GREEN MATERIALS FOR ROADS CONSTRUCTION IN NIGERIA

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Abstract- Reclaimed asphalt, used automobile tires and rice husk, were regarded as waste. These materials could be used in construction of new roads and for roads rehabilitation. Investigation into the production of a Green Hot Mixed Asphalt (GHMA) pavement using Reclaimed Asphalt Pavement (RAP) as partial replacement for coarse aggregate, Crumb Rubber (CR) from waste automobile tires as modifier for bitumen binder and Rice Husk Ash (RHA) as partial replacement of ordinary portland cement (OPC) filler, for roads construction and rehabilitation was presented. 30% Reclaimed asphalt of total aggregate, 15% Crumb Rubber of total binder content, 5% Rice Husk Ash of total mix, and 5.2% Crumb Rubber Modified Bitumen content were recommended for optimum performance. Loss of marshal stability was investigated on mix with the recommended optimum CRMB. The mix revealed good performance with only about 13% loss of stability after 24 hours of immersion in hot water bath, as against about 24% marshal stability lost reported in previous studies for conventional Hot Mixed Asphalt (HMA).

Keywords- Rice Husk, Reclaimed Asphalt, Filler, Crumb Rubber, Bitumen Content Green Hot Mix Asphalt

I. INTRODUCTION

1.1 Preamble

There is considerable research interest in the re-use of waste materials for roads construction e.g. (Abarshi, 1988; Sadeeq, et al., 2014). Green Hot Mixed Asphalt (GHMA) refers to Hot Mixed Asphalt (HMA) that uses waste material as one or more of its components. This study investigated the possible use of three waste materials for the production of HMA in roads construction. The materials are, Reclaimed Asphalt (RA), Crumb Rubber (CR) and Rice Husk (RH). Possible utilization of these materials will contribute to the proper management of solid waste and sustainable roads construction.

1.2 Reclaimed Asphalt (RA)

Reclaimed Asphalt is generated from the removal of deteriorated road surface during roads rehabilitation. In Nigeria, this material is usually dumped by the roads side as waste. This results to environmental nuisance; polluting roads side and usually inhibiting side drains for water. Previous studies revealed that, reclaimed asphalt can be re-used for roads construction (e.g. Joel, 2010; Vicroads, 2011; Abiola, et al., 2014; Delfosse, et al., 2014). If carefully crushed, high quality and well graded aggregates that are coated with bitumen are produced from Reclaimed Asphalt (NIDEP, 2014). Since the process of production of virgin aggregate is expensive and environmentally unsustainable, construction and rehabilitation of roads using reclaimed asphalt is expected to be more economical and environmentally sustainable (Kennedy et al., 1998; Salman, 1998).

1.3 Crumb Rubber (CR)

The growing number of cars produced in the world is enormous. It was established in the literature that about 1.4 billion tires are sold worldwide each year (Mousavi, et al., 2012; Davide, 2013). In Nigeria, alone, approximately 15 million scrap tires are currently in existence (Aisien, et al., 2011). The management of waste-tire rubber is very difficult, because it is generally non-biodegradable even after long-period of landfill treatment (Guneyisi, et al., 2004). One important area for the possible utilization of waste tire is on highway construction and rehabilitation (Teleb, et al, 2008). Crumb Rubber is a materially that are used as partial replacement for bituminous binder. It is obtained after shredding waste tires to smaller sizes. Crumb rubber is added to bituminous binder in a specified proportion to produce what is known as Crumb Rubber Modified Binder (CRMB). CRMB was extensively used in advanced countries for a very long time (Epps, 1994; Heitzman, 1992).

1.4 Rice Husk Ash (RHA)

Due to much construction activities going on around the world, the demand for Ordinary Portland Cement (OPC) had risen continuously. This is in addition to heavy CO_2 emission during cement manufacturing process. CO_2 is the major contributor to ozone layer depletion, hence global warming. Identification of more sustainable cement replacement materials in Hot mixed asphalt would be a welcomed development. The possible utilization of Rice Husk Ash as cement replacement is investigated in this study. Rice husk ash is obtained by control burning of the Rice Husk. This ash has high specific surface area and pozzolanic in nature (Tsado, et al, 2014). Rice husk is a readily available agricultural waste that has found useful application in engineering and other field of studies. Rice is grown on every continent except Antarctica and covers 1% of the earth's surface. It is a primary source of food for billions of

people, and ranks second to wheat in terms of area and production (FAO, 2002; Omatola and Onojah, 2009).

