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EVALUATION OF SAWDUST ASH AS A PARTIAL REPLACEMENT FOR MINERAL FILLER IN ASPHALTIC CONCRETE

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ABSTRACT

This paper evaluated the effects of sawdust ash on the characteristics of asphaltic concrete with a view to investigating its suitability as an additive in asphaltic concrete. The sawdust was obtained from Alekuwodo in Osogbo, Osun state, Nigeria. The bitumen, coarse aggregates, fine aggregates, and mineral filler were obtained from Espro Asphalt Plant, Ife- Ibadan Road, Osun state, Nigeria. The sawdust was burnt into ash using a furnace at a temperature of 800°C, allowed to cool and sieved through 75 µm BS sieve (No.200). The properties of the materials were determined using standard procedures. Asphaltic concrete samples were prepared with sawdust ash at 0, 5, 10, 15, 20, and 25 % by weight of the granite filler. The samples were subjected to Marshall Stability test. The stability, flow, density, voids filled with bitumen (VFB), air voids (AV) and voids in mineral aggregate (VMA) were determined. The values of stability, flow, bulk density, voids filled with bitumen, air voids and voids filled in mineral aggregates at 15 % optimum sawdust content were, 18.2 kN,3.40 mm, 2.36 g/cm^3, 77.13 %, 4.05 % and 17.71 %, respectively. The result showed that, the inclusion of sawdust ash in asphaltic concrete improved its properties.

Keywords: Sawdust Ash, Asphaltic Concrete, Asphaltic Concrete Properties

INTRODUCTION

In recent years, many countries have experienced increase in traffic volume. This increase meant that pavements are exposed to higher stresses. Higher density of traffic in terms of commercial vehicles, overloading of trucks, and significant variation in daily and seasonal temperature of pavements have been responsible for the development of distresses such as, ravelling, rutting, and fatigue failures of bituminous surfaces (Tomar *et al.*, 2013).

A good design of asphaltic concrete is expected to result in a mix which is adequately strong, durable, and resistant to fatigue and permanent deformation and at the same time environmentally friendly and economical. Suitable material combination and modified asphaltic concrete have been found to result in longer life for wearing courses depending on the type and percentage of mineral filler used (Tomar *et al.*, 2013). Improvement in asphaltic concrete performance can be achieved through various modifications such as the use of polymer, glass, fly ash, and furnace slag. Researchers have extensively investigated the use of various by-products as fillers in improving the properties of the asphaltic concrete (Sobolev and Naik, 2005). Mineral filler plays a significant role in the engineering properties of asphaltic concrete. Conventionally, stone dust, cement and lime are used as fillers (Tomar *et al.*, 2013). An attempt has been made in this study to assess the influence of non – conventional material like sawdust ash in the production of asphaltic concrete.

The aim of this study was to assess the influence of sawdust ash in the production of asphaltic concrete.

Mineral filler includes those materials which pass 75µm (No. 200) BS sieve. The most important properties of mineral filler are the geometry and composition. Filler geometry can be identified by size, shape, texture and angularity. Asphalt - filler interaction is affected by a number of chemical compounds. The two main properties of these interactions are the reactivity (calcium compound and water solubility) and the harmful fines (active clay content and organic content), (Bahia *et al.*, 2011). Mineral fillers which are used in the pavement industry can be divided into two groups namely; the natural fillers and the imported filler. Natural fillers include andesite, basalt, caliche, dolomite, granite, volcanic ash and limestone, while the imported fillers include fly-ash, furnace slag, and hydrated lime (Bahia *et al.*, 2011).Mineral fillers were originally added to dense graded asphaltic concrete mix to fill the voids in the aggregates skeleton and to reduce the voids in the mix (Powell *et al*, 2005). A number of studies have been made on the use of different fillers in various paving mixes. Although, filler particles are very small in size, it is well documented that filler exerts a significant effect on the characteristics and performance of asphaltic concrete mix. Good packing of the coarse and fine aggregates and filler provides a strong backbone for the mix (Zulkati *et al.*, 2011). Higher filler content results in stronger pavement attributed to better asphalt cohesively and better internal stability. However, excess amount of filler may weaken the mix by increasing the amount of asphalt needed to coat the aggregates (Kandhal *et al.*, 1998).

