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Evaluation of Hot Mix Asphalt Properties with Solid Waste Incinerator Ash as Fine Aggregate

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Abstract: It is imperative to develop a means of utilizing municipal solid waste incinerator ash (MSWIA) for a proper environmental protection. Hence, this research is to evaluate the influence of municipal solid waste incinerator ash (MSWIA) as a substitute for fine aggregate in hot-mix asphalt concrete. The physical properties and chemical oxide composition tests were carried on MSWI ash with the view of evaluating its suitability for used as fine aggregate. Marshall mix design method was adopted for sample preparation. Preliminary samples were prepared to determine the optimum bitumen content (OBC). The OBC was determined as 5.5% and was used for the preparation of samples with varying proportion of MSWIA (10%, 20%, 30% and 40 by total weight of the fine aggregate). The samples were subjected to mechanical and volumetric evaluations, which include stability, flow, bulk specific gravity, void in mineral Aggregate (VMA) void filled with bitumen (VFB) and Voids in the mix (VIM). The results revealed that the flow, void in mix (VIM), void in mineral aggregate (VMA) increased, while bulk specific density (BSD) and void filled with bitumen (VFB) became less as the percentage of MSWI ash raised. However, the use MSWI ash in the preparation of hot mix asphalt as a substitute for fine aggregate should not be beyond 20 % MSWIA. Moreover, the results fulfilled the Standard Specification and requirements specified by Nigerian Standard Specification for Roads and Bridges.
Keywords: Bitumen, Hot Mix Asphalt, Marshall Method, Municipal Solid Waste Incinerator Ash, Fine Aggregate.

1. Introduction

Municipal solid waste incinerator (MSWI) is the spin-off that obtained from burning of municipal solid waste (MSW) and stays on the stoker at the windup of the burning cycle in solid waste combustion facilities. In some developing countries, MSW contains different amounts of industrial waste [1]. Solid waste is accumulated in amalgamated stage and dumped to decay in many areas like roadsides, public places and so on, creating lots of inconveniences to the environment [2]. The frequency at which the society generated the solid waste is directly proportional to the increase in population and technological development. This forced researchers to look for various ways of managing MSW in a sustainable way in our environment [3]. The increasing cost associated with the state-of-the-art design and setting of landfills, coupled with the rapidity with which they approach capacity has forced municipalities to consider a combination of recycling and incineration to minimize problems associated with proper disposal of MSW [4].

Incineration is a method for treating waste, which will cut down the waste by 70% to 90%. Municipal solid waste incineration (MSWI) ash is the by-product that is produced from the incineration of MSW in solid waste combustor facilities. Across the world, MSWI ash is either land-filled or utilized in various aspects. As a result of the large population of Nigeria with respect to land size, utilization of residues will be more beneficial owing to limited land-filling sites.

MSWI ash has been recycled in the areas of roadbed, asphalt paving, and concrete products in many European and Asian countries. In those countries, recycling programs (including required and environmental criteria) of ash residue management have been developed to encourage and enforce the reuse for MSWI ashes instead of land-fill disposal. Several studies have attempted to characterise MSW ash and using it in asphalt concrete, the studies demonstrated the beneficial use of MSWI ash as an engineering material with minimum environmental impacts. [5] Conducted a study on characterization of Solid Waste Incinerator Bottom Ash and the Potential for its Use" the result shows that MSWI ash has very similar properties to natural sand. The study classified the MSWI ash as well graded based on USCS classification and A-3 material in accordance with ASHTOO classification. [6] assessed the influence of oil palm mesocarp fibre ash (OPMFA) on the strength characteristics of hot mix asphalt, and the result showed that Marshall flow value and stability with the OBC for mixture with 5 % OPMFA content satisfied the standard specification of Nigerian general specification for road and bridges. The study by [7] Suggested that up to 32 % of filler material can be replaced with MSW bottom ash for base course hot-mix asphalt concrete and for low-density traffic road surface applications. [8] Used MSW bottom ash with 75% aggregate substitution. The Marshall Mix design results met the New Hampshire requirements. [9] Stated that the MSW bottom ash was used in a field project in New Hampshire using 50 % MSW ash as a substitute for aggregate in asphalt concrete.

