Strength Properties of Asphalt Mixture Produced with Polyvinyl Chloride (PVC) Modified Bitumen

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Abstract:
In recent time, more polyvinyl chloride (PVC) plastic are produced than what is currently being recycled, that contributes to the volume of waste. This occurrence prompted the exploration of polymer modified bitumen (PMB) to address the waste concern and thereby cuts cost in bituminous mix and improves pavement performance. This research evaluated the strength properties of asphalt mixture produced with polyvinyl chloride modified bitumen. Marshall method of mix design was used in the production of hot mix asphalt (HMA). Scanning Electron Microscopy (SEM), Fourier Transform Infra-red (FTIR) and Energy Dispersive X-Ray Spectrometry (EDS), used for microstructural examination and elemental analysis. These materials conform with its physical properties and characteristics. The shredded, grinded plastic revealed high binding properties when blend with bitumen. The percent incorporated was 2 - 10% PVC content and the Optimum Bitumen Content obtained was 10%, at 9.57kN for stability. The modified bitumen for penetration recorded at 68mm, which conformed with 60/70 grade bitumen, softening point recorded at 52oC, ductility was recorded at 107cm, specific gravity at 1.02, flash and fire point at 294oC and 306oC, solubility at 97% respectively. The properties were satisfactorily for grade 60/70 bitumen at 4% PVC by weight and be used as bitumen modifier for heavy traffic condition. Polyvinyl Chloride modified at 8 - 10%, be used at cold climates, while 2, 4, 6% PVC modified be used in warm regions. Therefore, the experiment proved these materials with characteristics, stability and stiffness be used for pavement constructions.

Keywords: Bitumen, hot mix asphalt, modified, polyvinyl chloride, pavement materials, strength properties

1. INTRODUCTION

One of the many ways of strengthening the performance of bitumen is to blend it with synthetic polymers, which can be either virgin or waste polymer. The modification of bitumen changes the bitumen resulting to an improved quality required for specific construction purposes [1]. Historically bitumen is known as one of the oldest construction materials dating back over 5000 years. The three good basic properties of bitumen are its ability to function as a cementing agent, its waterproof and thermoplastic nature, necessary for use in flexible pavement application and roofing needs. Bitumen can be liquefied by heating, applied in the liquid state, and it becomes solid cement again upon cooling, [2]. Elemental analysis shows that bitumen contains carbon (82-88 %), hydrogen (8-11%), Sulphur (0-6 %), oxygen (0-1.5 %) and nitrogen (0-1%). The last three elements may have considerable effect on bitumen properties, [2, 3]. Classified that bitumen as consisting of two chemical groups called asphaltenes and maltenes. The modification of polymeric material which are considered in enhancing the pavement strength and its properties for better performance on roads surface, [4]. Flexible pavement is referred to as an asphalt concrete pavement, which is a mixture of, aggregate and binder, a filler material, and bitumen combined in a carefully calibrated process to obtain a homogenous mix capable of being placed and compacted. Flexible pavements are designed to bend and rebound with the subgrade. The design concept is to place sufficient layers of base and intermediate courses of pavement as to control the strains in the subgrade, that no permanent deflections result. The major function of wearing course of hot mix asphalt is to carry a load transmitted from traffic and spread to the base course, sub-base and subgrade within the acceptance strength of those layers. The constituent materials establish the main structural element of hot mix asphalt and it is selected carefully to ensure the ideal performance of pavement during the service life, [5, 6]. There are two areas that can improve the serviceability of a road surface. Either by applying a thicker bituminous mixture which increases the construction cost or using a bituminous mixture with modified characteristics [7]. Hot mix asphalt is used in flexible pavement construction, due to its well-known strength properties. Nevertheless, hot mix asphalt is hugely susceptible to failure during its service life. Common failures patterns occurring in flexible pavement are distortion and disintegration appearing in the form of loss of bonding, cracking, chemical reactivity, binder aging, fatigue and rutting. Additionally, there is a recurrent deterioration of asphalt pavements produced with conventional materials over time. Waste materials contribute greatly to environmental pollution globally. More polyvinyl chloride (PVC) plastic are produced than what is currently being recycled, this too contributes to the volume of waste. This occurrence prompted the exploration of polyvinyl chloride (PVC) which will address the waste concern and enhance the pavement surface [8, 9].