Sawdust is an organic waste material resulting from the mechanical milling of timber (wood) into various shapes and sizes (Marthong, 2012). The ash is obtained by its combustion.

Udoeyo *et al.* (2006) evaluated the physical properties of waste wood ash. He reported that wood waste ash had a specific gravity of 2.43. He also carried out X-ray diffraction test to determine the oxide concentration of the ash. The result showed that its major oxides were; CaO, SiO_2, Al_2O_3, K_2O, Fe_2O_3, MgO, SO_3, TiO_2 and P_2O_5. Compounds such as Na_2O, ZnO, Cl, MnO, SrO, Cr_2O_3, CuO, ZrO_2 and Rb_2O were detected in trace amounts. The binder was replaced with sawdust ash at 5, 10, 15, 20, 25, and 30 % by weight of the binder, and subjected the samples to compressive test. The results showed that the strengths of the samples with sawdust ash were marginally lower than the control mix. However, there was increase in strength with curing age. This was attributed to pozzolanic action.

Sobolev and Faheem (2014) studied sawdust ash from four different sources. The study indicated that, the major oxides were; CaO, SiO_2, Al_2O_3, K_2O, Fe_2O_3, MgO, K_2O, Na_2O, SO_3, TiO_2 and P_2O_5. It was observed that CaO was dominant having the range of 28.1 to 51 %, SiO_2 (5.8 - 25.2 %), Al_2O_3 (4.7 - 14.2 %), Fe_2O_3 (1.2 - 4.5 %), MgO (2.2 - 4.7 %), K_2O (0.2 - 0.5 %), Na_2O (0.4 – 2.5 %), SO_3 (17.1 - 33.3 %), TiO_2 (1.0 - 1.0 %) and P_2O_5 (0.4 - 1.0 %). They replaced the filler in the mastic (a blend of bitumen and particulate filler) with 5, 10, and 15 % by weight of the filler. The various mastics were subjected to complex shear modulus and stiffness tests. The results showed that, CaO was very influential on asphalt performance and, they stated that increasein the values of CaO, SO_3, and loss on ignition (LOI) increases the complex shear modulus and stiffness of the mastic, which improve the rutting resistance at high temperatures, minimize pavement ravelling, stripping to moisture attack and also improve aging resistance. Complex shear modulus is the measure of the overall resistance to deformation under dynamic shear loading.

MATERIALS AND METHODS

The materials used in this research included bitumen, coarse and fine aggregates, mineral filler and sawdust ash. The bitumen used was 60/70 penetration grade. It was obtained from Espro Asphalt Plant, Ife-Ibadan road, Osun state, Nigeria. The coarse aggregate consisted of granite particles passing 12.5 mm and retained on 9.5 mm BS sieves, fine aggregate consisted of granite dust with fractions passing 4.25 mm and retained on 75 µm BS sieves, the mineral filler consisted of granite dust passing 75 µm BS sieve. The aggregates were obtained from Wasimi quarry along Ife-Ibadan Road, Osun State, Nigeria. The sawdust was obtained from a sawmill located at Alekwuodo in Osogbo, Osun State, Nigeria. The sawdust was burnt in a furnace at temperature of 800°C to obtain the ash. It was then dry sieved through 75 µm sieve. The properties of the bitumen, aggregates and the sawdust were determined using standard procedures.

The mix design proportion consisted of coarse aggregates; 12.5 mm (10 %) and 9.5 mm (30 %), fine aggregate, 4.75 mm (55 %) and mineral filler, 0.075 mm (5 %). The gradation test was carried out according to ASTM C136 (2003).

Preparation of Specimen

The asphaltic concrete samples were prepared as per ASTM D1559 at different bitumen contents to obtain the optimum bitumen content (OBC) of 5.9%. This was considered as the control mix. Samples were further prepared by replacing sawdust ash with 5, 10, 15, 20 and 25% by weight of the granite filler in the control mix..

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Marshal Stability Test

Marshal test was carried out and the values of stability, flow, bulk density, voids filled with bitumen (VFB), air voids (VA), and voids in mineral aggregate (VMA) were determined.

