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Influence of Oyster Shell Ash Filler on the Marshall Properties of Asphalt Concrete

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Abstract **Original Research Article**

Roads are vital for the movement of people and goods, and their durability and mechanical properties depend on various factors, including the construction materials used. Marshall properties are crucial for analysis of asphaltic concrete designed for road construction, Also, filler materials improves the properties of asphaltic concrete. Therefore, this study investigated the influence of oyster shell ash (OSA) on the Marshall properties of hot mix asphalt concrete. The Marshall properties analyzed include stability, flow, void in mineral aggregate (VMA), void in the mixture (VIM), void filled with asphalt (VFA), and Marshall Quotient (MQ). The research revealed that the addition of oyster shell ash enhanced the stability and flow of asphaltic concrete. VMA and VFA increased with increase in OSA content, while increase in asphalt content resulted in a decrease in VIM and increase in VFA. The optimum performance of the Marshall's properties was recorded at 10% OSA and 5% asphalt content. The study also showed that the OSA-filled asphaltic concrete improved the performance of the OSA-filled asphalt concrete stability and stiffness compared to the sample without OSA. Moreover, OSA enhances the stiffness of the mixture, as reflected by the Marshall Quotient. Therefore, the findings highlighted the potential of oyster shell ash as a viable and sustainable filler material in asphaltic concrete.

Keywords: Asphalt, Oyster Shell Ash (Osa), Filler, Asphalt Concrete, Marshall Properties

1. INTRODUCTION

Roads are important assets movement of people and goods from one location to another. Nevertheless, its durability and mechanical properties depend on several factors including the construction materials used. For road pavements constructed using asphalt concrete, the performance will also depend on asphalt mixtures. Asphalt concrete is mainly a composition of asphalt (asphalt cement), aggregate materials and fillers. It is commonly used for construction of road pavement, or surfacing of car parks and dam embankments (AASHTO, 2000a). Asphalt concrete can be produced with different mixes such as hot mix asphalt, warm mix asphalt and cold mix asphalt. Typically, the aggregate constitutes 90–95% (w/w) of the total mixture, while the asphalt constituent ranged from 5 to 10% (w/w) of the total mixture *(AASHTO, 2001).*

Recent researches are focusing on blending asphalt concrete with environmental friendly materials, which may act as filler or aggregate replacement. Agricultural and industrial wastes have been shown to enhance the properties of asphaltic concrete (Yoon *et al.,* 2003). Oyster shell is a by-product of oyster fish, mostly found in salt water environment, and it constitutes approximately 90% of an entire oyster fish by mass (Wang *et al.,* 2013). In coastal regions of oyster producing countries, a great quantity of shells including oyster shell has been being disposed rather than being recycled (Yang *et al.*, 2010). Previous studies on the use of oyster shell waste have mainly focused on the replacement of fine aggregate by oyster shells for cement concrete production (Yang *et al.,* 2010; Lertwattanaruk *et al.,* 2012; Li *et al.,* 2015), which improved the compressive strength of concretes.

There are developments on new additives and fillers for improvement of asphalt concrete, with distinct properties. Marshall's properties are an important analysis for the determination and suitability of asphalt concrete in road construction. Therefore, this study investigated the various Marshall's properties of hot mix asphalt concrete filled with oyster shell ash (OSA).

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2. MATERIALS AND METHODS

The procedures used were in accordance to known Standards (AASHTO, 2000a,b, 2001, ASTM, 2015; BSI PD6691, 2015; BS EN 12697, 2020). The test specimens were mixed and compacted at the appropriate temperatures based on the viscosity of the asphalt, and at the specified number of blows.

2.1 Materials Preparation

2.1.1 Oyster Shell Ash Preparation

Oyster shell wastes were sourced from the banks of Onuzor Eddy River in Ezza South Local Government Area of Ebonyi State. Surfaces of the oyster shells were brushed and soaked in water for a week or more to remove salt and foreign substances. Washed oyster shells were naturally dried and then crushed using edge milling machines manufactured by Paschal Engineering Co., Ltd, Crawley, Sussex (Model Number: 22498). Crushed oyster shells were calcined in an electric furnace at 1000 °C for 3 h. Calcined oyster shells were slowly cooled down to room temperature in the electric furnace, and then pulverized to pass a 150-µm sieve. This experiment was conducted in Ceramic and Glass Laboratory, Akanu Ibiam Federal Polytechnic, Unwana, Ebonyi State. The sun drying and calcination process is shown in Plate 1.

