International Journal of Mechanical Engineering and Technology (IJMET)
Volume 10, Issue 02, February 2019, pp. 273–287, Article ID: IJMET_10_02_029
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=10&IType=02
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

DEVELOPMENT AND PERFORMANCE EVALUATION OF CRUMB RUBBER – BIO-OIL MODIFIED HOT MIX ASPHALT FOR SUSTAINABLE HIGHWAY PAVEMENTS

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ABSTRACT

The asphalt industry has been perpetually challenged by its hazardous emissions and its contribution to the ongoing climate change and global warming crises. Likewise, the environment has been cumbered by the challenge of improper disposal of non-degradable solid wastes especially crumb rubber in form of scrap tyres resulting in serious environmental degradation. This research investigated the effect of modifying bitumen with bio-oil from cassava peels upgraded with a nondegradable polymer i.e. crumb rubber. Performance tests were carried out on the modified bitumen to evaluate its effect on its rheological properties. The percentage of bio-oil by volume used for modification of bitumen was 5%, 10%, 15% and 20%. Marshall Stability and flow tests were also carried out on the bio-asphalt produced. Experimental results of bitumen modification with cassava peel oil at 5%, 10%, 15% and 20% replacements showed an increment in flash point of 244°C, 250°C, 252°C & 259°C fire point of 259°C, 265°C, 269°C & 274°C and softening point values of 55°C, 55.5°C, 56.5°C & 57.5°C respectively of the base bitumen. Due to the high moisture content associated with bio-oils, properties such as ductility and viscosity were adversely affected. Upgrading with crumb rubber caused an improvement in the engineering properties of the base bitumen with penetration grade at 20% modification showed the resultant blend was 40/50 which is suitable for use on airport pavements. The highest Marshall Stability and Flow values were obtained at 20% modification with bio-oil upgraded with polymer with values of 26.5kN and 13.33mm as against 9kN and 10.5mm obtained on the control *sample. Finally, it was observed that the bio-oil could be utilized in the production of cutback bitumen due to the reduction of viscosity.*

Keywords: Bio-oil, Crumb Rubber, Marshall Stability, Flow, Bitumen, Rheological Properties, Sustainable Pavements, Cassava Peels

Cite this Article: Modupe Abayomi. E, Atoyebi, Olumoyewa D., Basorun, Adebayo. O, Gana A. J, Ramonu John A. L and Raphael O. D.c, Development and Performance Evaluation of Crumb Rubber – Bio-Oil Modified Hot Mix Asphalt for Sustainable Highway Pavements, International Journal of Mechanical Engineering and Technology, 10(2), 2019, pp. 273–287
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=10&IType=02