However, there has been limited studies on the use of MSWIA as fine aggregate in hot mixed asphalt. Hence, this study aims to evaluate the properties of asphalt produced with MSWIA as fine aggregate. Through which the findings of this study could lead to the extensive use of MSWIA in the production of asphalt mix, and will significantly reduce the exploration of natural fine aggregate and increase the production of ash from municipal solid wastes.

2. Materials and Methods

2.1 Materials

Materials used are;

The coarse aggregate, fine aggregate, municipal solid waste incinerator, bitumen, and cement.

The coarse aggregate and fine aggregate were obtained from Nagarta local quarry, Sokoto Road, Zaria, and in Zaria, Kaduna state respectively. While the municipal solid waste incinerator (MSWI) ash, Bitumen and Cement were obtained from Minna, Nigerian National Petroleum Cooperation (NNPC), Kaduna State and market in Zaria respectively.

2.2 Methods

The methods used to evaluate the physical properties of coarse aggregate, fine aggregate, Municipal solid waste incinerator (MSWI), Bitumen and Cement were in accordance with the relevant code requirements and specifications and are as highlighted in the following Sub Sections.

2.2.1 Test on coarse aggregates

Tests conducted on coarse aggregates are Aggregate impact value/hardness test (AIV) in accordance with [10], Aggregate crushing value (ACV) in accordance with,[11], specific gravity of coarse aggregate in accordance with [12], and finally, size distribution and gradation in accordance with [14] and water absorption test.

2.2.2 Test carried out on fine aggregate

The tests carried out on the fine aggregates are specific gravity in accordance with [14], sieve analysis in accordance with [13] and water absorption

2.2.3 Test on Bitumen

The tests conducted on the Bitumen are Penetration at 250C, softening point (0C), Flashpoint (Cleveland open cup), Fire point (Cleveland open cup), Ductility at 250C, Specific gravity at 250C, Solubility in trichloroethylene, and table shows the test results obtained

2.2.4 Test on Cement

The tests conducted on the cement are Consistency test based on BS EN 197-1:2009, Initial and final setting time [15], Soundness of cement [15], specific gravity [16], percentage passing 0.075 mm sieve [17].

2.2.5 Marshall Test

The specimens were prepared in accordance with Asphalt Institute [18] recommendations. A total of twenty-four (24) specimens were prepared and each specimen weighs 1200g, 101.5 mm in diameter and 63.5 mm in height and heavy traffic situation was simulated by compacting each specimen with 75 hammer blows on its top and bottom sides. The sample bulk-specific gravity was determined following the ASTM D2041 [19]. The specimens were tested for Marshall Stability and Marshall flow using the Marshall test method following the ASTM D6927 [20] The volumetric tests conducted include Bulk density(G_{mb}), void in mineral aggregate (VMA), void in the mix (VIM) and voids filled with bitumen (VFB). Theoretical Maximum Specific

Gravity of the Mix (Gmm) was determined using ASTM D2041 [19] and Bulk Specific Gravity(G_{mb}). Void in the Mix (VIM) was used to estimate in accordance with ASTM D3203 [21].

The optimum bitumen content (OBC) was determined based on the marshal test method of testing HMA samples. Therefore, fifteen (15) samples of HMA with 100% natural fine aggregate (control) at varying bitumen contents of 5.0, 5.5, 6.0, 6.5 and 7% were prepared in accordance with the asphalt institute [18] and Nigeria General Specification for Road and Bridges (NGSRB) specifications [22]. After which, the Marshal stability-flow and other volumetric properties; bulk density, voids filled with bitumen (VFB), void in mineral aggregate (VMA) and void in the mix (VIM) were determined. The OBC was obtained as the average binder content for maximum density, maximum stability and specified per cent air voids in the total mix.

This procedure was repeated to prepare other samples with various percentage replacements of fine aggregate with MSWIA. The level of replacement considered ranges from 10%-40% at an interval of 10% and all HMA samples were prepared using the OBC obtained.