RESULTS AND DISCUSSIONS

Physical Properties of Bitumen

Table 1 shows the results of the penetration, specific gravity and softening point of bitumen. The values for the penetration, specific gravity and softening point obtained were, 62.2, 1.02 and 50 respectively.The results show the bitumen conforms to all the requirements for asphaltic concrete production (Clause 6371, Table VI-15, FMWH, 19997)

Table 1: Physical Properties of Bitumen

Properties	Test method	Result
Penetration value at 25°C(0.1mm)	ASTM D5	62.2
Specific gravity	ASTM D70	1.02
Softening point (°C)	ASTM D36	50

Physical Properties of Aggregates

Table 2 shows the results of the aggregate crushing value, flakiness index, elongation index and water absorption. These values are all within allowable limits (Brennan and O'Flaherty, 2002; Kadyali and Lai, 2003; Roberts *et al.*, 1996).Furthermore, the aggregate crushing value, flakiness index and water absorption factor of 23.8, 24.1 and 0.38 % respectively, do not exceed the corresponding values of 30, 35 and 0.5 % respectively, provided for in the FMWH, 1997, specification (Clause 6371, Table VI-13). The aggregates are therefore of the quality required.

Table 2: Physical Properties of Granite Aggregate and Sawdust Ash

Properties	Values
Aggregate crushing value (%)	23.8
Flakiness index (%)	24.1
Elongation index (%)	28.8
Water absorption (%)	0.38
Specific gravity	2.71
Specific gravity of saw dust ash	2.29

Chemical Composition of Sawdust Ash (SDA)

Table 3 shows the chemical composition of sawdust ash (SDA) as obtained from X-Ray Fluorescence. From the table, SDA contained the following elemental oxides: calcium-oxide (CaO) 49.70 %, potassium oxide (K_2O) 21.72 %, sulphur oxide (SO_3) 9.04 %, silica (SiO_2) 5.30 %, magnesium oxide (MgO) 4.06 %, tungsten oxide (WO_2) 2.04 %, alumina (Al_2O_3) 1.90 %, iron-oxide (Fe_2O_3) 1.65 %, and phosphorous oxide (P_2O_5) 1.38 %, respectively. The loss on ignition was 7.3. The high content of calcium oxide (lime) is indicative of improvement in bond strength (Faheem, 2009, Sobolev and Faheem, 2014). The chemical characteristics such as silica (SiO_2), alumina (Al_2O_3), iron (Fe_2O_3) and quicklime (CaO) in the ash, govern the credibility of its use as a replacement for cement (Vassilev *et al.*, 2010).

Table 3 : Chemical Composition of Sawdust Ash (SDA)

Chemical composition	Percentage (%)
SiO_2	5.30
Al_2O_3	1.90
Fe_2O_3	1.65
CaO	49.70
MgO	4.06
SO_3	9.04
WO_2	2.04
K_2O	21.72
P_2O_3	1.38
LOI	7.30

Aggregate Gradation

Figure 1 shows the aggregate gradation curve. This gradation curve shows that the mix was well graded, and maximum volume of aggregate will be achieved in the aggregate mix (Chen and Richard-Liew, 2003). Also, a dense material will be obtained when the aggregate is compacted (Brennan and O'Flaherty, 2002). The aggregate gradation curve obtained was within the Federal Ministry of Works and Housing (FMWH, 1997) specifications, clause 6374, Table VI-16). The composition consequently complies the standard requirements.