1. INTRODUCTION

Bitumen is the main component of asphalt and has been used in road construction for several years across the world (Kolokolova, 2014). Most bituminous adhesives or binders that are used for pavement materials are derived primarily from fossil fuels (Airey, *et al*. 2008). Nevertheless, due to the petroleum reserves becoming depleted and the ensuing consequences (global warming, pollution, etc.) of combustion of fossil fuels as well as the subsequent urge to reduce these effects, there is a drive to develop and produce binders from alternative sources. The use of these alternative technologies often qualifies the resulting mixture to be classified as “sustainable”. A sustainable pavement is safe, efficient and environmentally friendly while meeting the needs of the present generation without affecting the ability of future generations to meet their needs (Uzarowski, 2008). Sustainable pavements minimize the use of natural resources, reduce energy consumption, reduce greenhouse gas emissions, limit pollution, improve health and safety, and ensure a high level of comfort for users. The economic impact of the use of alternative binders in the construction of flexible pavements should also be considered when discussing sustainability. Engineers must consider new technologies and design methodologies to comply with current and future demand for sustainable development. To achieve this, the use of bio-oils as asphalt binders has been proposed. By definition, bio-oils can be described as dark brown, free-flowing organic liquids that are comprised mainly of highly oxygenated compounds (Oasmaa, *et al*., 1999). In other words, it is the liquid produced from the rapid heating of biomass in vacuum condition (Oasmaa, *et al*., 2005). Bio-oils have many synonyms that can be listed as follows: pyrolysis oil, pyrolysis liquid, bio-crude oil (BCO), wood liquid, wood oil, liquid smoke, wood distillates, and pyroligneous acid (Mohan *et al.* 2006 and Oasmaa *et al.* 2005). Bio-oils are a complex chemical mixture of water, pyrones, acetic acid, formic acid, and other carboxylic acids with the concentrations of these chemical components depending on the bio-mass from which the bio-oil had been derived (Mohan *et al.* 2006). As a result of the presence of cellulose, hemicellulose, and lignin in forestry and agricultural crops, the production of bio-oils can be described as the rapid and simultaneous depolymerization and fragmentation of these compounds while rapidly increasing temperature (Mohan *et al.* 2006). Bio-oils can substitute for fuel oils and a variety of other chemical applications (Williams, *et al*., 2009). Bio-oils are produced by either thermochemical or biochemical conversion. Thermochemical conversion process, such as pyrolysis and transesterification allow for a more compact facility as well as a faster conversion time compared to biochemical conversion (Cantrell, K. *et al.* 2007). Bio-oils have distinct advantages when compared to fossil fuel oils. Bio-oils are renewable, environmentally-friendly and provide energy security. (Uzarowski, 2008). Over the years, bio-renewable resources have been tested as alternative sources for producing binders and adhesives (Airey, *et al*. 2008). Due to the availability of large quantities of bio-renewable sources from different botanical sources, there are various technical and economic prospects in utilizing them to produce bio-binders

(Airey, *et al.* 2008) and through the application of scientific research, a range of different vegetable oils have been investigated to determine their physical and chemical properties to determine their applicability to be used as modifiers for binders in the pavement industry (Tan *et al*., 2002). Bio-based materials include industrial products, co-products, and by-products made from agricultural or forestry feed stocks. These feed stocks could be wood, wood waste and residues, grasses, crops, and co-products of crops. It is essential that the feed stocks for bio-based materials do not compete with food or feed supplies. Bio-binders can be utilized in three different ways to decrease the demand for fossil fuel based bituminous binders summarized as follows: as a direct alternative binder (100% replacement), as a bitumen extender (25% to 75% bitumen replacement) and as a bitumen modifier (<10% bitumen replacement) (Williams, *et al.* 2009). The demand for bio-based fuel and mixtures is gaining popularity as it is not only sustainable, but also provides secure energy and a positive economic opportunity (Aziz *et al*., 2015). A lot of research effort has been put into using bio-binders as a modifier with little or no work being done on using them as an extender or as direct alternative. Appel and his team used swine manure to produce oil (Aziz *et al*., 2015). They successfully converted swine manure to oil with 50% efficiency at 380^{o}C and 40MPa (around 400 atm) pressure. Fini in his research produced a bio-oil from swine manure and used it as a partial replacement of bitumen (Fini *et al.*, 2011). According to Fini, this bio-binder can be an effective material when added to bitumen binder due to its ability to improve some of the asphalt binder properties (low-temperature properties and wettability) while also providing economic and environmental benefits.

Raouf and Williams conducted a study on bio oil in Iowa State University, U.S.A. They produced different bio-oils from various sources e.g., Oakwood, switch grass and corn stover (Raouf and Williams, 2010). In the research, bio oil was blended with polymer modifier and bitumen, and the temperature susceptibility of the mixture was checked afterward. Finally, they concluded that bio-oil based binders from agricultural wastes behave much rheologically like bitumen binders. Their behaviour changes when temperature increases and viscosity begins to decrease making bio-oils more vulnerable to temperature than bitumen binders (Raouf and Williams, 2010). Agricultural wastes are natural and non-natural by-products produced by farmers through various farming activities (Ashworth, *et al.* 2015). These activities or operations may include dairy farming, horticulture, livestock breeding, market, gardens, nursery plots and woodlands management (Onu, *et* al. 2016). It has been estimated that up to 30% of global agricultural produce are left behind in the farms as wastes (Ugwuanyi, 2013). The use of these selected bio-masses will provide a means of efficiently managing and even generate revenue from these waste materials.