II. MATERIALS AND METHODS

2.1 Materials Used in the Investigation

Materials used in this study are 80/100 penetration grade bitumen (virgin binder), shredded automobile tire (crumb rubber), Fresh Coarse Aggregate, Reclaimed Asphalt, Ordinary Portland Cement and Rice Husk Ash. The Reclaimed Asphalt was obtained from the site of an ongoing roads rehabilitation project along Katsina-Kano Road (5 km from Katsina) in Katsina State, Nigeria. The fresh aggregate, was obtained from a stone quarry belonging to a Nigeria-based construction company (Mothercat Limited) at Katsina. Ordinary Portland Cement (OPC), produced by the Sokoto, Cement Company of Nigeria, was used in the mix. The Rice Husk was obtained from a maize farm at Pambegua Ikara, Local Government area of Kaduna State, Nigeria. The Crumb Rubber was produced from waste car tires, obtained from local vulcanizers at Samaru, Zaria, Kaduna State, Nigeria.

2.2 Experimental Methodology

The first step in the utilization of the Reclaimed Asphalt, Crumb Rubber and Rice Husk Ash as partial replacement for Coarse aggregates, bituminous binder and Ordinary Portland Cement respectively is the appropriate mix design strategy. The objective of the mix design is to determine the best blend through several trial mixes. Marshal Mix design method was adopted (ASTM D1559). Investigation was conducted on Asphalt Briquettes, prepared by reconstituting Reclaimed Asphalt/Fresh Aggregate, Rice Husk Ash/Ordinary Portland Cement filler and Crumb Rubber/Bitumen binder.

2.2.1 Particle Size Distribution of the Aggregate

Particle size distribution tests were carried out on the Reclaimed Asphalt (RA) and the fresh virgin aggregate, in accordance with the general Specifications for Roads and Bridges, Federal Ministry of Works and Housing, Nigeria (FMWH, 1997). The results are presented in Table 1.0, placed alongside the gradation limits of the FMWH (1997). It is clear from the result that both the Reclaimed Asphalt (RAP) and the virgin aggregate, failed to fit within the envelope of the FMWH (1997). Based on a separate recent investigation (Sadeeq, et al., 2014), 30% RAP and 70% fresh coarse aggregate proportions were found to satisfied the FMWH (1997) requirement. This was therefore adopted.

2.2.2 Partial Replacement of OPC with RHA

Mineral filler in Hot Mixed Asphalt (HMA) consists of very fine inert mineral matter that is added to the hot mix asphalt to improve its density and strength. Filler is generally selected on the basis of its ability to increase the stiffness of the binder or improve adhesion between the binders and aggregate (Overseas Roads Note 19, 2002). Typical mineral filler completely passes a 0.060mm (No. 30) sieve with at least 65 percent of the particles passing the 0.075mm (No. 200) sieve. In this study, 10% mineral filler of total mix was adopted based on the previous studies (Sadeeq et al, 2014). Five trial mixes with the dosages of 0%RHA/10%OPC, 3%RHA/7%OPC, 5%RHA/5%OPC, 7%RHA/3%OPC and 10%RHA/0%OPC were subjected to various laboratory tests. The chemical composition of OPC and RHA are presented in Table 2.0.

Table 1.0 : Particle Size Distribution for RAP and fresh aggregate Compared with FMWH Specification

Sieve Size (mm)	Percentage Passing		FMWH Specification (FMWH, 1997)
	RAP	Fresh Aggregate	
25	-	100	-
19.00	100	99.1	100
12.50	84.2	82.8	85 – 100
9.50	70.0	72.7	75 – 92
6.30	47.0	58.6	65 – 82
2.36	21.5	42.1	50 – 65
1.18	12.8	34.1	36 – 51
0.60	7.7	27.8	26 – 40
0.30	3.9	19.9	18 – 30
0.15	1.8	9.9	13 – 24
0.075	0.6	6.0	7 – 14

Table 2.0 Typical Chemical composition of OPC and RHA

Chemical Constituents	Composition in OPC	Composition in RHS (%)
SiO_2	18.24	91.80
Al_2O_3	4.88	0.06
Fe_2O_3	3.47	0.09
Cao	60.82	1.02
MgO	3.20	0.42
Na_2O	0.02	0.06
K_2O	1.73	1.73
LOI	2.04	2.86

