, improves aging resistance, minimises stripping to moisture attack, and improves resistance of the pavement to deformation due to dynamic shear loading. A study by [6] indicates a 49% CaO, 7.3% LOI and 9.04% SO_3 content in SDA, which also affirms the high dominance of CaO, LOI and SO_3, signifying that SDA has an excellent bonding capability. They also found that SDA enhanced the stability of the asphalt concrete.

Quarry Dust

Quarry Dust (QD) is a by-product of the crushed aggregates which results in fines. The dust generated after the quarrying activity of crushed rocks into different grain sizes is called QD. This material is considered a waste material having particle sizes between 0 and 4.75mm. It is used in road construction as a surface finishing material in the form of a filler in the asphalt mix. It is cheap, and can also be used for moulding of hollow blocks. A study by [9] showed that, between 20% and 40% of sand replacement with QD, there was an increase in compressive strength of concrete at the 7 and 28 days curing periods. This had a direct positive effect on the environment, as it reduced the amount of sand to be dredged. However, a study by [10] reveals that fillers from SDA have higher air voids (60 to 70%) than the fillers from QD (30 to 40%). In a study by [11] QD was used to replace 9%, 11%, 13%, 13%, 15%, 17%, 19%, 21%, 23% and 25% of bituminous binder by weight. It was found that the 21% bitumen replacement with QD resulted in a maximum stability at optimum binder content of 5%.

III. MATERIALS AND METHODS

Asphalt binder, sand, granite, SDA and QD were the materials used to produce the asphalt concrete. The asphalt binder contents were 3%, 4%, 5%, 6% and 7% 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 dredges from a salt water river. 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 laboratory of the Rivers State University, Port Harcourt. Standard experiments in line with relevant codes were carried out in two parts: part 1 was for each of the constituent materials (asphalt binder, sand, granite, SDA and QD); while part 2 was for the asphalt concrete specimen. Two replicates were made for the 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 4%, 5%, 6% and 7% binder contents.

A. Mix Design

The mix proportions for the constituent materials of the asphalt concrete are shown in table 1. [1] described three methods of asphalt concrete mix design being the Marshall method (ASTM D 1559), Hveem method (ASTM D 1560), and Superpave method [12]. The Marshall method was adopted in this study. It consists of 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 Asphalt Concrete Ingredients

Description	Binder	Fine	Coarse	SDA Filler	QD filler
% aggregate		41	53	3	3
% weight of compacted specimen	3			97	
	4			96	
	5			95	
	6			94	
	7			93	

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

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

While the volume of each constituent material is given by

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

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

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

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

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

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

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

Where,

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

IV. RESULTS AND DISCUSSIONS

The results of the experiments [14] carried out on each of the constituent materials and on the asphalt concrete are shown in tables 2 to 5 and figure 1.

Table 2: Physical Properties of Bitumen

Test	Unit	Test Methods	60/70 Grade	Result (60/70)
Penetration, 100gm, 25˚C	0.1mm	ASTM D 946	60 – 70	67.7
Ductility, 5cm/min, 25˚C	cm	ASTM D 113	> 100	105
Specific Gravity at 25˚C	-	ASTM D 70	1.01 – 1.05	1.02
Softening point test	˚C	ASTM D 3461	47-54	49.5
Dynamic Viscosity test	Sec	ASTM D 4402	< 100	69.5

As shown in table 2, the results of each of 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 basic 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

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Table 4 shows the physical properties of the aggregates carried out in accordance with [15]. The uniformity coefficient indicates a uniformly graded aggregate for both the fine and coarse aggregates [16]. 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.