(a) (b)

Plate 1: Sun drying (a) and calcination of dried oyster shells (b)

2.1.2 Aggregate Preparation

The procedures used for preparation of the fine and coarse aggregates followed the established standards specified for production asphalt concrete used in road pavement according to the referenced Standard Codes (AASHTO 2001; ASTM C127; ASTM C128). Four (4) bags of coarse and two (2) bags of fine aggregates were used in the study. The aggregates were oven dried and weighed. The coarse component was separated into four fractions (+10000 µm, -10000 to +5000 µm, - 5000 to +1250 µm, and -1250 µm) using a Gilson shaker sieving equipment. The material from each fraction was placed in large pans and the total weight recorded. An average split of each fraction was obtained and a washed sieve analysis performed. The gradation of the aggregate was calculated based on the total weight of the aggregate. 5000g of aggregate samples was used for the Marshall's test.

2.1.3 Asphalt Preparation

Asphalt is commonly used as binder in asphaltic concrete. The asphalt used in this study is grade PG/60-70, which was collected from a road construction company in the South-East of Nigeria. The asphalt was poured into a pan, heated and mixed for 1½ minutes using a mechanical mixer. The hot asphalt was mixed with the oyster shell ash at various design proportions to obtain the OSA-filled asphalt prior to mixing with aggregate.

The chemical composition of the oyster shell ash is presented in Table 1, while the chemical and physical properties of the asphalt (PG/60-70) is presented in Table 2.

Table 1: Chemical composition of Oyster Shell Ash

Chemical	**Composition (wt %)**
C (Carbon)	12.072
H (Hydrogen)	0.092
N (Nitrogen)	0.189
S (Sulphur)	0.000
O (Oxygen)	34.023
Cao (Calcium Oxide)	99.033
SO_3 (Sulphur Trioxide)	0.518
SrO (Strontium Oxide)	0.311
Fe_2O_3 (Ferric Oxide)	0.086
CuO (Cuprous Oxide)	0.030
MgO (Magnesium Oxide)	0.023

Table 2: Chemical and physical properties of Asphalt (PG/60-70)

Elemental Analysis	
C (Carbon)	84.62 (wt%)
H (Hydrogen)	10.39 (wt%)
N (Nitrogen)	0.65 (wt%)
S (Sulphur)	3.69 (wt%)
O (Oxygen)	0.65 (wt%)
SARA Generic Fractions	
Saturates	4.47 (wt%)
Aromatics	17.45 (wt%)
Resins	45.18 (wt%)
Asphaltenes	32.90 (wt%)
Physical Properties	
Penetration at 25 ºC	60.00 mm
Softening Point	50.00 ºC
Ductility at 25 ºC	110.50 cm

2.2 MIX PREPARATION

The mix followed standard procedures for asphalt pavement (Asphalt institute, 2003; BS EN 12697, 2020). The aggregate content was kept constant throughout the mix, while the percentage of asphalt and OSA contents in the mix were varied. The asphalt content was varied from 4%, 5% and 6%. For each mix with specified asphalt content, five samples were prepared to contain 0% to 20% of the OSA content. The OSA acts as filler in the OSA-filled asphalt concrete. The addition of different OSA content in the mix was to determine the optimum mix proportion and also to develop the mix design model.

The aggregate batches were placed in the oven at set temperature for a minimum of four (4) hours prior to forming the specimens. Pail of oyster ash-filled asphalt was placed in an oven maintained at the mixing temperature for one hour prior to mixing. This was mixed with the aggregate to form the asphalt concrete. All mixing equipment such as scoops, spatulas, and tamping rods were kept warm in a hot sand bath. The blending pan was kept on the hot plate continually throughout the test. The mix was transferred to a flat bottomed distribution pan, specifically designed to reduce segregation. The prepared hot OSA-filled asphalt concrete samples were poured into bread pans using a flat bottomed scoop. The bread pans were placed in an oven maintained at the compaction temperature of 60±3°C. Calibrated dial thermometer was inserted into the pan to ensure the temperature range was not exceeded. Once the mix reaches compaction temperature, it was poured into a heated round pot and stirred gently to ensure a homogenous mixture. The entire mix from the round pot was quickly dumped into the mould.