3. Results and Discussion

3.1 Chemical analysis of MSWI Ash

The chemical analysis of MSWI ash was conducted at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, the results of the analysis are as presented in Table 1. The result obtained is in conformity with the oxide composition of quarry dust as reported by [23], which is majorly used as fine aggregate in the production of hot mixed asphalt.

Table 1: Chemical Analysis of MSWI ash

Element	Concentration (%)	Element	Concentration (%)
SiO_2	54.7	SO_3	0.05
Al_2O_3	7.18	K_2O	1.65
Fe_2O_3	18.34	Na_2O	0.44
CaO	3.18	MnO_2	0.03
MgO	0.16	TiO_2	0.39

3.2 Physical Properties of Fine, Coarse Aggregate and Cement

The results of physical properties of fine and coarse aggregate are presented in Table 2, while the physical properties of cement are presented in Table 3. It was discovered that all the results were within the limits and satisfied the code limit.

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Table 2: Physical properties of fine and coarse Aggregate

Test	Code	Result	Limit
Aggregate Crushing Value (%)	BS 812 Part 112	20	Max. 25
Aggregate Impact Value (%)	BS 812 Part 111	20.6	Max. 25
Specific Gravity of Coarse Aggregate	ASTM C127	2.72	2.55 – 2.75
Density of Coarse Aggregate	ASTM C127	169.52	>160
Specific Gravity of Fine Aggregates	ASTM C128	2.57	2.55 – 2.75
Density of Fine Aggregates	ASTM C127	164.15	>160
Water Absorption of Coarse Aggregate (%)	BS 812 Part 2	0.46	< 2
Water Absorption of Fine Aggregate (%)	BS 812 Part 3	8.62	< 15
% Passing 2.36 mm Sieve	ASTM C115	4.00	< 5
% Passing 0.075 mm Sieve	ASTM C116	0.20	< 5

Table 3: Test Result on Filler Materials

Test	Code Used	Value	Code Limit
Initial Setting Time of cement (minute)	BS EN 196 PART 3	68	>45
Final Setting Time of cement (minute)	BS EN 196 PART 3	255	<375
Soundness of cement (mm)	BS EN 196 PART 3	3.0	<10
Specific Gravity of cement	ASTM C188	3.1	3.15
% of cement passing the 0.075 mm sieve	ASTM C117	97	>90

3.3 Particle Size Distribution of Materials

The particle size distribution curves for the coarse aggregate, fine aggregate/ MSWI ash, and cement used are respectively presented in Figure 1, Figure 2 and Figure 3. It was observed from Figure 2 that the fine aggregate and MSWIA sizes are conformity and classified as zone-1 based on [13]. Hence, all the materials satisfied the requirement for use in HMA.

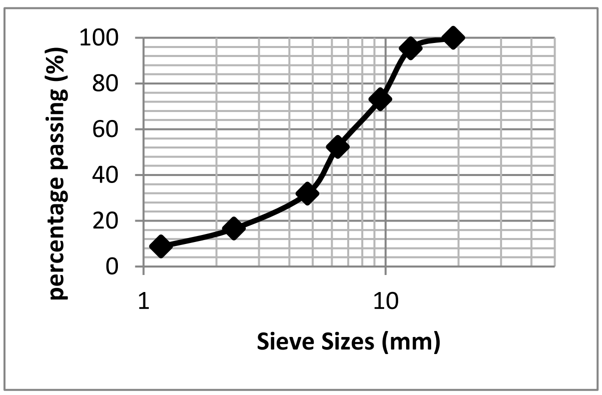
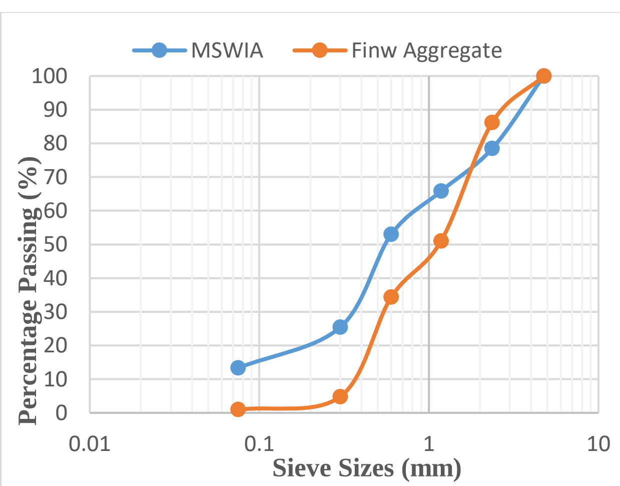