II METHODOLOGY

Materials

The materials used in this research are grade 60/70 bitumen, coarse, fine aggregates, quarry dust and waste polyvinyl chloride PVC plastic. The bitumen, aggregates and quarry dust were obtained from Mother Cat Construction Company, Palladan, Zaria. The polyvinyl chloride waste was sourced from open dump site in Zaria, Kaduna State. Figures 1-4 show the materials and processing adopted.

Methods

The following method in this research was adapted and brief illustration in Fig. 5.

Test on Aggregates

For the aggregates; the following test was carried out

(i) Specific Gravity [11].
(ii) Sieve Analysis [12].
(iii) Aggregate Crushing Value [13].
(iv) Elongation Index Test [14].
(v) Flakiness Index Test [14].
(vi) Aggregate Impact Value Test [15].

Test on Bitumen

(i) Fourier Transform Infra-Red (FTIR) Test [16].

Test on Polyvinyl Chloride PVC

(i) Fourier Transform Infra-Red (FTIR) Test [16].

Test on Hot Mix Asphalt

The following test was done on the asphalt Samples

(i) Marshall Stability and Flow, [17]
(ii) SEM/EDX, [10]

Asphalt Institute (A1), 50 chart was used for calculating percentages for combined gradation (Table 2). The coarse aggregates, fine aggregates, and filler materials sieved with the following sieves size: 12.5mm, 9.5mm, 6.4mm, 3.2mm, 1.25mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm. Below plates shows the sieved used in the experiment.

For characterization of the bitumen, the following tests were performed,

i Fourier Transform Infra-Red (FTIR)

ii SEM/EDX ([10].

Scanning Electron Microscopy is a type of electron microscope which produces images of a sample by scanning the surface with a focused beam of electrons. The electron interacts with the atom in the sample, producing different signals which consist information on material surfaces topography and composition of the sample. EDS Is Energy Dispersive X-ray techniques use to identity elemental composition of materials. This application includes particle identification, coating analysis, contaminant identification and corrosion analysis. EDX normally is as silicon detectors attachment to SEM. These are image identifier capable of analyses data specimen of interest making true element composition for forensic investigations.

Thermogravimetry Analysis

The analysis is a technique used to appraise the physical property of a material underneath observed heat temperature. Differential thermal analysis (DTA) is used to measure a material's heat capacity i.e. the temperature at which material is transformed physically (stage transition). For this study PerkinElmer STA 8000 simultaneous thermal analyzer was used in accordance with [16]. For this paper, ThermoFisher scientific Agilent Cary 630 spectrometer was used in accordance with [16] wavelength ranged from 3800-750 cm^{-1}. The wavenumber is plotted against the transmittance percentage.

Test on Hot Mix Asphalt

The following test were performed on the asphalt Samples

(i) Marshall Stability and Flow

Marshall stability is the maximum load a compacted asphalt specimen can withstand before a deformation at a standard temperature of 60°C with a load applied at constant rate of 50mm/min. The stability and flow are read from the dial gauge. The flow which is measured in 0.25mm units is the deformation that the specimen has undergone at the maximum load. The Test was conducted in accordance with [17]. Fig.6 shows the Marshall stability and flow experiment process.

(ii)SEM/EDX

Scanning Electron Microscopy (SEM) is a technique that uses high energy beam to create image resolution surface. Energy Dispersive Spectroscopy (EDS) is a technique used to identify elemental composition of a material's surface. SEM/EDS shows surface microstructural arrangement between aggregates and bitumen materials. It also aides in qualitative and quantitative elemental analysis. The test was done in accordance with standard code [10].

Fig.1: PVC Waste Plastic, (Ceiling)

Fig. 2: Grinded PVC Waste Powder

Fig. 3: Experiment Process on Hot Mix Asphalt sample

III RESULTS AND DISCUSSION

Results of test on aggregates

The results of the physical property test conducted are presented in Table 1. The aggregate impact value and aggregate crushing are 27.28 and 24.86% respectively. The elongation and flakiness indices are 22.44 and 25.73% respectively. The specific gravity for coarse, fine and mineral filler are 2.63, 2.63 and 2.51respectively. All properties tested performed satisfactorily and were within the limits specified by [18] and therefore are considered to be good quality to be used in the production of hot mix asphalt. Similar results were obtained by [19].

Fig. 4: Experiment Process on HMA sample Produce for Marshall testing.

Results of particle size distribution test (Sieve analysis)

The particle size distribution for combined coarse aggregate, fine aggregate and mineral filler is shown in Fig. 5. The results obtained satisfied the upper limit and lower limit boundary condition as specified by [18] for gradation of aggregate used in hot mix asphalt

production. The results of the particle size distribution show a well graded aggregate, which can contribute to the interlocking ability of the mixture. Similar results were obtained by [19].