The mixture was vigorously spaded with a flexible heated spatula 15 times around the perimeter, while the surface of the mix was smoothened with a heated trowel to a slightly rounded shape, and placed in a disc. the required number of blows was applied with a heated compaction hammer. The collar and base plate were removed and the mould was reversed and reassembled. After compaction, the base plate, collar and cardboard discs were removed. The specimen was allowed to cool for safe handling, and then extruded using an extrusion jack and placed on a clean, flat surface. Loose materials on the specimens were cleaned. It should be noted that each batch was processed separately as described above. However, the batches were completed in succession. The experimental mix design program is presented in Table 3.

Table 3: Experimental mix design for the OSA filled asphalt

Percentage (%)		**Weight (g)**			
Asphalt	OSA	Asphalt	OSA	Aggregate	Total weight
4	0	50	0	1200	1250
4	5	52.75	65.93	1200	1318.68
4	10	55.81	139.54	1200	1395.35
4	15	59.26	222.22	1200	1481.48
4	20	63.16	315.79	1200	1578.95
5	0	63.16	0	1200	1263.16
5	5	66.67	66.67	1200	1333.34
5	10	70.59	141.18	1200	1411.77
5	15	75	225	1200	1500
5	20	80	320	1200	1600
6	0	76.6	0	1200	1276.6
6	5	80.9	67.42	1200	1348.32
6	10	85.71	142.86	1200	1428.57
6	15	91.14	227.85	1200	1518.99
6	20	97.3	324.32	1200	1621.62

2.3 Marshall Characteristics Test

The Marshal test was conducted in line with standard procedures (ASTM D1559) in the laboratory operated by a road construction company in Nigeria. Marshal properties investigated include stability, flow, void in mineral aggregate (VMA), void in the mixture (VIM), void filled with asphalt (VFA) and Marshall quotient (MQ). The Marshall test was conducted at temperature of 60 °C.

Plate 2: Equipment for Marshall's test

3. RESULTS AND DISCUSSION

The Marshal properties of the oyster shell ash-filled asphaltic concrete were performed at various percentages of OSA content (0 – 20%) and varying asphalt content (4 – 6%) at constant temperature of 64 ºC. The percentage of OSA was varied for every percentage of asphalt in the OSA-filled asphaltic concrete. The Marshal properties investigated include stability, flow, void in mineral aggregate (VMA), void in the mixture (VIM), void filled with asphalt (VFA) and Marshall quotient (MQ). The results of the Marshal properties are presented in Table 4.

Table 4: Marshall Properties of the OSA-Filled Asphaltic Concrete

Asphalt (%)	OSA (%)	Stability (kg)	Flow (mm)	VMA (%)	VIM (%)	VFA (%)	MQ (kg/mm)
4	0	535.42	2.86	12.92	4.16	65.24	187.21
	5	912.76	3.36	15.94	3.79	70.19	271.65
	10	1045.52	3.33	16.02	3.67	70.84	313.97
	15	926.7	3.27	16.17	3.49	70.77	283.39
	20	785.97	3.22	16.25	3.18	72.21	244.09
5	0	698.42	2.81	12.77	3.93	66.35	248.55
	5	991.09	3.29	15.66	3.62	70.69	301.24
	10	1195.59	3.21	15.87	3.57	71.63	372.46
	15	1104.94	3.14	15.96	3.35	71.97	351.89
	20	924.71	3.12	16.08	3.04	72.71	296.38
6	0	615.42	2.83	12.59	3.85	67.48	217.46
	5	954.29	3.32	15.54	3.51	70.95	287.44
	10	1115.23	3.28	15.78	3.44	71.92	340.01
	15	1014.32	3.22	15.83	3.26	72.13	315.01
	20	846.38	3.18	15.95	2.93	73.19	266.16
ASTM D6927-15		917.73(9.00kN) minimum	2 – 4	13.00 minimum	3–5	65 – 75	203.94 – 509.85 (2–5) kN/mm