Figure 1: Gradation curve of coarse aggregate



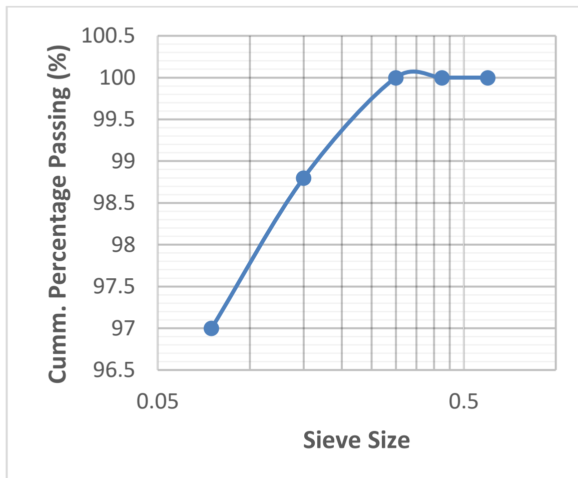


Figure 3: Sieve Analysis for Cement

3.4 The Result of Preliminary Test on Bitumen

The results of the preliminary test conducted on bitumen are shown in Table 4. It was revealed that all the results fall within the limits specified by the ASTM codes and also satisfied the specification for medium-weight traffic as 60/70 penetration grade bitumen [25]. So, this indicated that the bitumen is suitable for Hot Mix Asphalt (HMA) design.

Figure 2: Gradation curve of fine aggregate and MSWIA

Table 4: Results of Preliminary Test on Bitumen

Test conducted	ASTM Code	Test Result	Code Limit
Penetration at 25^{0}C, 0.1mm	ASTM D946-20	64.7	60 – 70
Softening point (^{0}C)	ASTM D36-00	48.5	46 – 56
Flash point (Cleveland open cup) ^{0}C	ASTM D92-02	248	Min. 232
Fire point (Cleveland open cup) ^{0}C	ASTM D92-02	256	Min. 232
Ductility at 25^{0}C, cm	ASTM D113	116	Min. 100
Specific gravity at 25^{0}C, (g/cc)	ASTM D70	0.98	0.97 – 1.02
Solubility in trichloroethylene, %	ASTM D2042	99	Min. 99

3.5 Marshall Test Results

The results for the Marshall stability, flow and the other volumetric properties are as presented in the following sub-sections. However, the optimum bitumen content (OBC) was determined based on the average of bitumen contents obtained at maximum Marshall stability, maximum bulk density and median percentage of air void in the mix as specified by the Asphalt Institute [18]. The OBC was found to be approximately 5.5%.

3.5.1 Stability

The results for stability test on hot mix asphalt (HMA) is presented in Figure 4. It can be observed that the stability at 5 % bitumen content was 4.01 kN and then increased to maximum of 4.3 kN at 5.5 % bitumen which then reduced continuously as the bitumen content increases. Similar trend was observed by [7] and [24]. The maximum stability of 4.3 kN was attained at 5.5% bitumen content while the lower stability of 3.25 kN was recorded at the 7.0% bitumen content.