Cassava (*Manihot esculenta*) is extensively cultivated in Nigeria as one of the major staple food resources. The root of this plant contains high amount of carbohydrates but the main drawback of this staple food is a poor source of protein. For industrial application, cassava is used as raw material for glucose, fructose, ethanol, and cassava starch production. During the process of production, those kinds of industries produce significant amounts of cassava peel waste. Since the Cassava peel contains cyanogenic glucosides, mainly linamarin, the direct discharge of this solid waste often creates problem to the environment due to the release of hydrogen cyanide after hydrolysis by an endogenous linamarin. This further justifies the use of cassava peel as a bio-mass for the production of bio-oil. Cassava peel has been utilized as a renewable resource for activated carbon preparation (Sudaryanto *et al*, 2006), super capacitor (Ismanto *et al*, 2010) and as an absorbent (Kosasih *et al*, 2010); (Kurniawan *et al*, 2011). Suryadi *et al*., (2012), reported in their experiment that bio-oil yield from fast pyrolysis of cassava peel ranged from about 38.7 % to 51.2 %. The maximum yield of bio-oil was obtained at temperature of 525^{o}C. Main organic composition of bio-oil can be grouped into acids, esters, aldehydes, ketones, phenols, alcohols, hydrocarbons, and other organic compounds and some un-identified organic compounds. The physicochemical properties of bio-oil produced from pyrolysis of cassava peel were comparable to the ASTM standard for bio-oil. However there has been no research until now that studies the applicability of utilizing bio oil from cassava feedstock as partial replacement for bitumen for sustainable pavement works. In order to explore other sources of biomass, this study evaluated the performance of petroleum-based mixtures replaced with up to 50% bio-oil produced from agricultural wastes such as cassava peels.

2. EXPERIMENTAL MATERIALS AND METHOD

2.1. General

The experimental schedule of this study was designed to characterize the bio-oil, modify conventional bitumen with the developed bio-oil and hence evaluate its effect on the rheological properties of bitumen, then subsequently produce bio-asphalt with the resultant blend using the Marshall Mix Design.

2.2. Materials Used

The materials used in this study include: Biomass (from Cassava peels), Bitumen, Mineral aggregates. The bio-oil was extracted from the bio-mass using a fabricated pyrolysis system as shown in figure 1.

Figure 1 Pyrolizer

Specifications

The dimensions for the pyrolizer are as follows:

Internal diameter = 30 cm, Radius = 15 cm, Thickness = 2 cm Height = 41 cm, Diameter of overhead steel pipe = 1.5 cm, Area = $\pi r2$ = 3.142 x 1.5^2 = 7.0695 cm^2, Area of pyrolizer = $2\,\pi r2\ +\ \pi rl$ = 3346.23 cm^2, Volume of the pyrolizer = $2\,\pi r2h$ = 28984.95 cm^3

2.3. Material sourcing

The cassava shavings were obtained from the *Garri* processing plant located at the commercial farm of Landmark University, Omu-Aran, Kwara State, Nigeria. The bitumen was obtained from a bitumen processing plant in Akure, Ondo State.

Figure 2 Cassava Peels

2.4. Experimental Plan

The experimental plan was designed in order to determine the overall characteristics of the bio-binders developed from different kinds of bio-oils. The experimental plan was not concerned only about the rheological properties, which are the main factor in predicting the behaviour of the developed bio-binders as pavement materials, but the experimental plan emphasized the overall physical and chemical characteristics in order to have a better understanding of the applicability of developing bio-binders from bio-oils. The experimental plan included three different plans, i.e. physical plan, chemical plan and rheological plan.

2.4.1. Physical Testing Plan for bio-oil

Due to the variety of chemical compounds present in bio-oils a well as the complexity associated with chemically characterizing these oils, physical characterization offers the most accurate means of determining the properties of the oils. The physical testing of the bio-oils is a significant phase before using the bio-oils/developed bio-binders as pavement materials. The following tests were carried out on the produced bio-oils: Density, Viscosity, Specific gravity which is a very important parameter needed during the design of pavements.

