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Marshall Properties of Warm Mix Asphaltic Concrete Incorporating Various Proportions of Sasobit Additive

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ABSTRACT

Asphalt is widely used as pavement material for easy road construction. However, poor performance of Hot Mix Asphalt (HMA) concrete necessitate the utilization of Warm Mix Asphalt (WMA) pavement technology. The WMA concrete offers a reduction in production temperature, gaseous emission and occupational health hazard. Sasobit is an organic additive being used in producing WMA concrete. It has been recommended by the manufacturer of sasobit that 3% of its proportion should be used in the production of WMA to achieve maximum temperature reduction. However, there is sparse literature on the Marshall properties of WMA concrete modified with varied proportions of sasobit. Hence, this study investigated the Marshall properties of WMA concrete incorporating various proportion of sasobit. A 60/70 penetration grade of bitumen was weighed into nine separate containers prior to heating to produce unmodified and modified samples. Sasobit (S) was added to eight samples at 0 – 4% at 0.5% intervals by weight of the 60/70 bitumen. The WMA concrete samples were produced by mixing coarse aggregate, fine aggregate and mineral filler with modified bitumen samples. Index properties of aggregates and mineral filler were evaluated. Marshall properties (stability, flow and quotient) were evaluated on the unmodified and modified WMA concrete samples. Index properties of aggregates satisfy the required specifications for a quality concrete production. Marshall properties (stability, flow and quotient) values increase as the sasobit content increases. Therefore, sasobit modified WMA concrete enhanced Marshall properties of the asphaltic concrete. The Marshall quotient values range from 2.50 – 4.14 kN/mm with 3.5% sasobit modification having the highest Marshall quotient of 4.14 kN/mm. Thus, WMA concrete produced with a 3.5% sasobit content is recommended for Nigerian WMA concrete pavement construction projects seeking improved performance.

Keywords: Hot mix asphalt, Marshall properties, Marshall quotient, Sasobit, Warm mix asphalt.

1. INTRODUCTION

Warm Mix Asphalt (WMA) has a production temperature between 100 and 140°C, whereas Hot Mix Asphalt (HMA) has a temperature over 140°C (Milad *et al.*, 2022). The HMA is widely used for asphalt pavement construction in Nigeria because most roads are flexible pavement designs (Akinleye and Tijani, 2017). According to Onoja and Alhassan (2019), temperatures between 140 and 163°C are typically used to manufacture conventional HMA and compacted at about 80 to 135℃. There is the need for environmental sustainability, which involves the production of asphaltic concrete at a lower temperature, reduction in high energy consumption, and the reduction of environmental discomfort brought on by the gaseous emissions produced during the manufacture of HMA concrete. Issues with HMA concrete necessitated the use of sasobit in producing WMA concrete which has a lower production temperature.

Warm Mix Asphalt can reduce fuel energy consumption by 30%, resulting in fuel cost reductions for the asphalt company (Akinleye *et al.*, 2020a). The WMA provides the reduction of any emissions that may contribute to health, odour concerns, or greenhouse gas emissions (Diab *et al.*, 2016). Considering that 30 to 50% of an asphalt plant's administrative expenses are attributable to emission control, the reduction in emissions represents a significant savings (Attaelmanan *et al.*, 2022). It may be possible for asphalt facilities to be located in non-attainment areas, where air pollution regulations are stringent, if they emit less pollution. Having an asphalt facility located in a non-attainment area and producing HMA with a product that allows for a lower operating temperature will allow for shorter haul distances, which will improve production, shorten the construction period, and reduce traffic congestion delays. With the lower operating temperatures, oxidative hardening of the asphalt will be minimized, which may result in modifications to pavement performance, such as decreased thermal cracking, block cracking, and preventing the mix from being fragile when placed (Akinleye *et al.*, 2020b).

There have been identified several heated asphalt processes. This report evaluated Sasobit, a product of Sasol Wax as one of organic additives. Sasobit, an example of an organic additive, is a white powder or granulate consisting of Fischer-Tropsch (FT) wax. It is a byproduct of the Fischer-Tropsch process, which is used to produce synthetic gasoline, and contains about 10% paraffin (Diab *et al.*, 2016). At operating temperatures, sasobit creates a lattice structure in bitumen that imparts stability to the mixture. Consequently, it is wholly soluble in bitumen at temperatures greater than 115°C (Behl *et al.*, 2016). Sasobit reduces the binder's viscosity and functions as a flow modifier in the mixture, which facilitates the aggregate's free movement and coating by the bitumen. Sasobit can be introduced directly to the mix during the manufacturing process or blended with bitumen and stored before mixing. Then the blend can be used to produce asphalt mixes (Benert *et al.*, 2017).