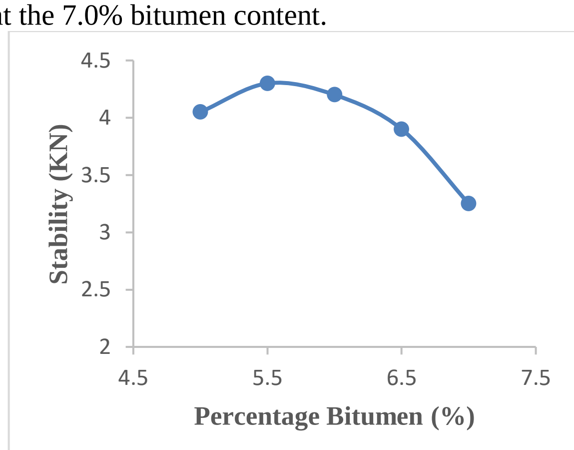


Figure 4: Graph of Stability against Bitumen Content

3.5.2 Flow

The results for Marshall flow of hot mix asphalt (HMA) specimen in relation to the percentage bitumen content is presented in Figure 5. It shows that the flow of HMA increased with an increase in the bitumen content. A maximum flow value of 3.7mm was obtained at a bitumen content of 6.5% and the lowest of 1.95mm was obtained at 5.0% bitumen content.

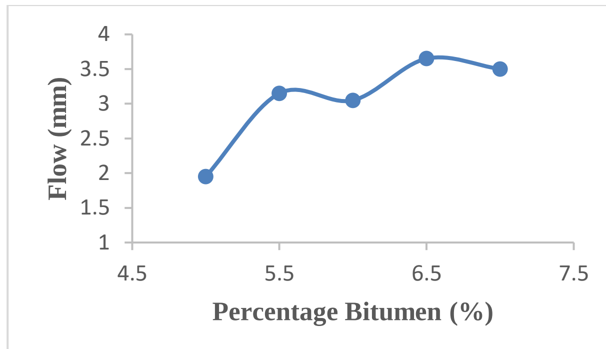


Figure 5: Graph of Flow against Bitumen Content

3.5.3 Voids in the mix (VIM)

Figure 6 presents the results of percentage of voids in the mix (VIM) against the bitumen content. It was observed that the percentage of VIM increases with an increase in the bitumen content from 5% to 6% before it drops down to about 3.72% at 6.5% bitumen content afterward it rises again to about 4.2% at 7% bitumen content.

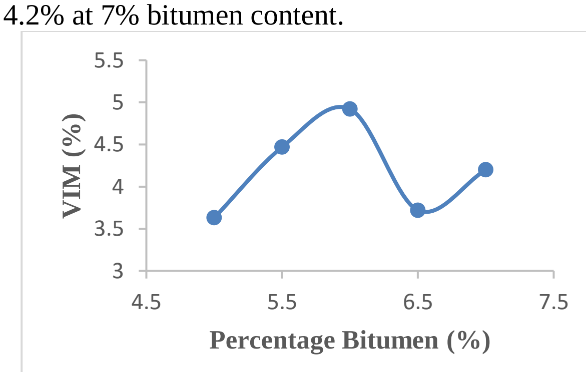


Figure 6: Graph of VIM against Bitumen Content

3.5.4 Void in Mineral Aggregate (VMA)

The results for the VMA is as presented in Figure 7. It was discovered that the value of VMA increases up with the increase in the percentage bitumen content. A maximum VMA value of 20.7% was attained at 7 % bitumen content.

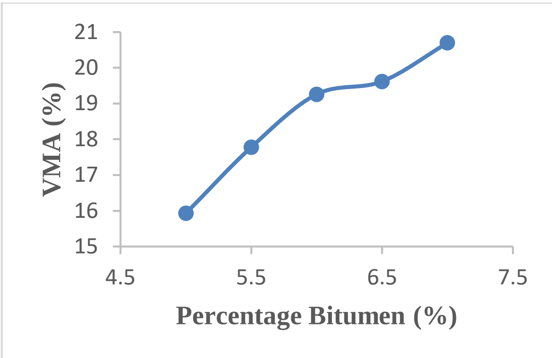


Figure 7: Graph of VMA against Bitumen Content

3.5.5 Bulk Specific Gravity

Figure 8 presents the Bulk Specific Gravity of the specimen. It can be observed that the bulk specific gravity value increased with an increase from 5% to 5.5% bitumen content afterwards decrease continuously. The maximum specific bulk density of 2.39g/cm^3 was attained at 5.5% bitumen content and the minimum for the test was 2.30g/cm^3 for the bitumen content of 7%.