2.4.2. Chemical Testing Plan for bio-oil

The chemical characterization was done using the Gas Chromatography/Mass Spectrometry tests This test was performed to quantify the amount of oxidative aging that occurred with the developed bio-binders, and to identify the different types of chemical bonds (functional groups) presented in the developed/original bio-binders.

2.4.3. Performance based testing plan

Various tests were conducted on bitumen to assess its consistency, gradation, temperature susceptibility, and safety. These tests include:

I. ***Penetration test***: Penetration test was performed to determine the consistency of the modified bitumen sample. This test was conducted by determining the distance in tenths of a millimeter using a standard needle penetrated vertically into a sample of the material under fixed conditions of temperature, load, and time. Other tests conducted are: *Ductility test, Flash and Fire Point Test, Loss on Heating Test, Viscosity, Specific Gravity, water content and Softening point test.*

II. ***Softening Point Test***: Softening point test was conducted to determine the softening temperature of bitumen by using ring and ball apparatus.

Figure 6 Softening Point Test

2.5. Aggregate Characterization

The mineral aggregates were characterized through the following tests viz: Aggregate Impact Test, Aggregate Crushing Test, Los Angeles Abrasion Test, and Flakiness & Elongation.

2.6. Marshall Stability and Flow:

Bio-asphalt was produced with the resultant blend of the bio-oil, a suitable polymer and the conventional bitumen. The bio-asphalt was subsequently subjected to the Marshall Stability and flow tests to predict the performance criteria of bituminous concrete. Approximately 4000 grammes of aggregates and filler mix was heated to temperature of 175-190°C. Bitumen was heated to a temperature of 121-125°C with first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates). Subsequently, the heated aggregates and bitumen were thoroughly mixed at a temperature of 154-160°C. The mix was placed in a preheated mould and compacted by a rammer with 50 blows on either side at temperature of 138°C to 149°C. Upon complete compaction, the asphalt briquette was extruded from the mould using the extruder as shown in figure 8.

Figure 8: Extruder and Asphalt Briquette

2.6.1. Properties of the mix

Theoretical Specific Gravity (G_t): This is the specific gravity of the mix without considering the air voids.

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_b}{G_b}}$$

Where: W1 = Weight of coarse aggregate in the mix

W2 = Weight of fine aggregate in the mix

W3 = Weight of filler in the mix

W_b = Weight of bitumen in the mix

G1 = Apparent specific gravity of coarse aggregate

G_2 = Apparent specific gravity of fine aggregate

G_3 = Apparent specific gravity of filler

G_b = Apparent specific gravity of bitumen

2.6.2. Bulk specific gravity of the mix (G_m): This is the specific gravity of the mix considering the air voids.

$$G_m = \frac{W_m}{W_m - W_w}$$

Where W_m = Weight of mix in air

W_w = Weight of mix in water

Air Voids Percentage (V_v): This represents the percentage of air voids by volume in the mix

$$V_v = \frac{(G_t - G_m)}{G_t} \times 100\%$$

2.6.3. Percent by Volume of bitumen (V_b):

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1 + W_2 + W_3 + W_b}{G_m}}$$

2.6.4. Voids in mineral aggregate (V_{ma}):

This is the total volume of voids in the aggregates. It is the sum of air voids and volume of bitumen.

$$V_{ma} = V_v + V_b$$

2.6.5. Voids filled with bitumen (V_{fb}): This represents the voids in the mineral aggregate frame work filled with the bitumen.

$$V_{fb} = \frac{V_b}{V_{ma}} \times 100\%$$

Figure 9 Asphalt Briquettes

3. RESULTS AND DISCUSSION

Measured results of samples showed different change of properties towards conventional bitumen and bio-oil modified bitumen. This involves the data obtained and analysis of results from tests carried out on bio-oil produced from Cassava peels, bio-oil modified bitumen, Bio-oil & Polymer Modified bitumen, mineral aggregates and bio-asphalt.