(Sources: Rodrigues, et al, 2006; Tsado, 2014)

2.2.3 Crumb Rubber Modified Binder (CRMB)

80/100 penetration grade bitumen was used in this study as the virgin binder. This material is widely used in Nigeria for the production of Hot Mix Asphalt (HMA). Modification of the bitumen with the Crumb Rubber was carried out using wet process. The 80/100 bitumen was first heated up to a temperature of 400^0C. The Crumb Rubber was then added to the hot binder and thoroughly mixed. Propelled blade mixer at blade speed of 200 rpm was used for the preparation. The resulting mixture was then maintained at the mixing temperature for 50

minutes in order to permit good interaction between the Crumb Rubber and the Bitumen. During interaction, which is purely physical, the Crumb Rubber absorbs the aromatic fraction of the bitumen and swell. This physical interaction lead to the reduction of the oily part of the bitumen and Asphalt-rubber of higher viscosity compared to the virgin bitumen was obtained.

Six laboratory tests were conducted to investigate the effect of the addition of the Crumb Rubber on the Bitumen. The tests include penetration grade test, ductility test, elastic recovery test, softening point test, viscosity test and dynamic shear Rheometer test.

Penetration test was used to measure the binder consistency. The penetration test was performed using penetrometer, according to ASTM D5 (2005). Ductility test was performed according to ASTM D113 (2007). Ductility gives a measure of adhesive property of binder and its ability to stretch. The determination of the softening point was made using Ring and Ball test, according to ASTM D36 (2009). While, Brookfield's Viscometer was used for the viscosity test. Dynamic Shear Rheometer measures the flow properties of liquid asphalt binders at intermediate (i.e., 20ºC) to high (i.e., 64ºC) temperatures. It works by applying a sinusoidal shear stress to produce a resulting shear strain. The complex shear modulus (G*) is a ratio of the applied shear stress (t) to the resulting shear strain (g). The phase angle, d, (related to the time lag between input and output signals) provides a relative indication of the viscous and elastic behavior of the asphalt binder. Materials with a phase angle of 90 degrees are completely viscous; while materials with a phase angle of 0 degrees are completely elastic. At intermediate temperatures, such as 20ºC, asphalt binders are said to be viscoelastic (phase angle near 45 degrees).

2.2.4 The Marshal Test

Marshal Briquettes were prepared for the Marshal Stability Test. The material for the briquettes includes Reclaimed Asphalt, Virgin Aggregate, Crumb Rubber, Rice Husk Ash and Ordinary Portland Cement. The aggregate, consist of 30% Reclaimed Asphalt Pavement and 70% Virgin aggregate. The bitumen content was varied from 4.5 to 6.5% at 0.5% interval according to ASTM D 1559. 10% filler of total mix was used, with Rice Husk Ash replacing Cement in the proportion of 0%RHA/10%OPC, 3%RHA/7%OPC, 5%RHA/5%OPC, 7%RHS/3%OPC and 10%RHA/0%OPC of the total mix. A total of 75 marshal briquettes were prepared for the test. The properties that are of interest in the Marshal test include:

a. Marshal stability. This is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60˚C.

b. Flow. This is a measure of flexibility, measured by the change in diameter of the test sample in the direction of load application between the start of loading and at the time of maximum load.

c. Compacted Density of the mix (CDM).

d. Voids in the Mix (VIM). This is the percentage of air voids by volume in the specimen.

e. Percentage voids in mixed aggregates (VMA). This is the volume of inter-granular void space between the aggregate particles of a compacted paving mixture. It includes the air voids and the volume of bitumen not absorbed into the aggregate. It is expressed as a percentage of the total volume of the mix.

f. Percentage voids filled with bitumen (VFB). This is the voids in the mineral aggregate frame work filled with bitumen binder. VFB is inversely related to air voids and hence as air voids decreases, the VFB increases.

III. DISCUSSION

3.1 Effect of Crumb Rubber on the Physical Properties of the Bitumen Binder

The proportion of the Crumb Rubber used in the bituminous binder was 0%, 5%, 10%, 15% and 20% of the total binder. Six performance tests were conducted on three specimens for each mix. The tests include Penetration, Ductility, Elastic Recovery, Softening point, Brookfield viscosity and dynamic shear rheometer. The test results are presented in Figs. 1.0 to 6.0.