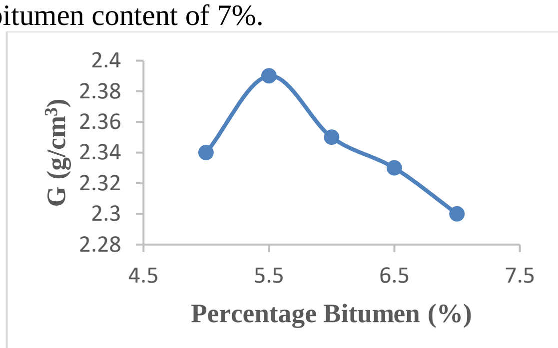


Figure 8: Graph of Specific Density against Bitumen Content

3.5.6 Void Filled with Bitumen (VFB)

The relationship between void filled with bitumen (VFB) is shown in Figure 9. It shows that there was a steady decrease in VFB, as the percentage bitumen content increased from 5% to 7%, and then the VFB increased from 74.45% to 81.04% when the bitumen content increased to 6.5%, but thereafter decreased with further increase in bitumen content to 7%.

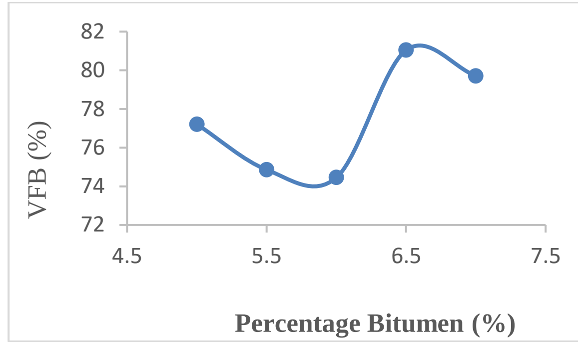


Figure 9: Graph of VFB against Bitumen Content

3.6 Determination of Optimum MSWI ash percentage

The results for the Marshal stability-flow and the volumetric analysis at varying MSWIA percentage replacement of fine aggregate are presented in the following sub-sections.

3.6.1 Stability

Marshall stability indicate the strength of compacted HMA specimen. The result for stability test at varying MSWI ash percentage replacement of fine aggregate in hot mix asphalt is presented in Figure 10. It showed that the stability decreased from 4.01 kN at 0% MSWI to 3.04 kN at 10% MSWI content and then increased to maximum of 4.3 kN at 20 % MSWI content which afterward decreased as the MSWI content increased. Similar pattern was observed by [7] and [24]. The decrease in stability may be due high quantity of MSWI content that is finer and lower specific gravity of MSWI compared to that of sand. However, the stability value of the HMA satisfies the minimum value of 3.5kN with exception of the value at 10% replacement for use in the wearing course as prescribed by Nigerian General Specification for Roads and Bridges specifications (NGSRB). Hence, the optimum percentage replacement can be taken as 20%.

Figure 10: Graph of Stability against portion of MSWI ash at 5.5% Bitumen Content

3.6.2 Flow

The result for Marshall flow is presented in Figure 11. It was observed that the flow increased as the MSWI content increased. The highest value of the flow of 4.7 mm was recorded at 40% MSWI content while the lowest flow of 3.15 mm was recorded at 0 % MSWI content. However, the increase in flow indicates that the mix has low resistance to track load, hence it can say is only 10% and 20% replacement meets the requirement of 2mm-4mm as specified by the Nigerian General Specification for Roads and Bridges specifications (NGSRB).