3.1. Production and Characterization of Bio-oil

The bio-oil extruded from the cassava peels, rice husk, oil palm, and coconut shell, showed significant potential as a bitumen modifier because it possesses similar chemical properties with petroleum binders. The oil was extruded by the pyrolysis process which involves the combustion of organic matter at high temperatures and in anaerobic conditions i.e. in the absence of oxygen and consequently producing solids, bio-oil, and gases. It was established by Raouf *et al* in 2010 that bio-oils perform poorly without any pre-treatment procedure carried out on them due to the presence of water and other volatile materials. For this investigation, the bio-oil was placed in a water bath set at 50°C for 24 hours to attempt to reduce the moisture content of the bio-oil.

3.1.1 Elemental Analysis

Elemental analysis of the Cassava peel bio-oil was carried out. The results are shown on Table 1. It is important to characterize the bio-oil that is used in the studies as every bio-oil has different composition depending on its biomass source and the pyrolysis conditions used.

Table 1:

Elemental Analysis of Bio-oil compared to Virgin Bitumen

Elemental Composition (%)	Cassava Peel Bio-oil	Bitumen
Carbon	57	85
Hydrogen	4.85	11
Oxygen	38	1
Nitrogen	0.15	0.3

3.2. Bio-oil modification of bitumen

These results describe the effect of the bio-oil produced on conventional bitumen

3.2.1. Penetration test

It was observed that upon modification with the bio-oil, there was an alteration of the penetration grade as detailed in Table 2. An increase in the percentage volume by weight of bio-oil caused an increase in the penetration grade.

Table 2 Effect of bio-oil and Crumb rubber on penetration grade of bitumen

Bio-oil percentage by volume of Bitumen	Penetration Value (mm)		Penetration Grade	
	Bio-oil	Bio-oil + Crumb rubber	Bio-oil	Bio-oil + Crumb rubber
0% (Control)	67	67	60/70	60/70
5%	62	61	60/70	60/70
10%	76	54	70/80	50/60
15%	81	51	80/90	50/60

20%	93	47	80/100	40/50

The purpose of this test is to classify the modified bitumen into their penetration grades. CT had penetration grade of 60/70, BO (5%) and BOP (5%) had 60/70, BO (10%) and BOP (10%) had 70/80 and 50/60 respectively, BO (15%) and BOP (15%) had 80/90 and 50/60 respectively and BO (20%) and BOP (20%) had 80/100 and 40/50 respectively.

3.2.2 Ductility

It was observed that the addition of the Crumb rubber had an adverse effect on the ductility value as there is a reduction of ductility as the percentage of crumb rubber added increases as shown on Table 3. However, it is important to note that the lack of ductility does not indicate poor quality.

Table 3: Effects of bio-oil modification on ductility of bitumen

	Ductility (cm)		
Bio-oil percentage by volume of Bitumen	Bio-oil	Bio-oil + Crumb rubber	Standard Requirement (Minimum)
0% (Control)	80	80	75
5%	82.3	83.3	75
10%	71	84.7	75
15%	69	87.2	75
20%	55	87.9	75

3.2.3. Softening Point

The softening point gives an idea of the temperature at which the bituminous material attains a certain viscosity. Bitumen with higher softening point is used in warmer places. Values are as shown on Table 4.

Table 4: Effects of bio-oil modification on softening point of bitumen

Bio-oil percentage by volume of Bitumen	Softening Point (°C)		
	Bio-oil	Bio-oil +Crumb rubber	Standard Requirements
0% (Control)	54.5	54.5	45-60
5%	55	57.5	45-60
10%	55.5	58.5	45-60
15%	56.5	62	45-60
20%	57.5	62.5	55-65

3.2.4 Loss on Heating

This test involved weighing out 50 grammes of bitumen, heating it for 5hours at a temperature of 163^{0}C in a special oven after which it was reweighed. The loss in weight due to heating was then expressed as a percentage by weight of the original sample. Values are as shown on Table 5.