NB: 101.97kg = 1kN

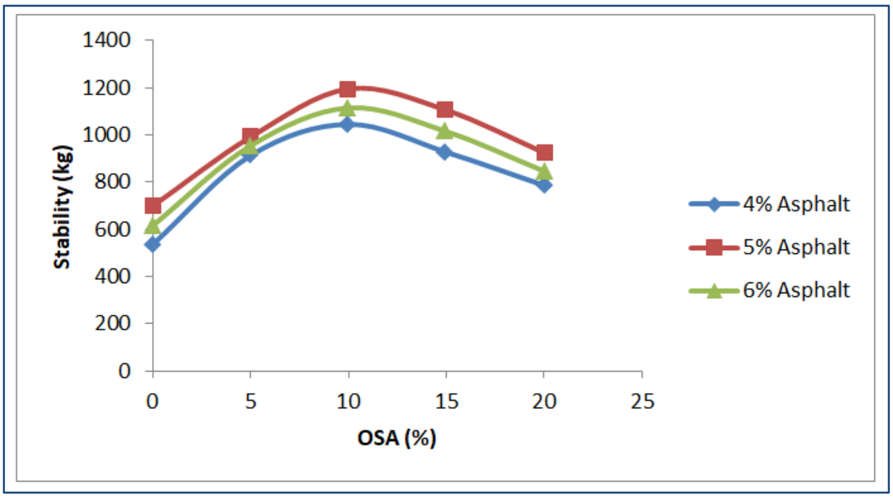

Figure 1: Effect of % OSA on stability of OSA-filled asphalt

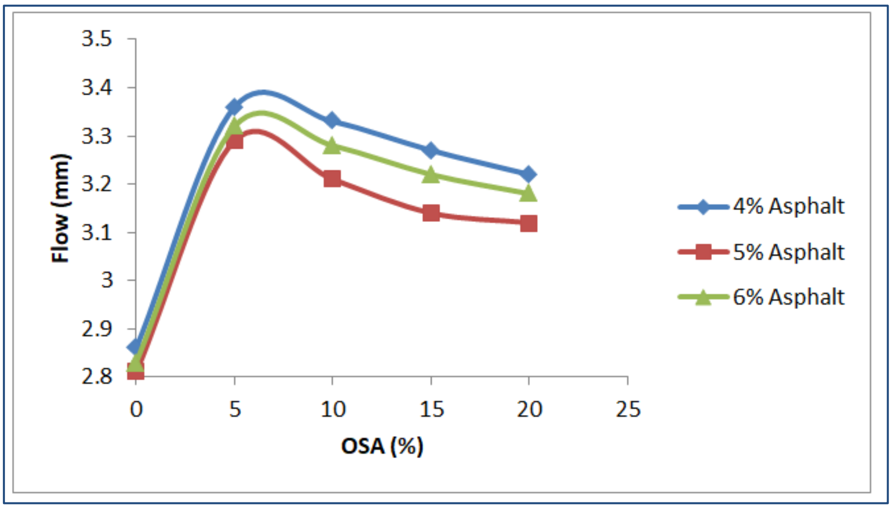

Figure 2: Effect of % OSA on flow of OSA-filled asphalt

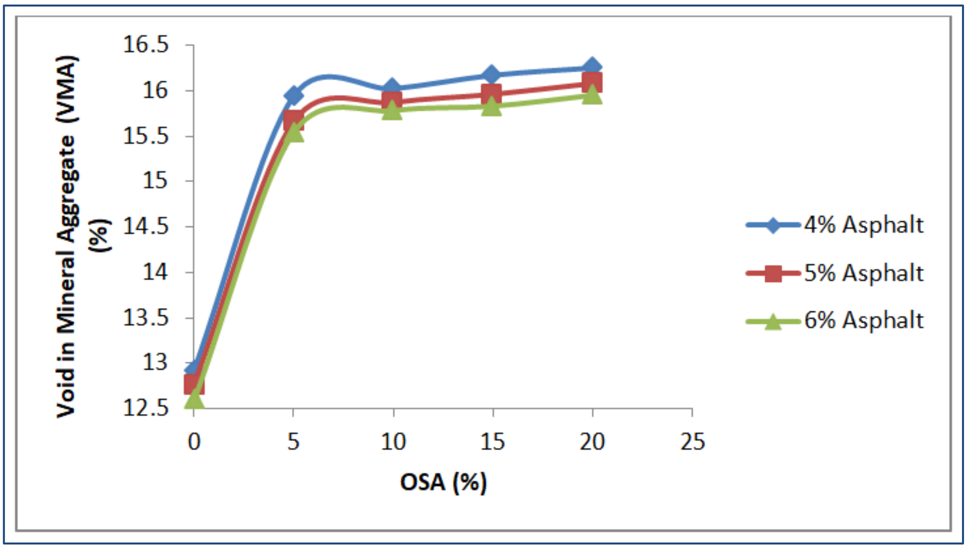

Figure 3: Effect of % OSA on VMA of OSA-filled asphalt

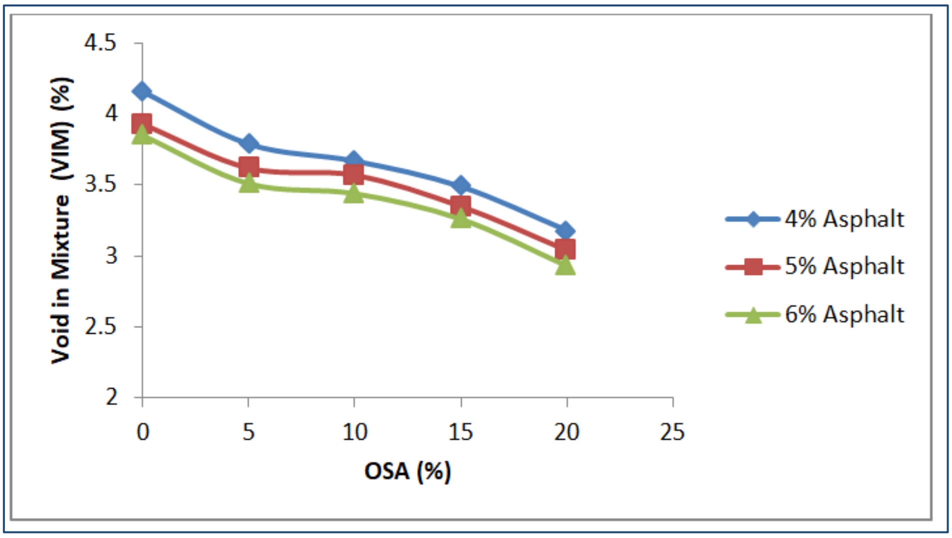

Figure 4: Effect of % OSA on VIM of OSA-filled asphalt

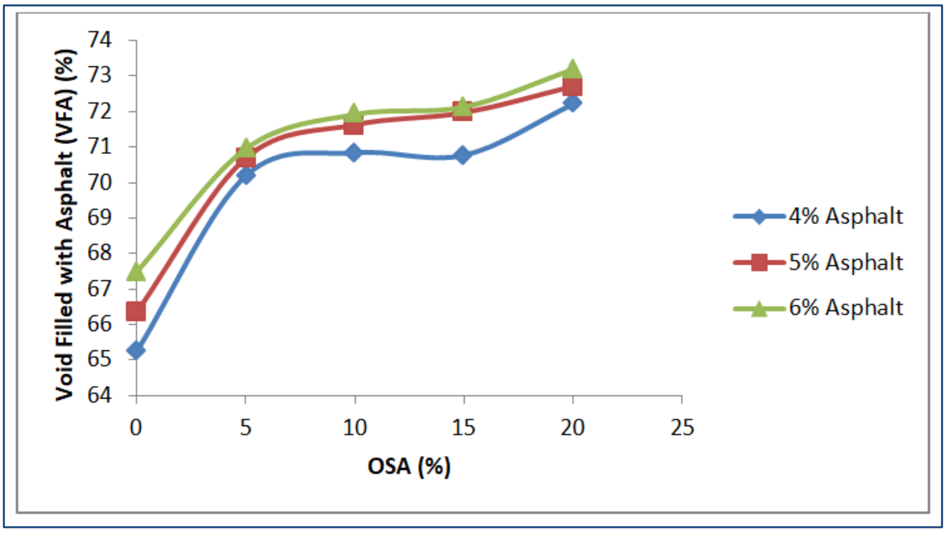

Figure 5: Effect of % OSA on VFA of OSA-filled asphalt

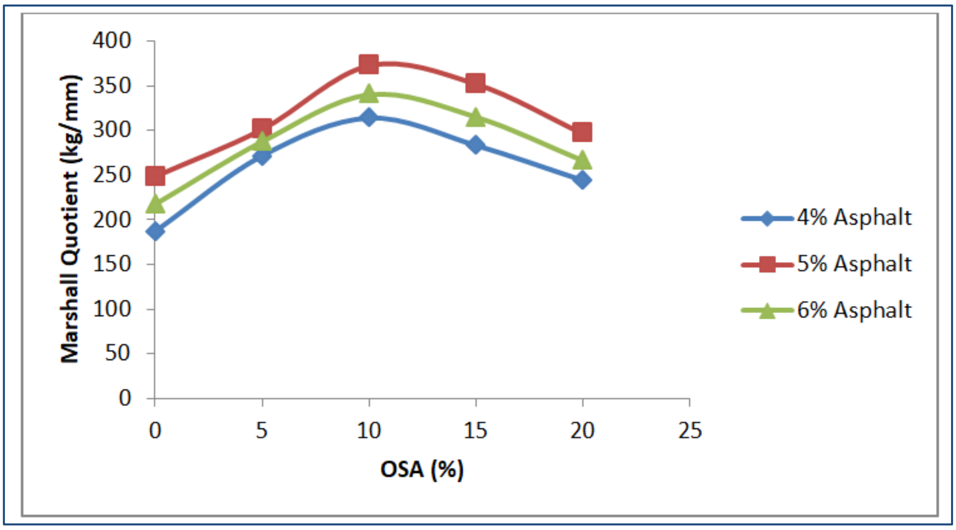

Figure 6: Effect of % OSA on Marshall Quotient of OSA-filled asphalt

Figure 1 shows the effect of OSA content on the stability of OSA-filled asphaltic concrete at different content of asphalt in the mixture. From the results presented in Table 4, the stability of the OSA-filled asphaltic concrete increased as the percentage of OSA increased from 0% to 10% OSA and then decreased gradually as the OSA content was increased further to 15% and 20% for a given content of asphalt in the mixture. On the other hand, the stability of the OSA-filled asphaltic concrete increased with increasing asphalt content from 4 to 5% and thereafter decreased as the percentage of the asphalt was increased to 6%. This implies that the optimum stability of the OSA-filled asphaltic concrete occurred in sample with 10% OSA at 5% of asphalt content (1195.59 kg or 11.72kN). Other studies have also shown that waste fillers such rice husk and fly ash equally increased Marshall stability of asphaltic concrete at controlled percentages (Mistry & Roy, 2020; Wang *et al.*, 2021; Caroles *et al.