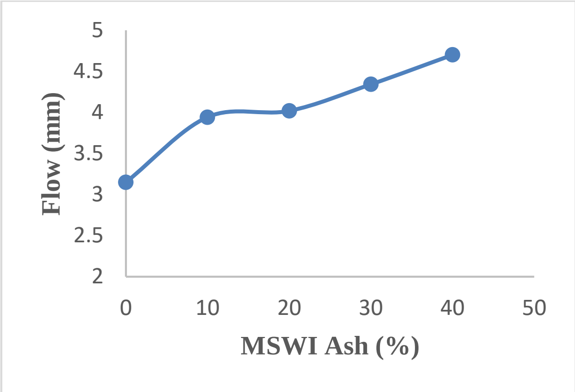


Figure 11**:** Graph of Flow against portion of MSWI ash at 5.5% bitumen content

3.6.3 Bulk Specific Density

The test results for bulk density at varying percentage replacement of fine aggregate with MSWI content is as presented in Figure 12. It was observed that the value of bulk density decreased as the percentage of MSWI content increased. It was also observed that the highest bulk density was recorded as 2.35 g/cm^3 at 0 % MSWI content while the lowest one was recorded as 2.18 g/cm^3 at 40 % MSWI. The decrease in the bulk density may be attributed to the low specific gravity of MSWI when compared with that of the natural sand.

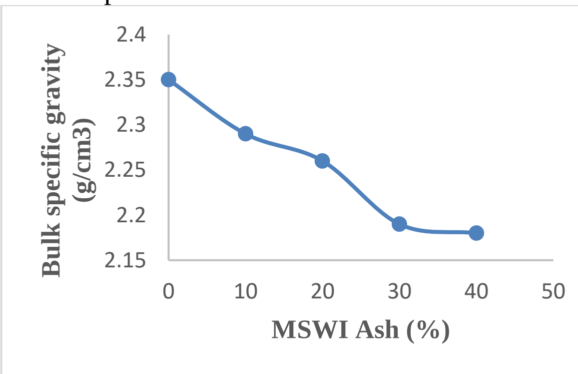


Figure 12: Graph of Specific Density against Percentage MSWI ash

3.6.4 Void in Mix

The relationship between the MSWI and VIM is displayed in Figure 13. It was discovered that as the percentage content of MSWI went up the value of VIM increased, and a similar trend was recorded by [6]. The highest VIM of 11.02% was recorded for the specimen with the 40% replacement while the lowest VIM of 4.47% was recorded for the control specimen. However, none of the percentage replacement of the MSWIA of 4% to 5% as specified by NGSRB

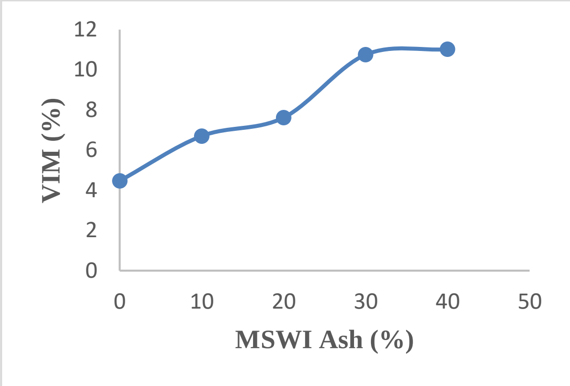


Figure 13: Graph of VIM against MSWI Ash

3.6.5 Void in Mineral Aggregate (VMA)

The relationship between the VMA and MSWI content is presented in Figure 14. The result shows that VMA value increased with an increase in the portion of MSWI ash and the increase in VMA may be due to surplus of MSWI in the mix which caused the bitumen not coat to adhere with some other aggregate [6]. On the other hand, the lowest value of VMA was recorded as 17.78% when there was no replacement and the highest VMA of 27.47% was recorded when the fine aggregate was replaced with 40% MSWI ash.