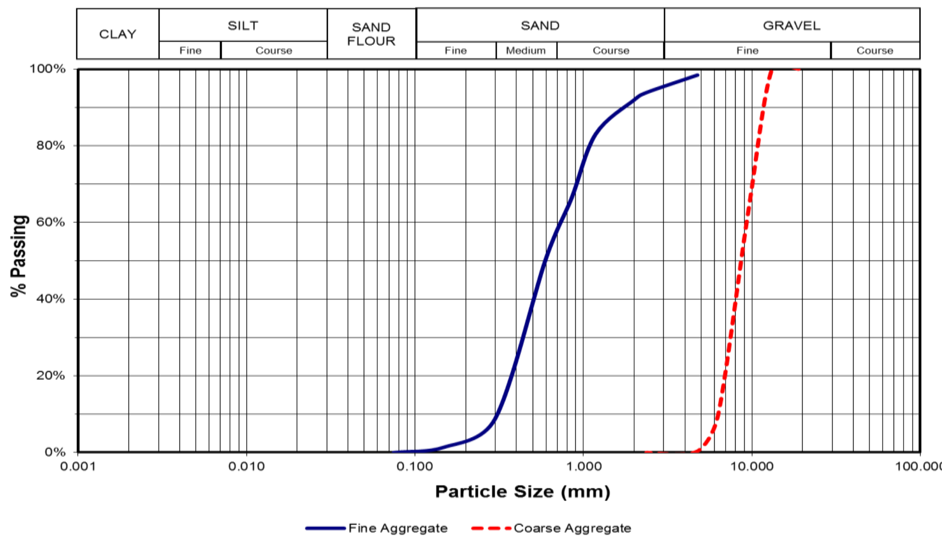

Figure 1: Particle Size Distribution of Aggregates

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	4	5	6	7
Bulk Density G_{mb} (g/cm^3)	2.313	2.337	2.363	2.370	2.376

Table 5 shows the bulk density of the compacted Asphalt specimen with different binder contents ranging from 3 to 7%. Table 6 shows 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	3	0		41	53	3	3	0
Percentage weight of compacted specimen (%)					97			
Bulk density of compacted specimen (g/cm^3)				2.313				
Volume of compacted specimen (cm^3)				514.815				
Total weight (g)	35.722	0.000			1155.016			
Weight of ingredient (g)	35.722	0.000		473.557	612.159	34.650	34.650	0
Specific gravity	1.02	0		2.67	2.68	2.06	2.64	
Volume (cm^3)	35.106	0.000	35.106	177.302	228.540	16.830	13.107	43.930
VTM (%)				8.53				
VMA (%)				15.35				
VFA (%)				44.42				

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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 4%, 5%, 6% and 7% binder contents and the summary of the results shown in table 7 below. Experimental results from the stability, flow and bulk specific gravity were also shown in table 7.

Table 7: Marshall Mix Design Results

P_b (%)	G_{mb} (g/cm^3)	VTM (%)	VMA (%)	VFA (%)	STABILITY (kN)	FLOW (0.25mm)
3	2.313	8.53	15.35	44.42	5.34	12.53
4	2.337	6.18	15.37	59.77	6.00	14.99
5	2.363	3.70	15.31	75.84	5.81	15.96
6	2.370	1.96	15.94	87.71	5.33	17.19
7	2.376	0.30	16.64	98.21	2.67	21.64

The usual six graphs were plotted as shown in fig. 2 and the optimum binder content determined to be 4.85% 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.