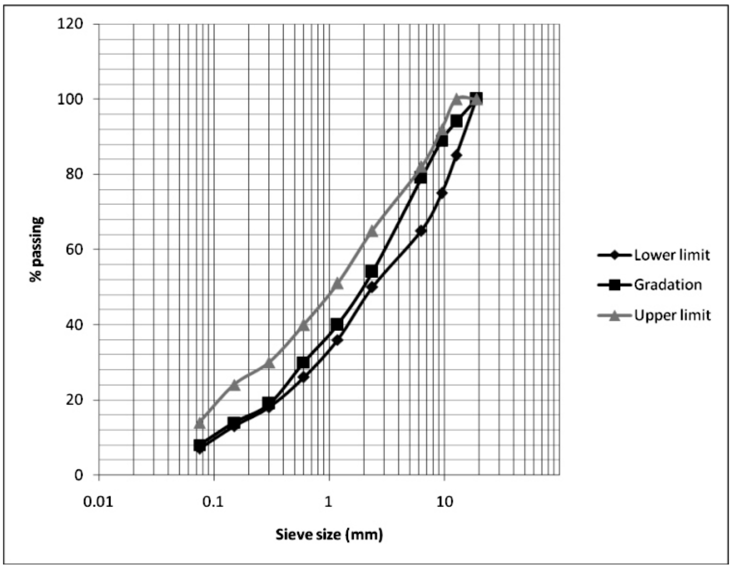

Figure 1: Aggregate Gradation Curve

Marshal Properties with Sawdust Ash
Stability

Figure 2 shows the stability curve of the mix. The stability values from 5 to 20 % sawdust ash exhibited higher values than the control mix. This indicates that sawdust ash enhanced the stability of the mix. The increase in stability could be attributed to high percentage of calcium oxide in the sawdust ash (Faheem, 2009). Sobolev and Faheem (2014) reported that the addition of sawdust ash with high percentage of calcium oxide to mastic increased the complex shear modulus of the mastic. This shear modulus correlates with stability of asphaltic concrete in terms of rutting resistance measurement.

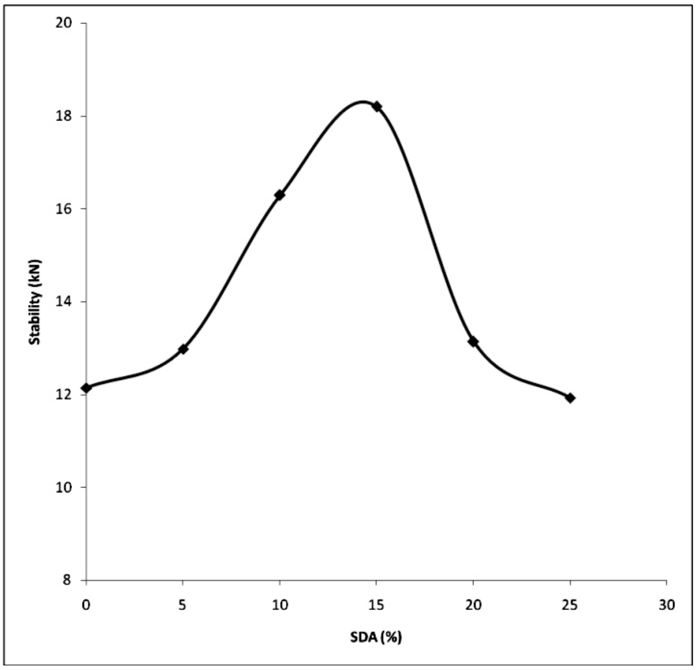

Figure 2: Variation of Stability with Increasing Sawdust Ash in the Asphaltic Concrete

Physically, lime particles (contained in sawdust ash) have higher voids (Ridgen air voids) with typical values ranging from 60 % - 70 %, while granite filler have values ranging from 30 % - 40 % as shown in Figure 3. The different in porosity comes from the fact that the voids in granite filler are between particles while the voids in the lime are inside the particles summing up to the porosity between particles leading to higher values.

At higher temperatures, the internal porosity of hydrated lime particles are filled with bitumen and these particles are seen as hard spheres in the bitumen matrix thereby increasing the volume fraction of the mix which controls the stiffening effects (Lesueur *et al.*, 2012).