The ability of sasobit to achieve target specifications with WMA while still possessing the advantages of WMA is the essence of this study. Sasobit is being manufactured in South Africa and the manufacturer of sasobit advised that a 3% sasobit addition yields the greatest results when attempting to reduce the temperature by no more than 30°C. Furthermore, review of literatures revealed that the 3% proportion was generally adopted (Milad *et al.*, 2022; Yu *et al.*, 2022; Akinleye *et al.*, 2020a; Sasol 2004). However, this study varied the proportion of the organic additive (sasobit) using locally available materials in Nigeria in other to determine the best proportion suitable for Nigeria's condition. Nigeria, a tropical nation, has a problem with rising road surface temperatures. Therefore, a surface layer capable of withstanding temperature fluctuations is desired (Adebayo and Mohammed, 2016). Thus, this study investigated the Marshall properties of WMA incorporating various proportion of Sasobit in a bid to determine the best proportion for Nigeria's situation.

2. METHODOLOGY

2.1 Materials

The mineral filler, fine and coarse aggregate were obtained from Ejiwumi quarry, Omu-Aran, Kwara State, Nigeria. The mineral filler consists of quarry dust passing 75 µm BS sieves. The coarse aggregate comprised of granite particles that passes 19 mm BS sieve and retained on 12.5 mm BS sieves for the wearing course while the fine aggregate consists of granite dust (stone dust) fractions that passes 4.75 mm and retained on 75 µm BS sieves. The bitumen was obtained at Construction Products Nigeria Limited in Ilorin, Kwara State. The bitumen was categorized as VG-30, or Grade 30 for Viscosity. The VG-30 grade of bitumen is commonly referred to as the 60/70 grade of bitumen. Reynolds Construction Company Ltd., Lagos-Ibadan Expressway, Ibadan, Oyo State, Nigeria, was the source for the sasobit. Materials used for the study are shown in Figure 1.

2.2 Methods

The basic properties of aggregates and mineral filler were determined in the laboratory. These include gradation, aggregate crushing value, aggregate impact value, flakiness index, elongation index and specific gravity tests. The bitumen was modified with sasobit at a proportion of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3, 3.5 and 4% by the weight of the bitumen for production of the WMA concrete samples. Marshall properties

(Marshall stability and flow) were carried out on the unmodified and modified WMA concrete samples. Thereafter, the Marshall Quotient was determined. The optimum value of the Sasobit at different proportions was determined from the Marshall Quotient. The Marshall stability test is used for assessing two crucial features of flexible characteristics and strength. The Marshall stability of a mixture measures its tensile strength, while the Flow value quantifies its pliability. The machine's upper dial gauge displays the stability value, while the lower dial gauge displays the flow value. The Marshall Stability test was successfully carried out in accordance with the specifications of ASTM D2487 (2011). The Marshall Quotient is the ratio of asphaltic concrete mixture stability to flow. It is also known as asphaltic concrete mixture toughness and Marshall stiffness. Modification with the highest Marshall quotients has the optimum performance (Choudhary *et al.*, 2020). Marshall stability test set-up is shown in Figure 2.