Results of Strength Properties Test on Modified Hot Mix Asphalt

Marshall Stability

The stability and PVC content relationship are shown in Fig. 6. Stability is referred to as the maximum load a compacted asphaltic sample can carry at a temperature of 60°C [20]. The stability value increases with increase in PVC content from a value of 3.7 kN at the control to a maximum value of 9.57 kN. This increase in Marshall stability could be attributed to the stiffening effect PVC had on the asphalt mixture, resulting in a denser mixture. All stability values for the modified mixtures satisfied [18] of 3.5 kN for both wearing course and base course. Marshall stability measures the strength of asphalt samples that relates to plastic deformation.

Marshall Flow

The flow and PVC content relationship is shown in Fig. 7. Jendia, [18] as cited in [21] described flow as the total amount of deformation that occurs at maximum load. It was observed that the PVC modified hot mix asphalt had higher flow than the control (2.05mm). The flow values of PVC modified hot mix asphalt was outside the requirement of [18] of 2mm-4mm limit, however it did meet requirement of 2mm – 6mm for base course.

Table 1: Physical Properties of Aggregate with Standard Specifications

Properties	Test Values	Standard Spec. Min.	Standard Spec. Max.	Remarks
Specific Gravity (Coarse)	2.63	2.5	3.0	Okay
Specific Gravity (fine)	2.63	-	-	Okay
Specific gravity (filler)	2.51			Okay
Flakiness Index	25.73	-	35	Okay
Elongation Index	22.44	-	25	Okay
Aggregate Crushing value (%)	24.86	-	30	Okay
Aggregate Impact value (%)	27.28	-	35	Okay

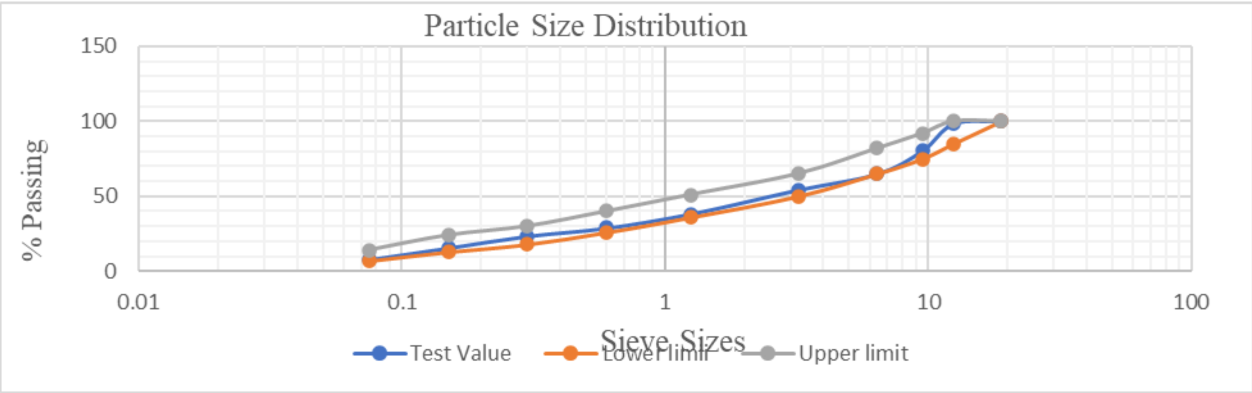


Fig. 5.: Particle Size Distribution

Table 2: Proportioning and Computation of Percentages of Aggregates of Different Sizes

Sieve sizes (mm)	Specified (%) Passing	(%) Passing	(%) Retained	(%) Coarse Aggregate	(%) Fine Aggregate)	(%) Mineral Filler
19	100	96.1				
12.5	85 - 100	83.1	1.7	1.7		
9.5	75 - 92	67.7	18.11	18.11		
6.4	65 - 82	54.4	15.31	15.31		
3.2	50 - 65	31.9	10.69	10.69		
1.25	36 - 51	16.7	15.97	5.19	10.78	
0.6	26 - 40	11.1	9.36		9.36	
0.3	18 - 30	8.2	5.4		5.4	
0.15	13 - 24	5.6	7.82		7.82	
0.075	7 - 14		7.82		7.82	
Pan			7.82			7.82
Total			**100**	**51.0**	**41.18**	**7.82**