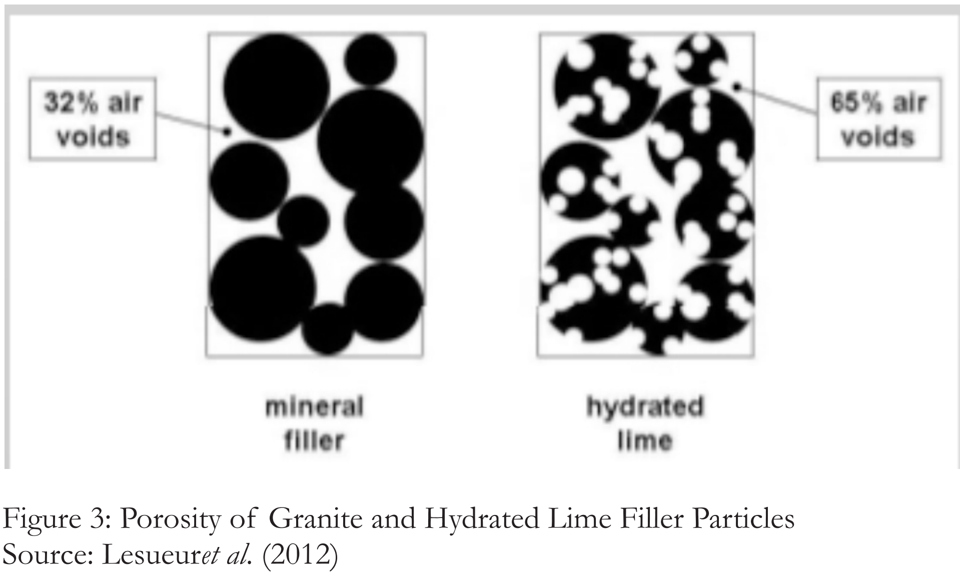

Figure 3: Porosity of Granite and Hydrated Lime Filler Particles
Source: Lesueur*et al.* (2012)

Chemically, the increase in stability could be attributed to sawdust having the elemental oxide, CaO (lime), which inhibits the solubility of the bitumen by chemical reaction to form insoluble salts (Faheem, 2009; Sobolev and Faheem, 2014). Ishai and Craus (1977) pointed out that one of the effects of lime is to allow the precipitation of calcium ion (Ca2+) onto aggregate surface, making it more favourable to bitumen. Plancher *et al.* (1977) stated that calcium ions from lime react with COOH to form calcium salts of relatively low solubility. Fromm (1974) reported that the addition of hydrated lime absorbs carboxylic acids in the asphalt which results in more water-resistant asphalt-aggregate bonds. When lime is added to the asphalt, some dissociation of hydrated lime molecules occurs, resulting in calcium ions (Ca^{2+}). These ions interact with carboxylic acids (RCOOH) in order to form rather insolublecalcium organic salts (Petersen *et al.*, 1978) as illustrated in equation 1. These bonds are strongand contribute to adhesion (Little and Jones, 2003). The chemical reaction is as shown below:

$CaO + 2RCOOH \rightarrow (RCOO\text{-})_2Ca + H_2O$ (1)
Quick lime Carboxylic acid Insoluble salt water.

Flow

Figure 4 shows an initial decrease in the flow from 5 % SDA to an optimum value at 20 % SDA and then increased. The decrease could be attributed to the stiffening effect of lime particles in sawdust ash on the bitumen (Sobolev and Faheem, 2014). By stiffening the mix, the lime increases the resistance of the mix to rutting and fatigue cracking, and improves the moisture resistance (Epps *et al.,* 2003).

Bulk Density

Figure 4 shows a decrease in the bulk density value from 5 to 25 % SDA. This could be attributed to the fact that sawdust ash has a lower specific gravity than the granite filler. This could lead to lower mix density (Elinwa *et al.*, 2005).