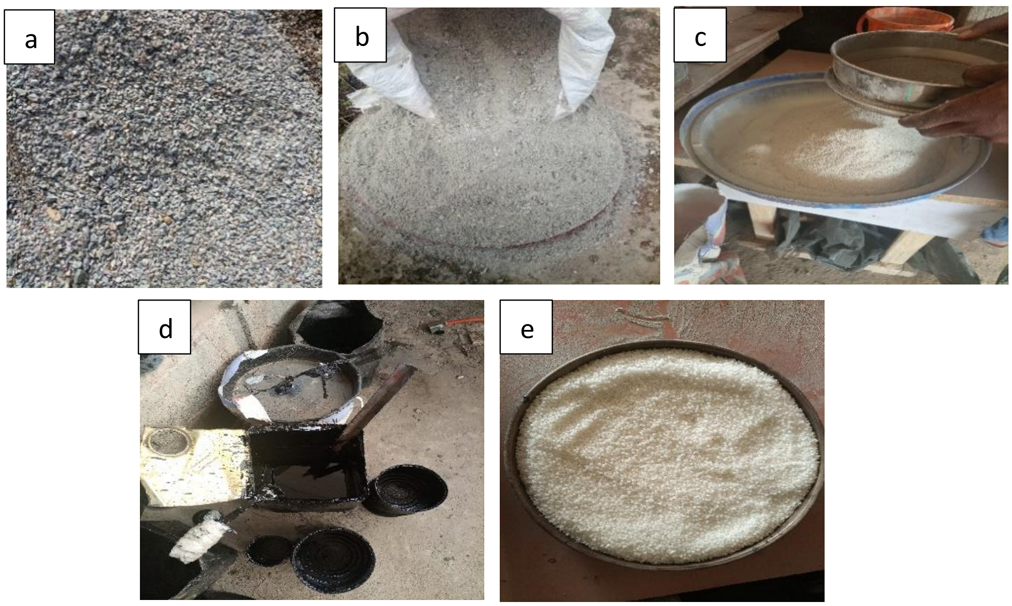

Figure 1: Materials: a. Coarse aggregate b. Fine aggregate c. Mineral filler d. Bitumen e. Sasobit

Figure 2: Marshall stability test set-up

3. RESULTS AND DISCUSSION

3.1 Aggregate Properties

Figure 3 depicts the particle size distribution curves for coarse and fine aggregates while Table 1 shows the other properties of aggregates used. The grading curve (Figure 1) indicates that coarse aggregate predominantly comprises medium grain size particles in the range of 6 – 20 mm with values of 5, 12.9 and 16.35 mm respectively for D_{10}, D_{30} and D_{60}. The C_u and C_c obtained for coarse aggregate were 3.27 and 2.04 respectively. Since C_u is between 1 to 5, the coarse aggregate can be categorized as uniformly graded aggregate in accordance with Unified Soil Classification System (USCS) as recommended in ASTM D2487 (2011). Furthermore, the result of C_c obtained satisfies the ASTM D2487 (2011) soil classification for a well-graded material of $Cc \leq 3$. This implies that the granite used is suitable for producing concrete of good quality. On the other hand, the value of 0.06 – 0.6 mm on the grading curve (Figure 3) for the fine aggregate shows that it is predominantly dominated by fine to medium particles with values of 0.062, 0.11 and 0.42 mm, respectively for D_{10}, D_{30} and D_{60}. The C_u and C_c obtained for fine aggregate were 6.77 and 0.46 respectively. The value of Cu greater than 6 is an indication that the fine aggregates are well graded in agreement with ASTM D2487 (2011) thus, it is suitable as aggregate for producing concrete.

From Table 1, the aggregate crushing value was 13.85% which satisfy the 30% maximum specification by the FMW (2016) and ASTM (2018) requirements. According to Ajagbe *et al.* (2015) and Yu *et al.* (2022), an aggregate having a crushing value less than 30% implies that such aggregate has crushing resistance materials. Hence, the aggregate crushing value gotten in this findings is lower than 30% which implies that the aggregate has crushing resistance materials. The aggregate impact value was 17.25%. According to Rehman *et al.* (2020), an aggregate having an impact value less than 20% implies that such aggregate has impact resistance materials. Hence, this sample's aggregate impact value is lower than 20%, which implies that the aggregate has impact resistance materials. Furthermore, the aggregate impact value derived in this study is less than the maximums of 30, 45, and 30% specified by the FMW (2016), and ASTM (2018) specifications respectively. Hence, the aggregate selected for the manufacturing of mixtures of asphalt in this investigation satisfies the desired characteristic.

The flakiness index value was obtained to be 24.60%. This is less than 35% maximum value specified by FMW (2016) for asphalt concrete. Furthermore, the flakiness index result obtained from this study is less than the 45 and 40% maximum value specified by ASTM (2018) and BS (1992) specifications. Hence, flakiness index result obtained satisfy the requirement of FMW (2016) and ASTM (2018) for crushed rock. Therefore, the desired property is satisfied with the aggregate selected for the manufacturing of mixtures of asphalt utilized in this investigation. The elongation index value obtained is 25.26% which is less than the 35% maximum specified by the FMW (2016) for asphalt concrete. Moreover, the result also satisfies the requirement of 45 and 50% maximum specified by ASTM (2018). Coarse aggregate, fine aggregate, and mineral filler had specific gravities of 2.8, 2.6, and 1.91, respectively. All the aforementioned values are less than the 3.0 - maximum specification for specific gravity of the materials as recommended by the FMW (2016) and ASTM (2018) specification. As a result, the aggregate selected for the manufacturing of bitumen mixtures utilized in this present investigation satisfies the desired property.