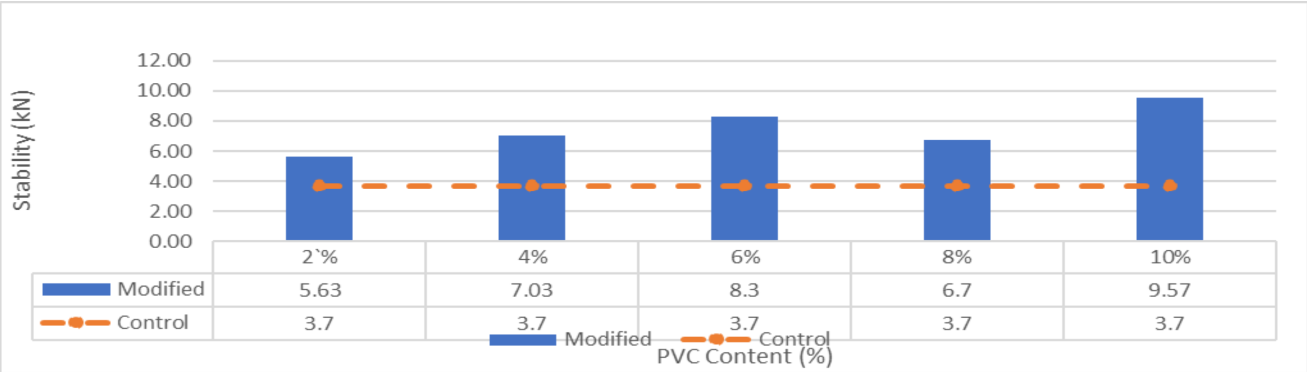


Fig. 6: Relationship between Stability and PVC Content

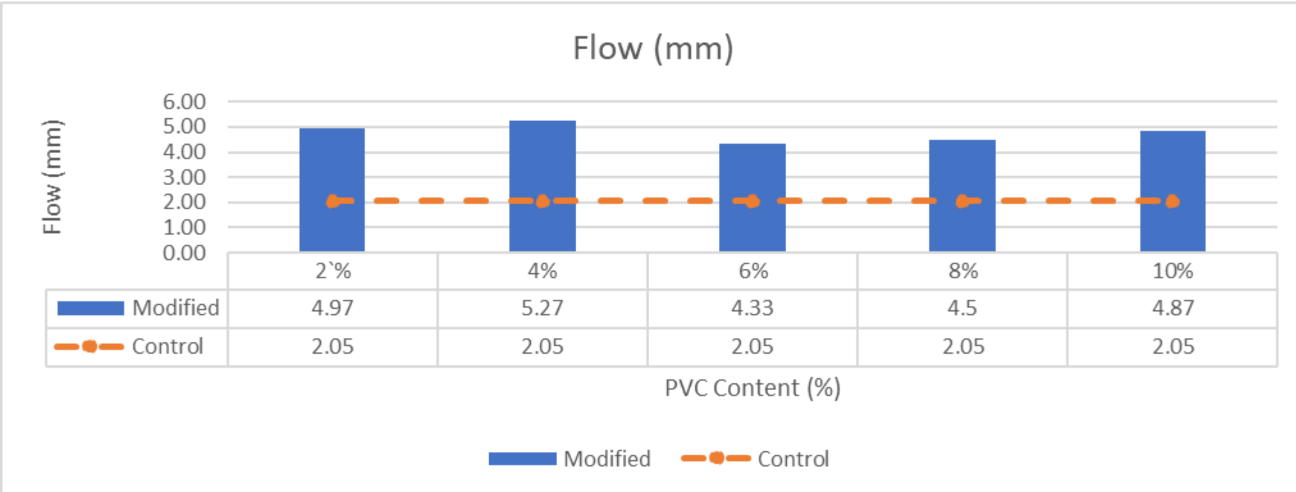


Fig. 7: Relationship between Flow and PVC Content

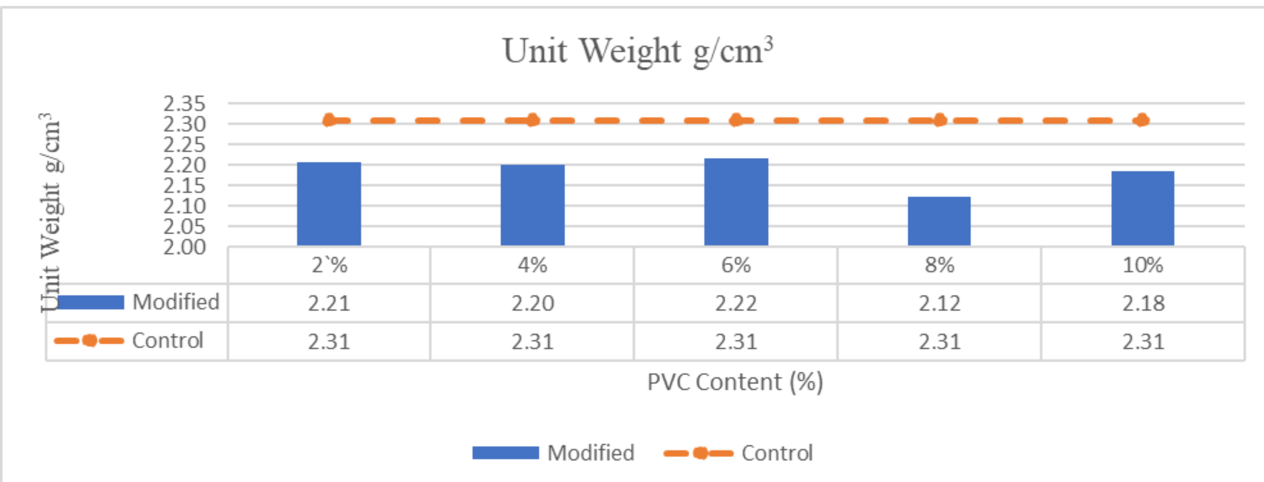


Fig. 8: Unit Weight and Bitumen Content Relationship

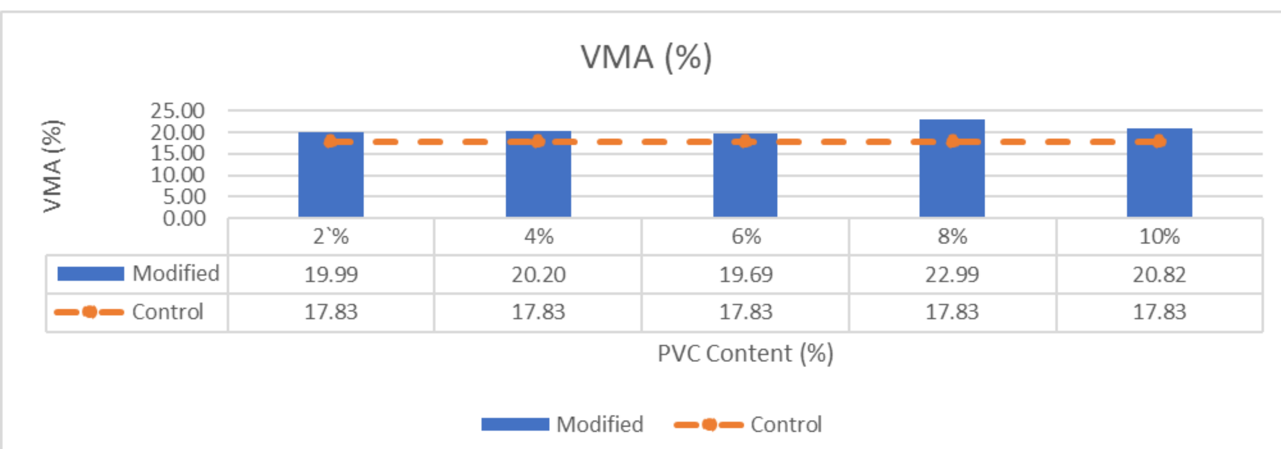


Fig. 9: Relationship between VMA and PVC Content

Unit Weight

The unit weight and PVC content relationship is presented in Fig. 8. The results of the voids in mixture showed an increase with addition of in PVC content. Unit weight values recorded for PVC modified mixes are 2.21, 2.20, 2.22, 2.12 and 2.18 g/cm3, for 2, 4, 6, 8, and 10% PVC content respectively. The values of unit weight for the modified mixes are all higher than the values of the control (2.31%). Unit weight is influence by the specific gravity of the different constituent hot mix asphalt [20]. Density-void analysis is directly related to the unit weight values.

Voids in the Mineral Aggregates (VMA)

The voids in mineral aggregates and bitumen content relationship is shown in Fig. 9. Voids in the mineral aggregates are considered the volume of inter-granular pore spaces existing between aggregate particles, [20]. The void in mineral aggregate (VMA) increased as the PVC content increased, the values of voids in mineral aggregate obtained are 17.83, 20.20, 19.69, 27.99 and 20.82%, for 2, 4, 6, 8, and 10% PVC content respectively. Sufficient voids in the mineral aggregates is necessary to reduce the asphaltic mixture susceptibility to plastic deformation. Similar trend of result was reported by [21].