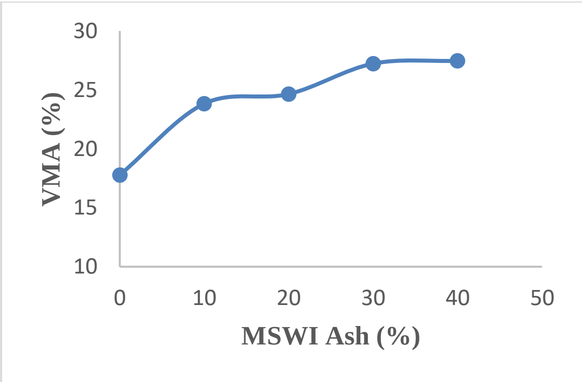


Figure 14**:** Graph of VMA against MSWI Ash

3.6.6 Void Filled with Bitumen (VFB)

The results of the VFB test carried out on hot mix asphalt (HMA) are presented in Figure 15. The decrease in VFB values as the percentage of MSWI content increased was observed. And the highest VFB values of 75% and the lowest of 60.55% at 0 % and 40 % MSWI ash content respectively. It can be deduced from the figure that all MSWIA percentage replacement meets up with requirements of Nigerian general specification for road and bridges of 75%-82% for wearing course.

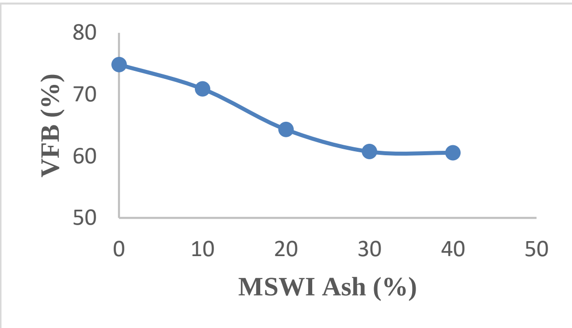


Figure 15: Graph of MSWI Ash against VFB.

3.6.7 Marshall quotient value

The Marshall Quotient (MQ) value of hot mixed asphalt is defined as a ratio of stability and flow of the asphalt mixture, it is also known as the rigidity of asphalt mixture. It quantifies the HMA's resistance to shear stresses, rutting and permanent deformation. The results for the marshal quotient value against percentage replacement of fine aggregate with MSWIA are as presented in Figure 15. It can be observed that at 0 % MSWI replacement, the MQ value is about 1.3 kN/mm which decreases to about 0.75kN/mm at 10 % MSWI and then increases to a maximum value of about 1.1kN/mm at 20 % MSWI replacement. However, a sudden decline was observed to be 0.82 kN/mm at 40 % MSWI replacement. The same pattern was observed by [7] and [24].

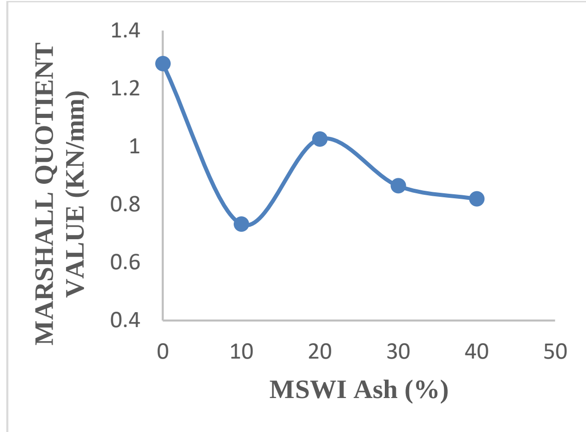


Figure 16: Graph of Marshall Quotient value against MSWI Ash

4.0 Conclusions

Based on the tests performed, the following conclusions were reached

i. The constituent materials used satisfied the specified requirement of standard codes.
ii. The values of the required properties of bitumen as a binder as regards its penetration, viscosity, flash and fire point, durability and solubility of bitumen were according to ASTM standard specification for asphalt design.
iii. The flow, void in mix (VIM), void in mineral aggregate (VMA) increased, while bulk specific density (BSD) and void filled with bitumen (VFB) decreased as the percentage of MSWI ash increased.
iv. The use MSWI ash in the preparation of hot mix asphalt as a substitute for fine aggregate should not be beyond 20 % MSWIA

Conflict of Interest

Regarding this work, there is no conflict of interest.

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