3.1.1 Penetration Test Result

The effect of the Crumb Rubber concentration on penetration values is highly significant as shown in Fig, 1.0. It is clear from the plot that, increase in the amount of crumb rubber result to decrease in penetration up to 20% crumb rubber content. The average percentage decrease in penetration values range from 16.28% to 53.40%, for 5% to 20% crumb rubber contents respectively. This is a clear indication of increasing binder stiffness as a result of addition of crumb rubber. This will contribute to the rutting resistance of the binder.

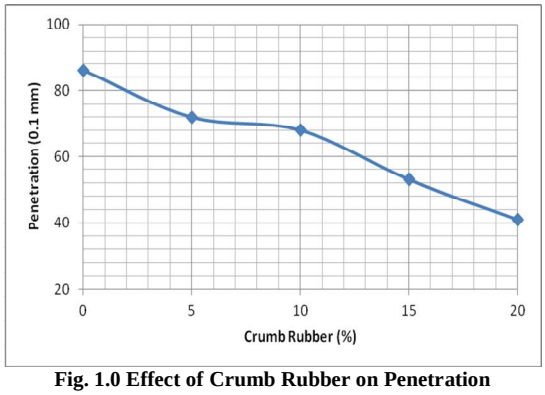


Fig. 1.0 Effect of Crumb Rubber on Penetration

3.1.2 Ductility Test Results

Ductility defines the tensile properties of bituminous materials. It is measured by the distance in centimeter to which standard specimen will elongate before

breaking. The test was conducted in accordance with ASTM D 113 specification. Continue addition of crumb rubber to the bitumen results to dramatic increase in the ductility values as shown in Fig. 2.0. Comparing the modified with the unmodified binder, the average decrease in ductility is 16.30% to 44.60% for 4% to 20% crumb rubber content respectively. The decrease in ductility could be as a result of thickening of the crumb rubber – bitumen blend as a result of the absorption of the oily part into the rubber component. The thickening of the binder is also an indicator of good rutting resistance.

3.1.3 Elastic Recovery Test Results

The Elastic Recovery test was conducted in accordance to ASTM D 6084 at 25^0C. As shown in Fig. 3.0, the elastic recovery increase with increasing crumb rubber content. For asphalt rubber content ranging from 5% to 20%, the percentage increase in elastic recovery ranges from 24% to 67% respectively. The results have shown pronounced effect of high amount of crumb rubber in the modification of bitumen to produce Asphalt rubber. High percentage of crumb rubber results to high elastic recovery, indicating improvement of binder resistance to rutting. The blend has high ability to recover its shape after removing applied load, considering the fact that the elastic recovery changed to over 90% at 20% crumb rubber from about 27% for the unmodified binder.

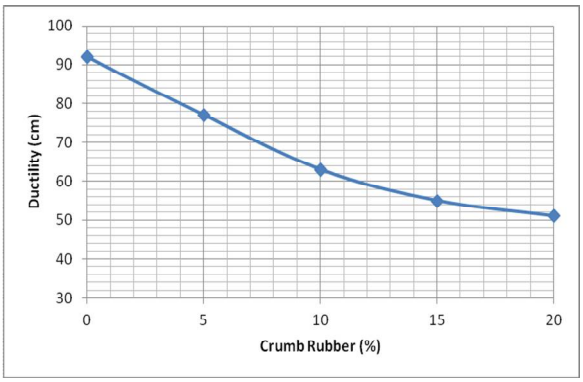


Fig. 2.0 Effect of Crumb Rubber on Ductility

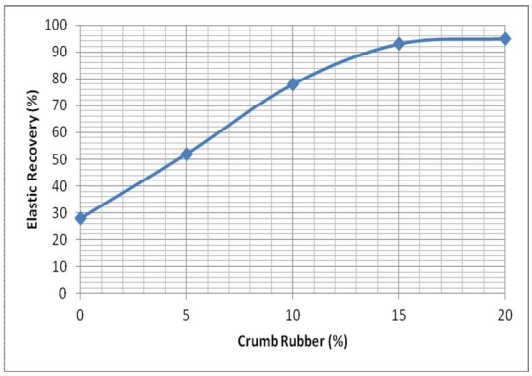


Fig. 3.0 Effect of Crumb Rubber on Elastic Recovery

3.1.4 Softening Point Test Result

The softening point test was conducted according to ASTM D36-95. As indicated in Fig 4.0, the softening point increases with increasing crumb rubber content. Two blending temperature of 160^0C and 180^0C were used. Also 30 minute and 60 minutes mixing times were considered. The results indicated that, blending time and mixing temperature have little effect on the softening point of crumb rubber modified asphalt.