3.2 Marshall Properties

Figure 4 shows the influence of sasobit on stability, flow and Marshall quotient of WMA concrete. It was revealed that the Marshall Stability values increased as the sasobit content increase in the WMA concrete. This implies that in a bid to get highest stability, the sasobit content can be used up to 3.5% modification. All the values obtained for stability satisfy the requirement of FMW (2016) and AI (1991). From the data obtained as shown in the Figure 2, 3.5% sasobit proportion has the highest Marshall stability value of 17.21 kN, which implies that asphalt samples give the highest strength at this proportion. Flow values increases as sasobit content increases in the asphaltic concrete. The flow values at 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5 and 4% sasobit modifications were; 3.60, 3.80, 3.90, 3.90, 4.10, 4.20, 4.50, 4.16 and 4.67 mm respectively. Flow values increase from 0 – 3% sasobit modification with a slight decrease at 3.5%. Furthermore, all the values obtained for flow meet the requirement range of 2 – 6 mm, as specified by the FMW (2016) specifications. Marshall quotient values increases as sasobit content increases. The Marshall quotient values range from 2.50 – 3.52 kN/mm. A slight decrease occurred at 4% modification. From the data obtained as shown in Figure 2, 3.5% sasobit modification has the highest Marshall quotient of 4.14 kN/mm. According to Mistry *et al.* (2018) and Choudhary *et al.* (2020), modification with the highest Marshall quotients has the optimum performance. Hence, 3.5% sasobit modification has the optimum performance.

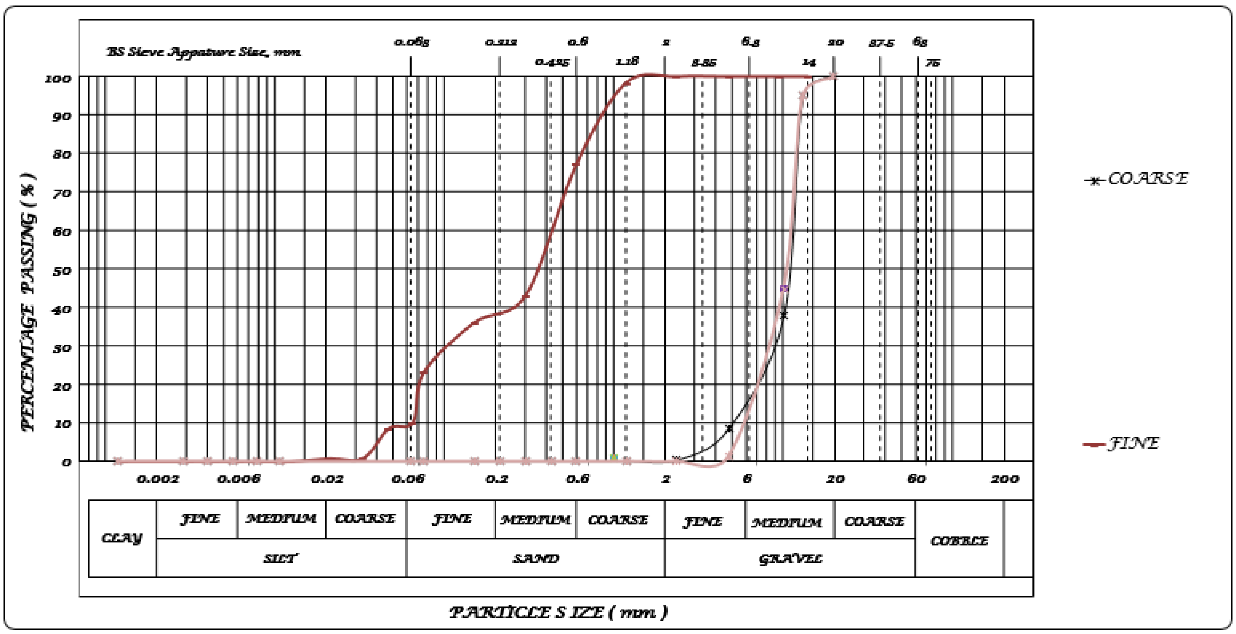

Figure 3: Particle size distribution curves for coarse and fine aggregates

Table 1: Properties of Aggregates

Tests	Results Obtained	FMW, 2016 Specification	ASTM, 2018 Specification	BS, 1992 Specification	Remarks
Aggregate Crushing value (CA)	13.85%	30% Max.	30% Max.	30% Max.	Satisfactory
Aggregate Impact value (CA)	17.25%	30% Max.	45% Max.	30% Max.	Satisfactory
Flakiness Index (CA)	24.60%	35% Max.	45% Max.	40% Max.	Satisfactory
Elongation Index (CA)	25.26%	35% Max.	45% Max.	50% Max.	Satisfactory
Specific Gravity (CA)	2.8	3 Max.	3 Max.	3 Max.	Satisfactory
Specific Gravity (FA)	2.6	3 Max.	3 Max.	3 Max.	Satisfactory
Specific Gravity (Filler)	1.9	3 Max.	3 Max.	3 Max.	Satisfactory