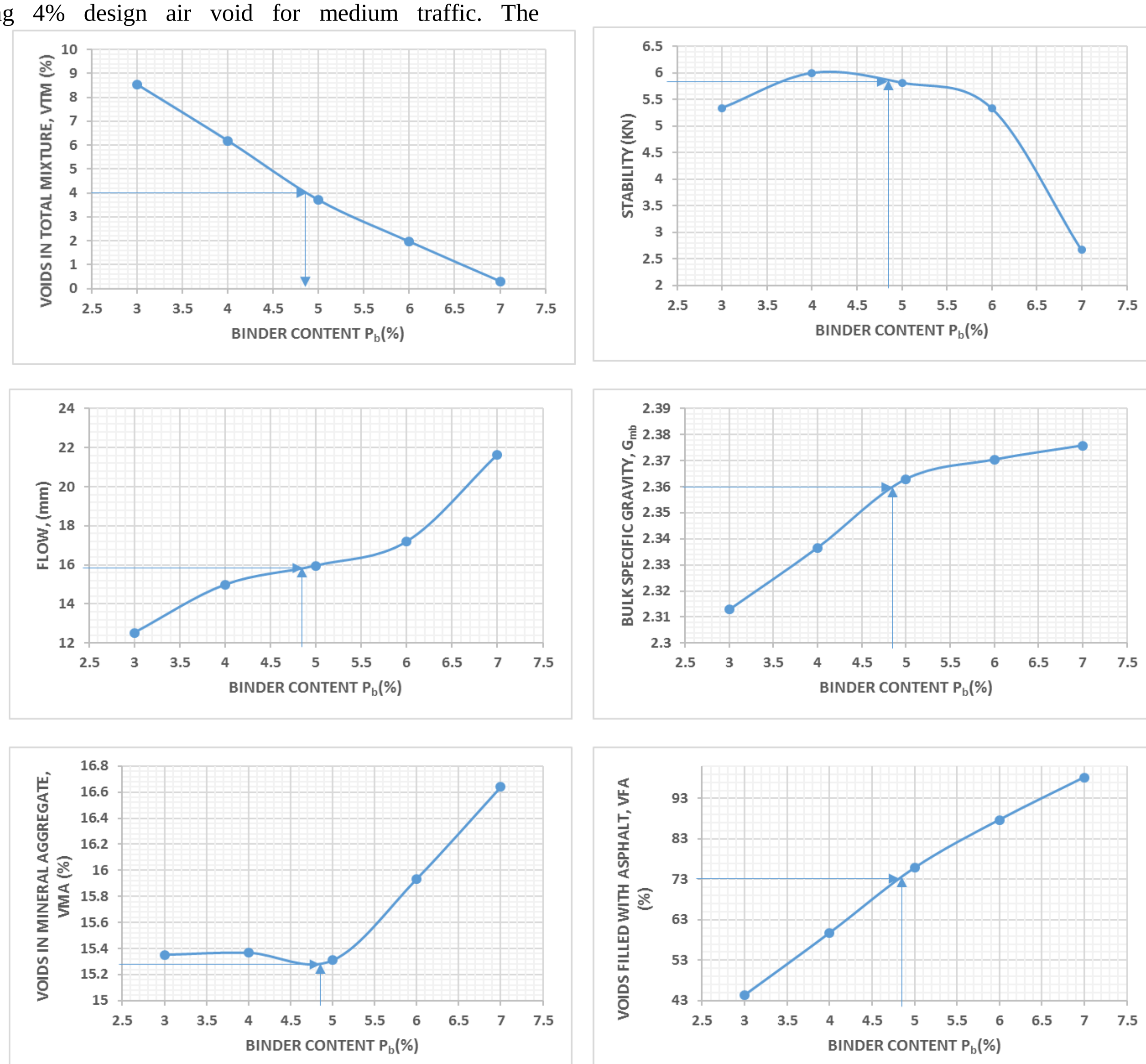

Figure 2: Marshall Mix Design Graphs

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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	4.85	5.83	15.73	2.36	15.28	73.25
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 3% QD and 3% SDA for 60/70 penetration grade binder contents of 3, 4, 5, 6 and 7% by total weight of specimen. This indicates a reduction in the cost of aggregates. It also indicates that a considerable amount of waste will be reused productively, thereby promoting environmental sustainability. From the experimental results on the constituent materials and on the asphalt concrete specimen with an optimum binder content of 4.85%, the study indicated that QD and SDA are suitable mineral fillers in accordance with AASHTO M17, and that the physical properties of the asphalt concrete were within the Asphalt institute design criteria. SDA can be used in similar research for construction purposes with 3% replacement as well as other percentages. Other filler materials can also be combined with SDA in further similar studies to expand the knowledge area and close up the gaps that may emanate from this study.

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