*, 2021), which is consistent with the results obtained in this study. This study further showed that the Marshal stability of the asphaltic concrete without filler (OSA) does not meet the ASTM D6927-15 minimum specified standard of 9.00kN (917.73kg) for road pavement (ASTM, 2015). Also, at 4% asphalt, only the sample with 10% and 15% met the standard requirement, while at 5% and 6% asphalt, all, except the sample with 20% OSA at 6% asphalt met the standard requirement.

Figure 2 shows the effect of OSA content on the flow of OSA-filled asphaltic concrete at different percentages of asphalt in the mixture. From the results presented in Table 4, the flow of the OSA-filled asphaltic concrete increased suddenly as 5% OSA was added in the mix, but from 5% to 20%, the flow decreased gradually for every percent of asphalt. There is slight decrease in the flow from 2.86 mm to 2.83 mm for the control sample when the asphalt was increased from 4% to 6%, which is consistent with the findings of Wang *et al.*, (2021). The flow obtained in this study is within the limit specified by standard (ASTM, 2015). Also, the Marshall flow recoded falls in range reported in previous studies (Wang *et al.*, 2019; Mistry & Roy, 2020; Caroles *et al.*, 2021), but it is below the values recorded in other studies (Siswanto *et al.*, 2017; Zakaria *et al.*, 2018). According a study, increasing asphalt content in the mixture can improve the flow of the pavement, but with excessive filler content can lead to a stiffer pavement (Al-Mansob 2018). Therefore, the addition of yester shell ash can improve the Marshall flow performance of the OSA-filled asphaltic concrete.