N.B.: FMW is Federal Ministry of Works Specifications for Roads and Bridges, 2016; ASTM is American for Testing and Materials, 2018; BS is British Standard, 1992; CA is Coarse Aggregates; FA is Fine Aggregates.

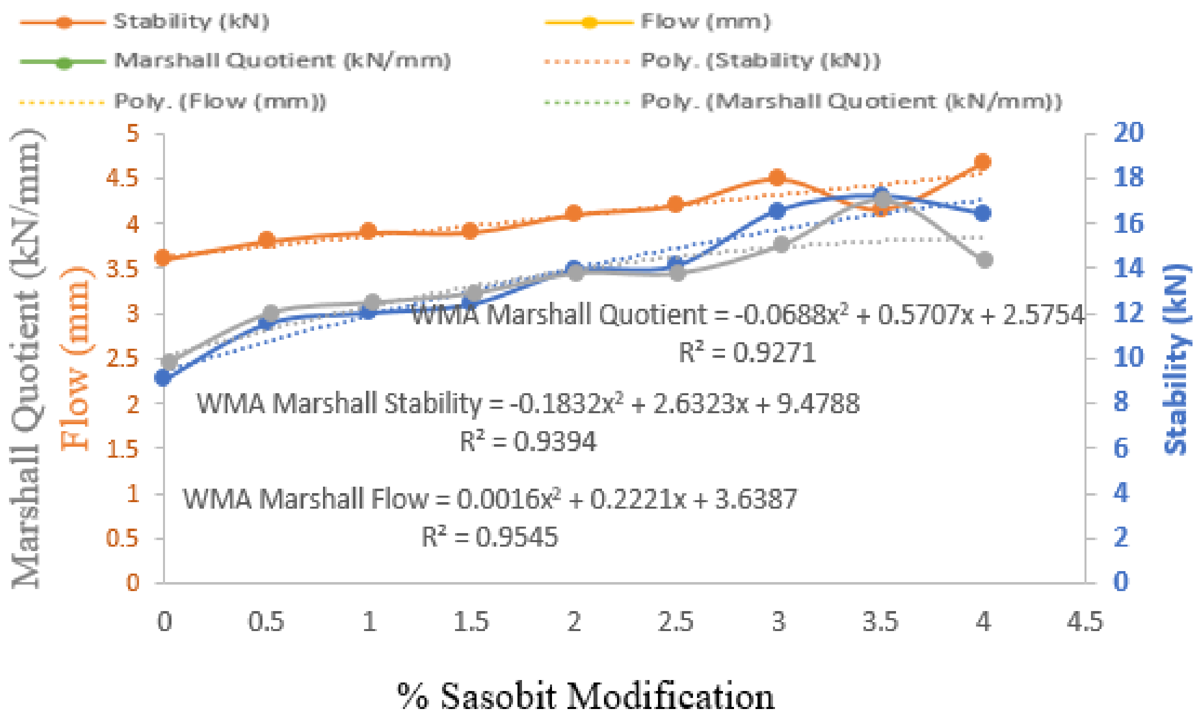

Figure 4: Influence of sasobit on stability, flow and Marshall quotient of WMA concrete

4. CONCLUSION

The Marshall properties performance of warm mix asphaltic concrete enhanced with various proportions of sasobit have been examined. Index properties of aggregates satisfy the required specifications. Marshall properties values increases as the sasobit content increases. Therefore, sasobit modified warm mix asphalt concrete enhanced Marshall properties of the asphaltic concrete. The Marshall quotient values range from 2.50 – 4.14 kN/mm with 3.5% sasobit modification having the highest Marshall quotient of 4.14 kN/mm. Thus, 3.5% sasobit modification is the optimum sasobit proportion and has the optimum performance for Nigerian warm mix asphalt concrete pavement construction projects seeking improved performance. This study has unveiled the proportion of sasobit for construction industry in Nigeria. This is in a bid to produce warm mix asphaltic concrete at a lower temperature, reduction in high energy consumption, and reduction in environmental discomfort as a result of gaseous emission during the hot mix asphalt concrete production process.

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