Table 5 Effect of bio-oil modification on the loss on heating of bitumen

Bio-oil percentage by volume of Bitumen	Loss on Heating (%)	
	Bio-Oil	Bio-Oil + Crumb Rubber
0% (Control)	0.88	0.88
5%	0.92	0.89
10%	0.96	0.81
15%	1.02	1.18
20%	1.18	1.39

3.2.5. Specific Gravity

This parameter is of great importance to obtain volumetric measurements for the mix design. Marshall Mix Design is used for mix design of bituminous concrete. Marshall Mix Design is a volumetric mix design process, so the result obtained from Marshall Mix design will be in terms of volume. However, while making the mix, we mix different constituents in terms of their weight. For finding out this weight, we need the value of Specific Gravity.

Weight = Specific Gravity * Volume

Apart from this, specific gravity is found out for Quality Control purpose. i.e. 80/100 bitumen will have a certain specific gravity value which will be different from 40/50 bitumen.

Table 6 Effect of bio-oil modification on Specific Gravity of Bitumen

Bio-oil percentage by volume of Bitumen	Specific Gravity		
	Bio-oil	Bio-oil + Crumb Rubber	Standard Requirement
0%	0.98	0.98	0.96-1.02
5%	0.973	1.03	0.96-1.02
10%	0.991	0.98	0.96-1.02
15%	1.012	0.97	0.96-1.02
20%	1.03	0.96	0.96-1.02

3.2.6. Moisture Content

This test is carried out to determine the content of water in a sample of bitumen. Results are as shown on Table 7.

Table 7: Effect of bio-oil modification on the Moisture content of bitumen

Bio-oil percentage by volume of Bitumen	Moisture Content (%)	
	Bio-Oil	Bio-Oil + Crumb Rubber
0%	0.09	0.09
5%	0.11	0.1
10%	0.19	0.14
15%	0.21	0.16
20%	0.29	0.19

3.2.7. Flash and Fire Point

The lower the flash point temperature, the greater the risk. This classification is then used to warn of a risk and to enable the correct precautions to be taken when using, storing or transporting the liquid. Table 8 highlights the performance enhancement of the bio-oil on bitumen.

Table 8: Effect of bio-oil modification on the Flash & Fire point of bitumen

Bio-oil percentage by volume of Bitumen	Flash Point (°C)			Fire Point(°C)		
	Bio-oil	Bio-Oil + Crumb Rubber	Standard Requirement	Bio-oil	Bio-Oil + Crumb Rubber	Standard Requirement
0%	240	250	175	240	250	205
5%	244	252	175	259	266	205
10%	250	267	175	265	274	205
15%	252	270	175	269	283	205
20%	259	271	175	274	`287	205

The flash and fire point of the modified bitumen were within the required safety limits. The modification improved this property, making it possible to mix bitumen safely at higher temperatures.

3.2.8. Viscosity Test

Table 9 Effect of bio-oil modification on the Viscosity of bitumen

Bio-oil percentage by volume of Bitumen	Viscosity (s)	
	Bio-oil	Bio-Oil + Crumb Rubber
0%	275	275
5%	275	278
10%	272	284
15%	270	291
20%	269	298

3.3. PRODUCTION OF BIO-ASPHALT

Of the two types of asphalt (i.e. hot-mix asphalt and Mastic Asphalt), hot-mix asphalt was produced using the bio-polymer modified bitumen blend. The material is practically impervious to water, with the fines, filler and bitumen forming a mortar in which coarse aggregate was scattered in order to increase its overall bulk.

3.3.1 Characterization of aggregates

3.3.1.1. Coarse Aggregate Testing

Table 10 highlights the tests carried out on the aggregates, the test results and comparisons to the standard requirements of those values.

Table 10 : Coarse Aggregate Characterization

Tests Carried Out	Test Results Obtained	Standard Test Values
Aggregate Impact Test	24.98%	30% Maximum
Aggregate Crushing Test	44.93%	45% Maximum
Los Angeles Abrasion Test	56.03	60% Maximum
Flakiness Index	28.62	30% Maximum
Elongation Index	29.53	30% Maximum
Density	1492.267kg/m^3	1500 kg/m^3

Specific Gravity	2.8	2.8

All the test results were satisfactory meaning the coarse aggregates were found suitable for use in flexible pavement works.