3.1.5 Brookfield Viscosity Test

The viscosity of modified bitumen at high temperature is indicator of its ability of easy pumping through bitumen plant. Brookfield Viscosity test was performed on the binder at various percentage of Crumb Rubber in accordance with the Asphalt Institute (2003). The viscosity test results are presented in Fig. 5.0. It is clear from the plot that, the increase in crumb rubber content results to considerable increase in viscosity of the binder. The viscosity of the binder increased by 338% when the percentage crumb rubber is increased from 0 to 20%. This is another indicator of rutting resistance for modified asphalt compared to unmodified asphalt.

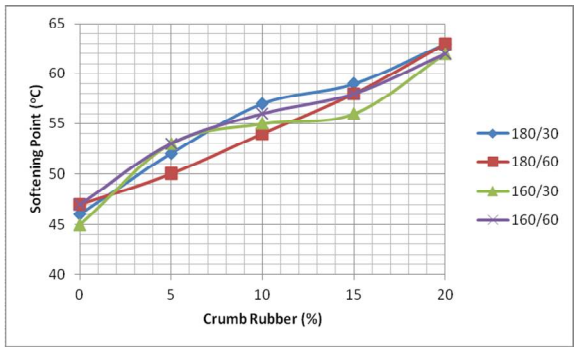


Fig. 4.0 Effect of Crumb Rubber on Softening point

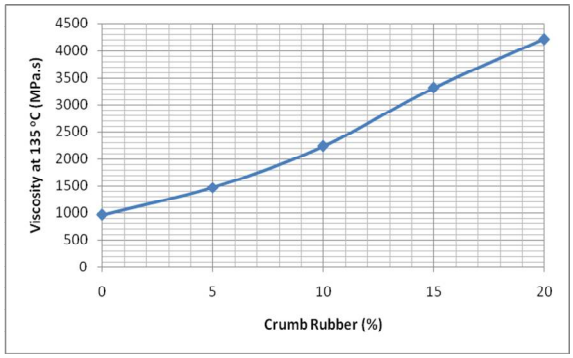


Fig. 5.0 Effect of Crumb Rubber on Viscosity

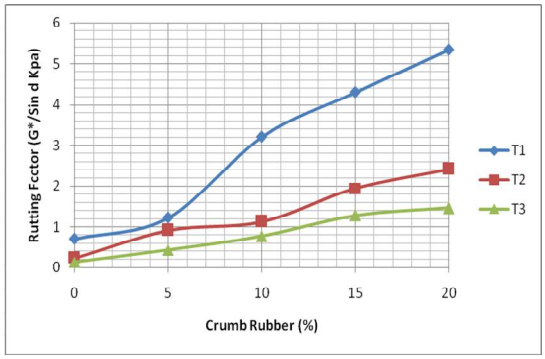


Fig. 6.0 Effect of Crumb Rubber on Rutting Resistance

3.1.6 Dynamic Shear Rheometer Test

Another important test for investigating the performance of asphalt binder is the Dynamic Shear Rheometer Test (DSR). The DSR test was performed on the asphalt rubber samples with various crumb rubber content (0%, 5%, 10%, 15% and 20%). In each case, Rutting factor (G*/sin d) which is an indicator of rutting resistance was obtained at three temperature of 64^{0}C, 70^{o}C and 76^{o}C. The results are presented in Fig 6.0. It is clear from the plot that the rutting factors increases with increasing crumb rubber content. It is also observed that, the rutting factor decreases with increasing temperature. However, even at 76^{o}C, the rutting factors for the modified binder are higher than for the base binder. The increased in the rutting resistance for the modified binder may be attributed to the physical interaction between the crumb rubber and the based bitumen resulting to increased viscosity and binder stiffness.

3.2 Marshal Stability Test Results

Figs 7.0 to 12.0 show the plots of stability, Flow, CDM, VIM, VMA and VFB respectively. For each of the five mixes, test samples were prepared for five different bitumen content, 4.5%, 5.0%, 5.5%, 6.0% and 6.5%, with three samples for each fraction. Fig, 7.0 shows the plots of the marshal stability against bitumen content. The stability values increases with increasing bitumen content up to maximum value, then decreases with increasing bitumen content. The maximum values of the stability are 9.0, 8.4, 7.5, 6.7 and 6.7 kN for 0%RHS/10%OPC, 3%RHS/7%OPC, 5%RHS/5%OPC, 7%RHS/3%OPC, 10%RHS/0%OPC mix respectively. The specification limit for marshal stability is that it should not be less than 5kN. This implied that all the mixes satisfied the minimum standard requirements for stability.