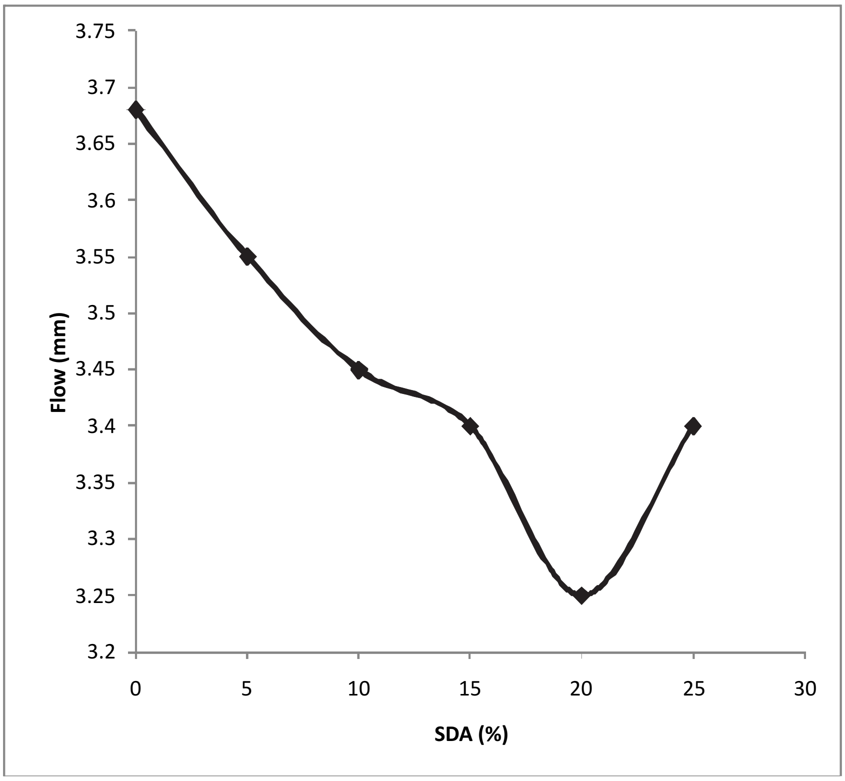

Figure 4: Variation of Flow with Increasing Sawdust Ash (SDA) in the Asphaltic Concrete

Voids filled with Bitumen

Figure 5 shows a significant decrease in the value of the voids filled with bitumen from 5 to 25 % SDA. This could be attributed to the high porosity of high calcium particles in the SDA; 4which at higher temperatures absorb the bitumen needed to fill the voids between aggregate particles (Lesueur *et al.*, 2012).

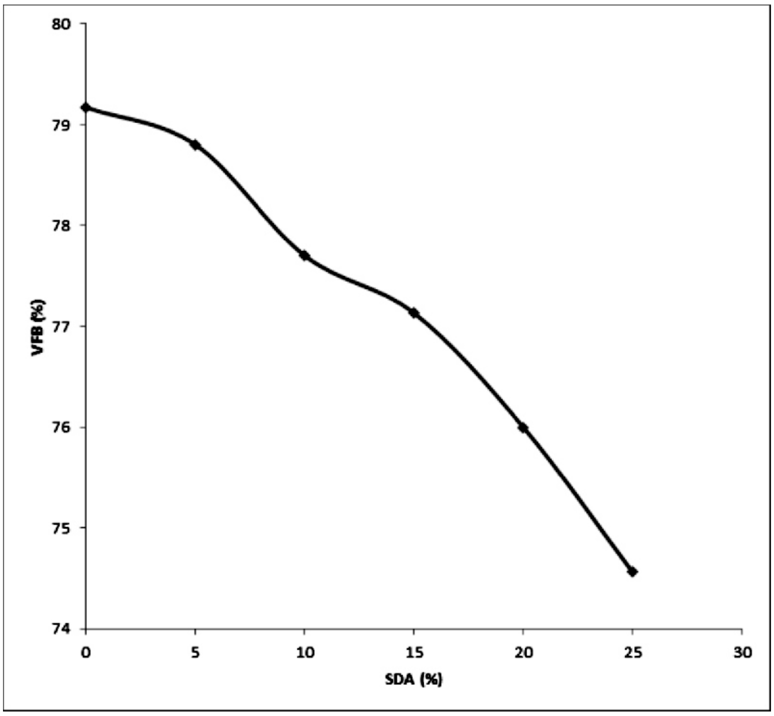

Figure 5: Variation of Voids Filled with Bitumen (VFB) with Increasing Sawdust Ash (SDA) in the Asphaltic Concrete

Air Voids

Figure 6 shows a steady increase in the value of the air voids (VA) from 5 to 25 % SDA. This could be due to the absorption of bitumen in the mix at higher temperatures by the highly porous calcium particles of SDA (Lesueur *et al.*, 2012), leading to increase in the value of the air voids in the mix.