Figure 3 shows the effect of OSA on the void in mineral aggregate (VMA) of OSA-filled asphaltic concrete at different percentages of asphalt in the mixture. The results presented in Table 4 showed that increase in OSA from 5% to 20%, also increased the VMA of the OSA-filled asphaltic concrete for a given percent of asphalt. However, increase in asphalt content from 4% to 6% resulted to slight decrease in VMA. Thus, from 4% to 6% asphalt, the VMA decreased from 12.92% to 12.59% for the control sample. This can be attributed to denser and less porous mixture at increased asphalt content, resulting in a lower VMA. However, the increase in VMA when the percentage of OSA was increased at constant asphalt content can be attributed to the fact that OSA acts as a bulking agent, which increased the volume of the mixture. The analysis further revealed that increasing the %OSA beyond a certain point does not lead to a significant increase in VMA. For example, at 4% asphalt content, increase in OSA from 15% to 20% only leads to 0.08% increase in VMA. The finding is consistent with the works other previous researchers (Olad & Ismail, 2018; Han *et al.*, 2019; Mistry & Roy, 2020), but also contrary to the work of Caroles *et al.*, (2021) which reported increase in VMA as asphalt content increased from 1 – 3.5%. This contradiction may be due to the variations in percentage of asphalt used. Nevertheless, the values of VMA obtained for samples with OSA are within the 13% minimum limit specified by ASTM D6927-15 (ASTM, 2015). Yet again, the addition of oyster shell ash improved the void in mineral aggregate.