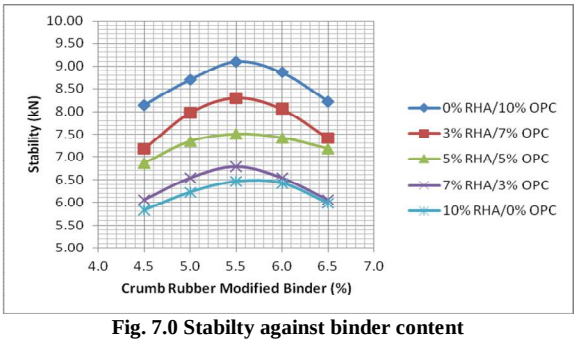


Fig. 7.0 Stabilty against binder content

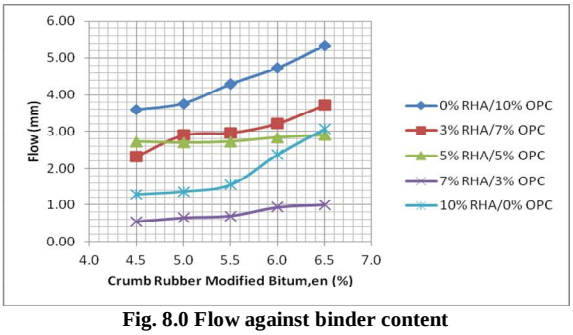


Fig. 8.0 Flow against binder content

Fig. 8.0 show the plots of flow against bitumen content. The results indicated that, increasing the bitumen content leads to linear increase in the flow values. The minimum specication limits for flow is 2.0. The use of Asphalt with flow value greater than 2.0 may result to rutting. This implied that the optimum value for RHS is 5%. This is because, the mixes with 7% and 10% RHS lead to flow values that are not acceptable.

The relationship between compacted density and bitumen content is presented in Fig. 9.0. It was found that as the RHS content of the filler increases, the value of the compacted density decreases. This may be attributed to the higher air voids created by the substittion of Ordinary Portland Cement with Rice Husk Ash.

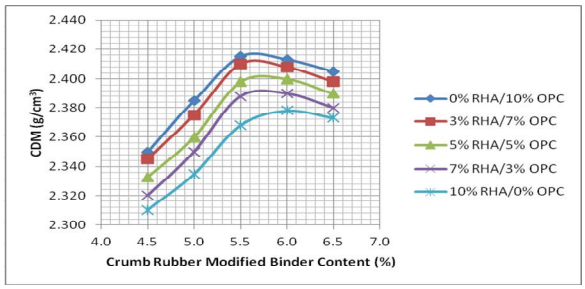


Fig. 9.0 CDM against binder content

Fig. 10.0 shows that the void in mix increases with increasing bitumen content. Likewise increase in RHS result to increase in the percentage air void. This is in aggreement with the earlier observation made from the CDM plots in Fig 9.0, confirming that the addition of RHS as partial replacement for OPC as mineral filler result to increased in air void. However, all point were above the lower limit of 3% air void in mix specified in Asphalt Institute (Asphalt Institute, 1984).

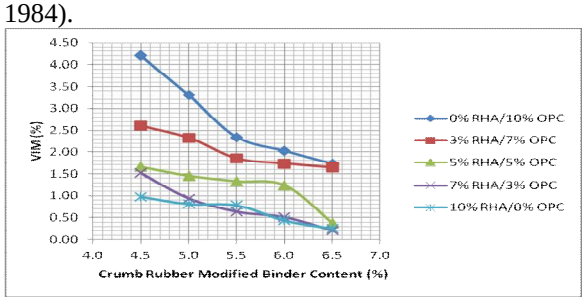


Fig. 10.0 VIM against binder content

Voids in mineral aggregates is the volume of intergranular void space between the aggregate particlles of a compacted paving mixture. It include the air voids, and the volume of asphalt not absorbed into the aggregate. The plots of the VMA against bitumen content are presented in Fig. 11.0. It is observed from the plots, that for all the consdered mixes, the VMA increase with increasing bitumen content. The control specimen has the least value of VMA. The increase in the VMA as a result of the addition of RHS may be attributed to the increased absorption of bitumenn content by the filler.