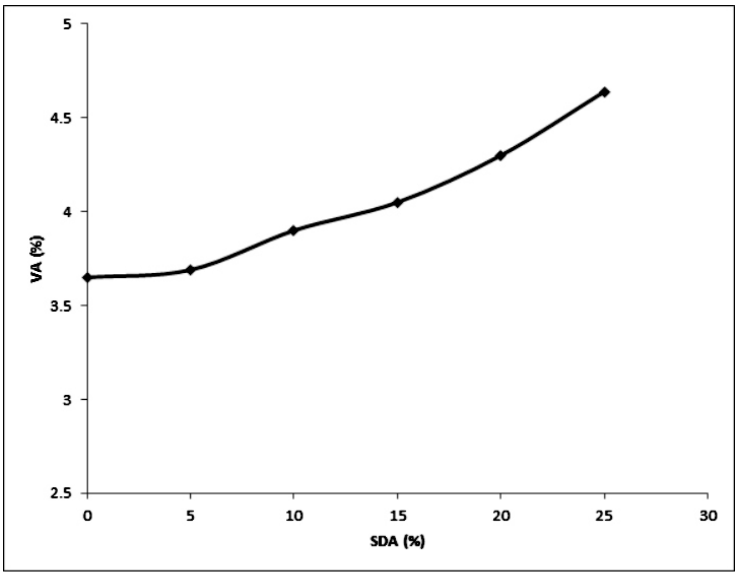

Figure 6: Variation of Air Voids (VA) with Increasing Sawdust Ash (SDA) in the Asphaltic Concrete

Voids in Mineral Aggregate

Figure 7 shows a steady increase in the value of the voids in mineral aggregate from 5 to 25 % SDA. This could be due to the absorption of bitumen in the mix at higher temperature by the highly porous calcium particles of SDA (Lesueur *et al.*, 2012), leading to increase in the value of the voids in mineral aggregate.

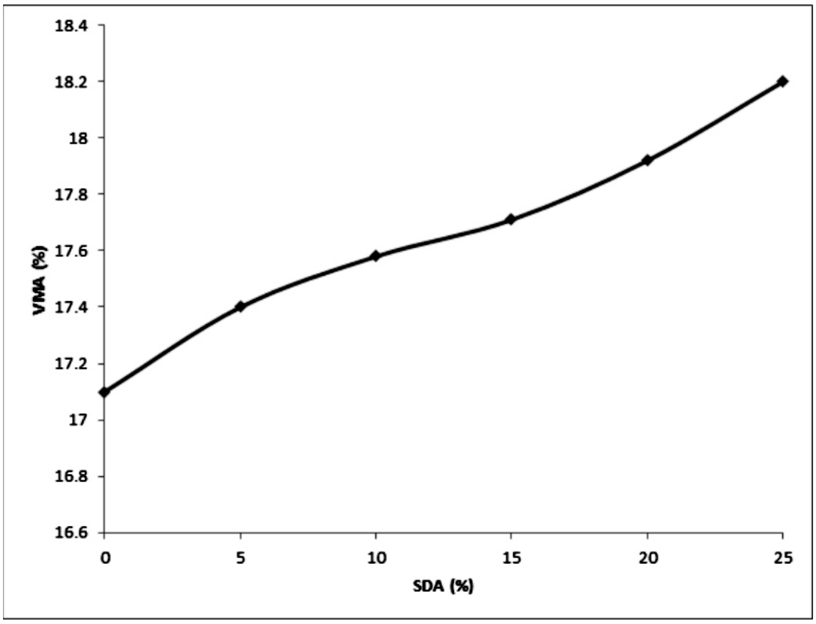

Figure 7: Variation of Voids in Mineral Aggregate (VMA) with Increasing Sawdust Ash (SDA) in the Asphaltic Concrete

CONCLUSION

The results from this study showed that physical properties of bitumen which included penetration, softening point and specific gravity; the physical properties of granite aggregates which included aggregate crushing value, flakiness index, elongation index, water absorption and specific gravity satisfied the specifications for road materials. The specific gravity value of 2.29 for sawdust ash indicated that the sawdust ash was a light weight material, while the chemical composition of the sawdust ash showed the presence of the calcium oxide (CaO) , silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), sulphur oxide (SO_3), potassium oxide. (K_2O), magnesium oxide (MgO), tungsten oxide (WO_2) and phosphorous oxide (P_2O_5) as the main elemental oxides. Calcium oxide had the highest percentage and is responsible for the improvement in the properties of asphaltic concrete. The modification of the asphaltic concrete mixed with different percentages of sawdust ash significantly and positively affected the properties of the asphaltic concrete. Thus, the sawdust ash has the potential to improve the properties of asphaltic concrete.

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