Figure 4 shows the effect of OSA on the void in the mixture (VIM) of OSA-filled asphaltic concrete at different percentages of asphalt in the mixture. The VIM is an important parameter in determining the durability and performance of pavement. Increase in the asphalt content decreased the VIM, and this is because the asphalt is the binding material that holds the aggregate together, leading to a denser mix with lower VIM. From Table 4, increase in asphalt from 4 to 6% for control sample, resulted to decrease in VIM from 4.16% to 3.85%, but the addition of 5% to 20% OSA led to a decrease in. For instance, at 4% asphalt, the VIM decreased from 3.93% at 5%OSA to 3.18% at 20%OSA. Previous studies also found that the VIM of an asphaltic concrete decreased with increasing percent of asphalt or filler (Abbas *et al.*, 2019; Wu *et al.*, 2020; Caroles *et al.*, 2021). The range of VIM obtained is within the 3% - 5% specified by ASTM D6927-15 (ASTM, 2015).

Figure 5 shows the effect of OSA on the void in the mixture (VFA) of OSA-filled asphaltic concrete at different percentages of asphalt in the mixture. Void filled with asphalt indicates the size of the void filled with asphalt and it is a critical parameter in road construction, as it affects the durability and longevity of pavement. From the results in Table 4, it can be seen that increase in asphalt from 4% to 6%, the VFA also increases from 65.24% to 73.19%. This indicates that higher asphalt content results in a better filling of voids in the mixture. Similarly, increase in OSA from 0% to 20%, the VFA also increased. This indicates that the OSA played an essential role in filling the voids in the mixture. According to a study increase in asphalt content lead to increased value of VFA due to proper filling of voids, which enhances the properties of mixture (Caroles *et al.*, 2021). Overall, appropriate percent of asphalt and filler in asphaltic concrete mixture lead to better performance of stability, stiffness, rutting and fatigue resistances and decreased moisture susceptibility (Mohammad *et al.*, 2018; Jafari *et al.*, 2020; Mistry & Roy, 2020). Again, the recommended range of 65 – 75% VFA by ASTM D6927-15 (ASTM, 2015) was attained by the OSA-filled asphaltic concrete.

Figure 6 shows the effect of OSA on Marshall Quotient (MQ) of the OSA-filled asphaltic concrete at different percent of asphalt in the mixture. Marshall Quotient is a function of stability and flow, which characterized the stiffness of the mixture. From Table 4.7, at constant asphalt content in the mixture, MQ increased as the OSA was increased from 0% to 10% and thereafter decreased with further increase of OSA. Also, MQ increased with increasing asphalt content from 4 to 5% and then decreased was at 6% asphalt composition. The optimum MQ occurred in the sample with 10% OSA and 5% of asphalt content (372.46 kg/mm or 3.65kN/mm). The result obtained is consistent with other similar studies on Marshall Quotient (Siswanto *et al.*, 2017; Zakaria *et al.*, 2018; Mistry & Roy, 2020). However, the standard specification of Marshall Quotient for road pavement, according to ASTM D6927-15, ranged within 2 – 5kN/mm (203.94 – 509.85kg/mm) (ASTM, 2015). Therefore, this implied that at 4% asphalt, the control sample does not meet the standard requirement.

4. CONCLUSION

The study investigated performance of Marshall's properties of oyster shell ash-filled asphaltic concrete. Based on the results obtained, it can be concluded that asphalt and OSA contents influenced the Marshal properties of the OSA-filled asphaltic concrete, with the maximum stability, flow and Marshal Quotient observed at 10% OSA and 5% asphalt content. Overall, the performance of the OSA-filled asphaltic concrete was improved by the addition of oyster shell ash and the Marshal properties met the minimum specifications, particularly, at 5 – 10% OSA. Therefore, oyster shell ash can be used as filler for asphalt concrete designed for road pavement.

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