Percent air Voids in the Mixture

The relationship between percent air voids in mixture (Pa) is shown in Fig. 10. The percent air voids in the total mixture can be referred to as the totality of effective pore spaces present in a mixture after compaction, [20]. The results of the voids in mixture showed an increase with addition of PVC content. Voids in mixture recorded for modified mixes are 6.70, 6.96, 6.35, 10.21 and 7.68%, for 2, 4, 6, 8, and 10% PVC content respectively. The values of voids in total mixture for the modified mixes are all higher than the values of the control (4.19%). It was observed that none of the VFB values for the PVC modified mixes met the criteria of 3 - 5% range specified by [18] for wearing course asphalt mixes, however it did satisfy the criteria of 3-8% VFB range for base course, except for 8 PVC content.

Voids Filled with Bitumen

The relationship of voids filled with bitumen and PVC content is shown in Fig. 11. Voids filled with bitumen is inversely related to percent air voids. Voids filled with bitumen is referred to as the parts of voids between the interlocked aggregate that is been filled with effective bitumen, [20]. The values of voids filled with bitumen for the PVC modified asphalt are 66.46, 65.57, 67.76 and 55.61%, 63.14% for 2, 4, 6, 8 and 10% PVC content respectively. The values of voids filled with bitumen for the modified mixes are all lower than the values of the control (76.5%). It was noticed that none of the VFB values for the modified mixes meet the criteria of 75 - 82% range specified by [18] for wearing course asphalt mixes, however it did satisfy the criteria of 65 - 72% VFB range for base course, except for 8 and 10% PVC content. Low VFB percentage indicates an insufficient bitumen film/coating around the aggregates, [22]. This trend directly affects durability performance of asphalt concrete.

The summary of the Marshall properties and Marshall Quotient

Marshall properties has been extensively discussed from section, here Marshall Quotient will be discussed. Marshall Quotient is referred to as the ratio of stability (kN) to flow (mm). Marshall Quotient is a metric for hot mix asphalt's ability to shear stresses, permanent deformation and rutting and overall flexibility index, [23]; [24]. The Marshall quotient for 4, 4.5, 5, 5.5, 6, 6.5 and 7% are 1, 0.9, 0.87, 0.80, 0.73, 0.62 and 0.55 kN/mm. It was generally observed that the Marshall quotient decreased with increase in bitumen content, this can be accredited to the effect of increase in bitumen content which reduced the overall stiffness and viscosity of the hot mix asphalt. The Marshall quotient has shown that the hot mix asphalt has reduced load bearing ability.

Microanalysis and Micrograph of Hot Mix Asphalt HMA Sample

The micrograph of control and PVC modified hot mix asphalt are presented in Plate V and VI respectively. Scanning electron microscopy (SEM) was done at 537μm scale and 1000μm magnification. The morphology of control hot mix asphalt shows a rough interlocking surface particle arrangement indicating a good bond between bitumen and aggregate. The morphology of the modified hot mix asphalt (10% PVC) showed a better structural interlocking arrangement matrix in comparison with the control, this could be attributed to improvement recorded in the Marshall stability. Micro-cracks in the mixtures are a result of the fracture during the Marshall strength test on the sample. The energy dispersive spectroscopy (EDS) revealed five major elements namely; Carbon, Silicon, Nitrogen, Aluminum and Potassium. Carbon's atomic weight increased from 77.32% to 86.04% in the control and modified Hot Mix Asphalt, (HMA) sample, this increment indicates that PVC plastic enhanced carbon content in the mixture. This further corroborated by FTIR results of the PVC modified bitumen. Silicon's atomic weight decreased from 9.0 - 4.96%, Nitrogen's atomic weight decreased from 7.21 - 4.66%, Aluminum's atomic weight decreased from 2.65 - 1.35%, Potassium's atomic weight decreased from 1.36 - 0.50% in the control and modified HMA sample respectively. These elements contribute significantly to hardening of hot mix asphalt.

Fourier Transform Infra-Red

Fourier transform infrared spectroscopy test is mainly used to inspect the structure and functional groups of chemical molecules. It is also used to indicate occurrence of chemical changes in blended materials.