3.3.1.2. Particle Size Analysis

Table 11 shows the particle size distribution for coarse aggregates, while Table 12 shows the particle size distribution for fine aggregates.

Table 11 Particle Size Distribution for Coarse Aggregates

Sieve No (#)	Sieve Size (mm)	Weight of aggregates retained (g)	% retained on each sieve	Cumulative % retained on each sieve	Cumulative % passing
$^{3}/_{4}$	19	0	0	0	100
$^{1}/_{2}$	12.7	526	28.56	28.56	71.44
$^{3}/_{8}$	9.52	375	20.36	48.92	51.08
4	4.75	155	8.41	57.33	42.67
10	2	234	12.7	70.03	29.97
16	1.18	95	5.16	75.19	24.81
30	0.6	175	9.5	84.69	15.31
40	0.425	181	9.83	94.52	5.48
50	0.3	44.5	2.42	96.94	3.06

3.3.2. Marshall Mix Design

In order to obtain the optimum bitumen content for the mix, several trial aggregate-binder blends were evaluated. The design ratio is:

$$5:45:30:20$$

Where 5% represents the binder, 45% represents the coarse aggregate, 30% represents the filler

20% represents the fine aggregate.

3.3.3. Marshall Stability and Flow Values

This aims to provide a means of predicting the performance of bituminous concrete for use in flexible pavement. The stability portion of the test measures the maximum load a specimen can support. The load is applied until the specimen fails and this maximum load is considered as stability. During the loading, an attached dial gauge measures the specimen's deformation (plastic flow) due to loading.

Table 12 Marshall Properties for Bio-oil Modification

% Bio-oil	PMB	Stability	Flow (mm)	V_v	V_b	V_{fb}	V_{ma}	G_m	OBC (%)
0%	-	-	-	-	-	-	-	-	-
5%	Bio-Oil	12.5	10.67	3.8	17	81.9	20.7	2.3	5.7
10%	Bio-Oil	12	10.83	3.9	17	81.3	20.9	2.3	5.2
15%	Bio-Oil	15.67	11.17	4.5	16.9	79	21.3	2.3	5.6
20%	Bio-Oil	19	11.5	4.4	16.9	79.5	21.2	2.3	5.6

Table 13: Marshall Properties for Bio-oil & Crumb Rubber Modification

% Bio-oil	PMB	Stability	Flow (mm)	V_v	V_b	V_{fb}	V_{ma}	G_m	OBC (%)
0	-	-	-	-	-	-	-	-	-
5	Bio-oil + Crumb Rubber	19.33	11.17	4	16.9	79.4	21.3	2.3	5.4
10	Bio-oil + Crumb Rubber	21.33	11.33	3.7	17	82.2	20.7	2.3	5.9
15	Bio-oil + Crumb Rubber	25.67	12.83	4.1	16.9	80.4	21	2.3	5.1
20	Bio-oil + Crumb Rubber	26.5	13.33	3.3	17	83.8	20.4	2.3	5.1