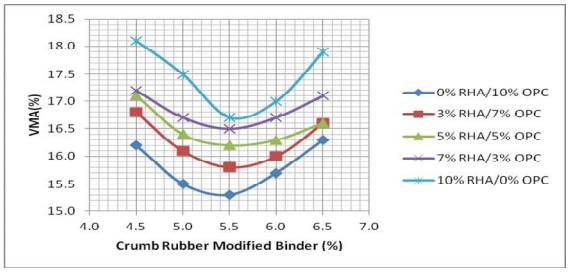


Fig. 11.0 VMA against binder content

The relationship between VFB and bitumen content is presented in Fig. 12.0. It is observed from the plots that VFB increases with increasing bitumen content. The values of the VFB for all the mixex containing RHS are lower than the control mix (10% OPC), implying that the addition of RHS reduces VFB values.

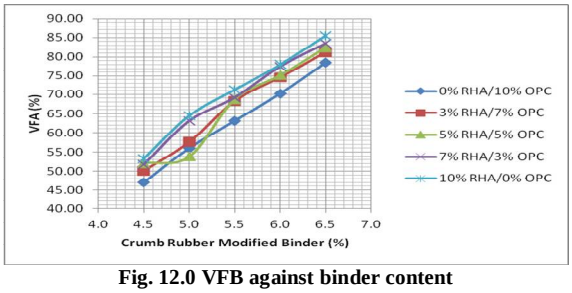


Fig. 12.0 VFB against binder content

3.3 Optimum Crumb Rubber Modified Bitumen Binder (Asphalt-rubber)

The optimum Crumb Rubber Modified Binder contents have been obtained by taking the average of the bitumen content at which the mix has maximum compacted density, maximum stability and 4% design air voids. The maximum bitumen contents were generated from the plots of stability, CDM and VIM. The maximum CRMB content for stability and CDM are 5.5%. At 4% air void, the value of CRMB content is 4.6%. The average value representing the optimum CRMB content is therefore 5.2%.

3.4 Performance of the Green Hot Mixed asphalt

The performance of the GHMA was investigated based on the loss of Marshal Stability. Ten Asphalt Briquettes samples were prepared using 30% Reclaimed Asphalt (RA), 70% virgin aggregate, 5% Ordinary Portland Cement (OPC), 5% Rice Husk Ash (RHA), 5.2% optimum Crumb Rubber Modified Binder; containing 15% Crumb Rubber (CR). All the ten samples were places in a water bath and maintained at 60^0. Five of the briquette samples were subjected to Marshal Stability test after 30 minutes of immersion based on the ASTM D1559 specification. The average marshal stability of the samples was computed as 7.35kN. The remaining five samples were tested after twenty four hours of immersion, and the average marshal stability of 6.4kN was obtained, representing 12.8% loss of stability. Comparing this result with what was reported in Taleb, et al. (2008), where an average of 24% loss of marshal stability was obtained for Marshal Briquettes when only conventional aggregate, bitumen binder and ordinary Portland cement where used. The reason for the low loss of marshal stability for the Green HMA is believed to be due to the following reasons.

a. Presence of hardened asphalt in the Reclaimed Asphalt,

b. Modification of the bitumen binder with Crumb rubber.

These resulted to increase in the binder viscosity that lead the mix to be less sensitive to the effect of hot water as a result of the 24 hours immersion. In conclusion therefore, it is clear that the performance of the Green HMA is quite encouraging.

CONCLUSION

This paper presented laboratory based study that was conducted to investigate the possible use of Reconstituted Reclaimed Asphaltic Concrete mix design with Rice Husk Ash (RHS) modified Ordinary Portland Cement (OPC) as filler and Crumb Rubber (CRM) Modified Bitumen as binder in the production of Hot Mixed Asphalt (HMA), for green road construction and rehabilitation. The following values for the Reclaimed Asphalt Pavement, Crumb Rubber and Rice Husk ash are recommended.

1. 30% Reclaimed asphalt as partial replacement for virgin aggregate.
2. 15% Crumb Rubber for Crumb Rubber Modified Bitumen production.
3. 5% RHA/5% OPC of the total mix as filler.
4. 5.2% optimum Crumb Rubber Modified Bitumen content.

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