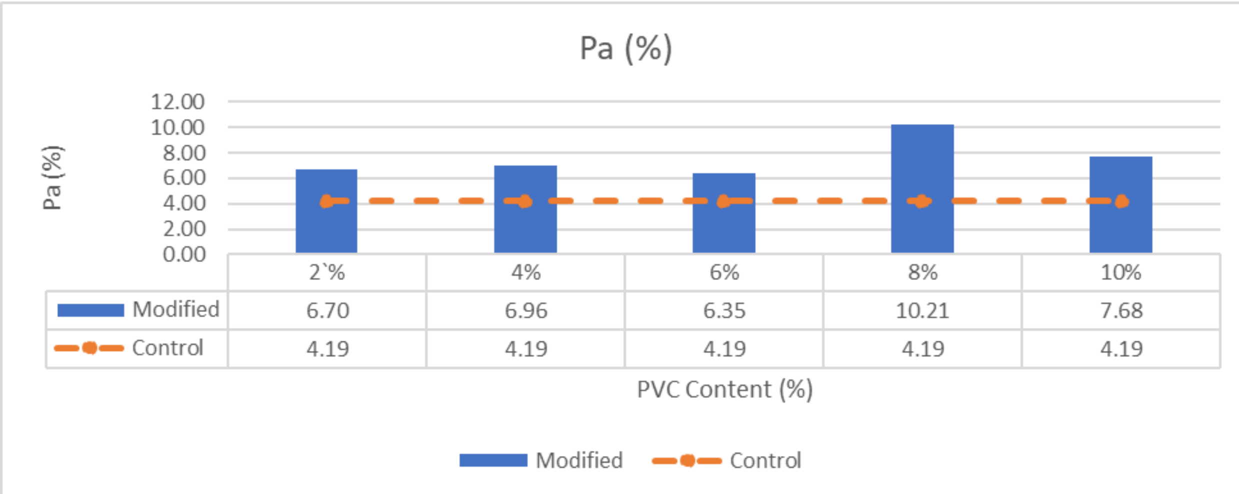


Fig. 10: Pa and Bitumen Content Relationship

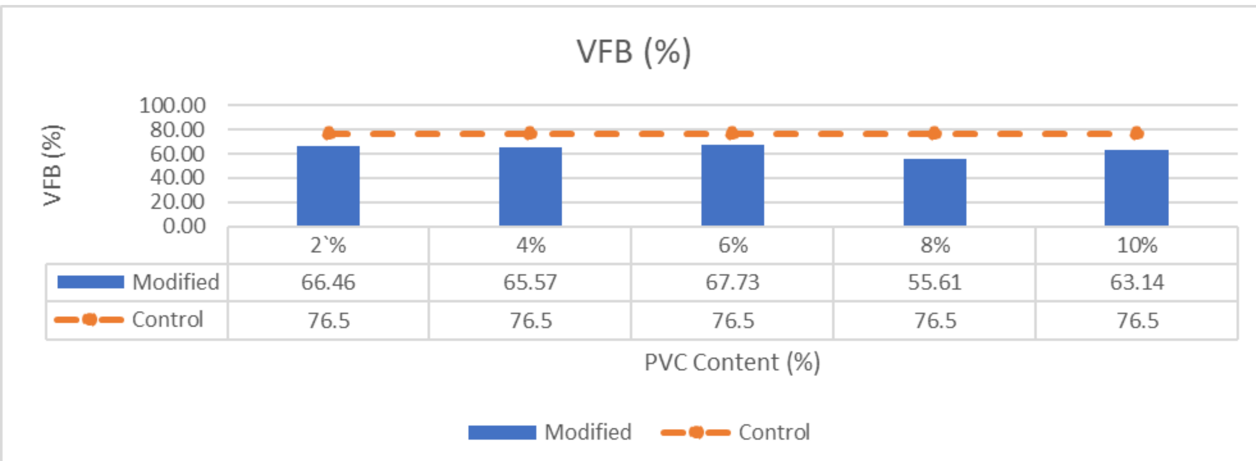
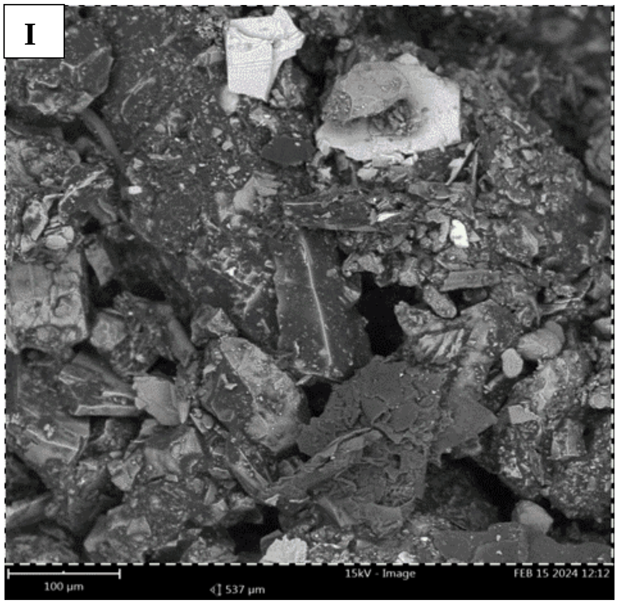