4. CONCLUSION

The objectives of this study were to produce and characterize bio-oil from cassava peels, modify bitumen with the bio-oil and a selected polymer and determine its effects on the rheological properties of bitumen and hence produce bio-asphalt and determine its Marshall Stability and Flow Values. From the obtained results, it was observed that modification with the bio-oil increased the penetration grade of the bitumen (i.e. made the bitumen softer) making it suitable for use in cold climates. The penetration values were improved upon modification with Crumb rubber. The penetration grade of bitumen was 60/70 and got reduced to 60/70, 70/80, 80/90 & 80/100 for modifications at 5%, 10%, 15% and 20% respectively. However, the values were 60/70, 50/60, 50/60 and 40/50 for crumb rubber modification of 5%, 10%, 15% and 20% respectively. The ductility values and penetration grade were found proportional to each other. As the penetration grade changed with increasing percentages of Cassava bio-oil, the ductility values also did. The ductility became 82.3cm, 71cm, 69cm, 55cm for bio-oil modification of 5%, 10%, 15% & 20% respectively. The ductility only improved at 5% modification. The addition of the crumb rubber made the bitumen mixture stiffer, hampering the ductility values as they became 55cm, 50cm, 48cm and 39cm for 5%, 10%, 15% and 20% respectively. It was observed that there was an increase in the softening point with the addition of bio-oil and a greater improvement as a result of the polymer modification. For bio-oil modification of 5%, 10%, 15% and 20%, the softening points became 55°C, 55.5°C, 56.5°C and 57.5°C respectively and for the polymer modification of 5%, 10%, 15% and 20%, the softening point became 57.5°C, 58.5°C, 62°C and 62.5°C respectively. The percentage lost on heating for bio-oil modification of 5%, 10%, 15% and 20%, was 0.92%, 0.96%, 1.02% & 1.18% and 5%, 10%, 15% and 20%, polymer modification caused 0.89%, 0.81%, 1.18% and 1.39% respectively. This was an increase on the 0.88% lost from CT. This is as a result of the introduction of more volatile substances being added to bitumen. The specific gravity of bitumen is to be in the range of 0.96-1.02. The modification with Cassava Peel bio-oil had 0.973, 0.991, 1.012 and 1.03 for 5%, 10%, 15% and 20% respectively. For polymer modification 5%, 10%, 15% and 20%, the results were 1.03, 0.98, 0.97 and 0.94 respectively. The moisture content of bitumen was increased with the modification with Cassava peel bio-oil due to the relatively high moisture content in the oil. 5%, 10%, 15% and 20% modification caused the moisture content to become 0.11, 0.19, 0.21 and 0.29 respectively, while the addition of crumb rubber in the following proportion 5%, 10%, 15% and 20% caused 0.1, 0.14, 0.16 and 0.19 moisture content respectively. The flash and fire point of the resultant blends were higher compared to virgin bitumen. 5%, 10%, 15% and 20% modification increased the flash and fire point to 244°C, 250°C, 252°C & 259°C (flash point) and 259°C, 265°C, 269°C and 274°C (fire point) respectively. With the addition of the crumb rubber, these values further increased to 252°C, 267°C, 270°C and 271°C (flash point) and 266°C, 274°C, 283°C and 287°C (fire point) for 5%, 10%, 15% and 20% modification. The viscosity of the blend was negatively affected by the addition of the bio-oil as 5%, 10%, 15% and 20% caused 75s, 72s, 70s and 69s viscosity. However, with an addition of crumb rubber in the proportion 5%, 10%, 15% and 20%, the viscosity increased to 78s, 84s, 91s and 98s respectively.

The Marshall Properties of bio-polymer modified bituminous concrete mixture (BPMBCM) were determined from the results of the Marshall Stability Test. The properties that were tested for were Marshall Stability, Flow Value, Volume of Bitumen in the mix, Voids in the mineral aggregate, Voids filled by bitumen, Volume of voids and the Bulk Density of the mix. It was observed that with the bio-oil and polymer modified bitumen mix had higher Marshall properties compared to the bituminous mix modified with the bio-oil alone. This implies that the bio-polymer mix is a suitable material for the modification of bitumen for use in flexible pavement. The flow values were within the range of 10-14mm and in accordance with the Asphalt Institute for heavy traffic at 75 blows. The lower the flow, the higher the mixture's resistance to deformation. Based on knowledge obtained from this research, the use of Cassava peel bio-oil can be recommended for modification of bitumen for use in flexible pavement, especially for the production of cutback bitumen since the penetration grades after modification suggested softer bitumen. The oil can serve as a suitable substitute for kerosene in the cut-back bitumen production process. I also recommend that the optimum combination volumes of both bio-oil from cassava peel and crumb rubber be investigated. The use of bitumen modified with bio-oil and crumb rubber for use in the construction of flexible pavements is recommended to reduce agricultural wastes and other environmental pollution issues as well as reducing road construction costs.

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