Fig. 11: Relationship between VFB and PVC Content

Table 3: Physical Properties of PVC modified Bitumen

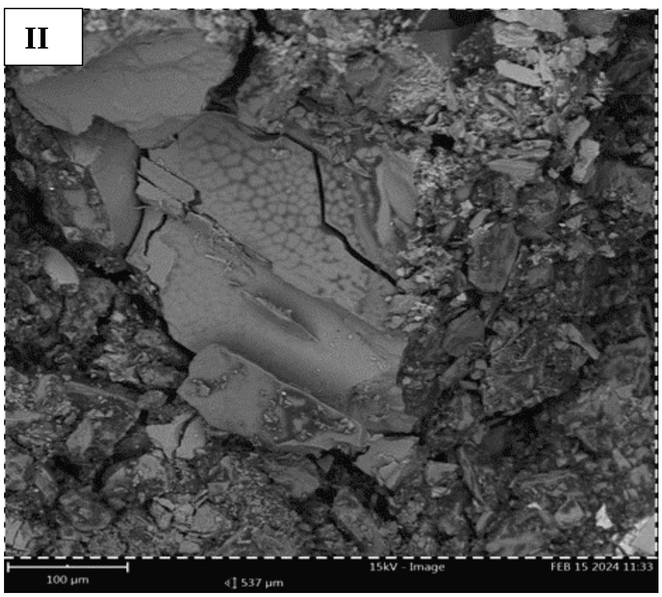
S/NO	PVC (%)	Penetration (mm)	Ductility (cm)	Softening Point (ºC)	Flash Point (ºC)	Fire Point (ºC)	Specific Gravity
1	0	68	107	52	294	306	1.02
2	2	59	59	38	243	249	1.01
3	4	63	109	43	254	274	1.01
4	6	67	113	47	259	302	1.01
5	8	72	114	51	275	309	1.02
6	10	102	116	45	279	314	1.03

Microanalysis and Micrograph for the Scanning electron microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX)



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	77.32	62.04
14	Si	Silicon	9.03	16.94
7	N	Nitrogen	7.21	6.75
13	Al	Aluminium	2.65	4.78
19	K	Potassium	1.36	3.56
26	Fe	Iron	0.65	2.41
11	Na	Sodium	0.60	0.93
20	Ca	Calcium	0.27	0.72
16	S	Sulfur	0.27	0.57
12	Mg	Magnesium	0.31	0.50
17	Cl	Chlorine	0.14	0.33
15	P	Phosphorus	0.13	0.26
22	Ti	Titanium	0.06	0.20

Fig. 12: SEM for Control Hot Mix Asphalt (HMA). Table 4: EDS for Control Hot Mix Asphalt (HMA)



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	86.04	74.55
14	Si	Silicon	4.96	10.06
7	N	Nitrogen	4.66	4.71
13	Al	Aluminium	1.35	2.62
26	Fe	Iron	0.57	2.31
19	K	Potassium	0.50	1.42
20	Ca	Calcium	0.43	1.26
11	Na	Sodium	0.53	0.87
16	S	Sulfur	0.33	0.77
17	Cl	Chlorine	0.24	0.61
12	Mg	Magnesium	0.19	0.34
15	P	Phosphorus	0.12	0.27
22	Ti	Titanium	0.06	0.20

Fig. 13: SEM for the Modified Hot Mix Asphalt (HMA) Table 5: EDS for the Modified Hot Mix Asphalt (HMA)

Table 4: The Modified Bitumen and PVC Sample

Functional Group	Wavelength	Vibration Type
CH_2 (Methylene)	3000-2500	Strong C- H Stretching
C=O (Carbonyls) C=C (Alkyl Halide)	1500 - 1300 1300 -1200	Strong C- C Stretching Strong C- H Bending
C-H (Alkyl)	1400 - 1200	Strong C-H Bending
C-O (Carbonyl)	1700 - Below	Stretching

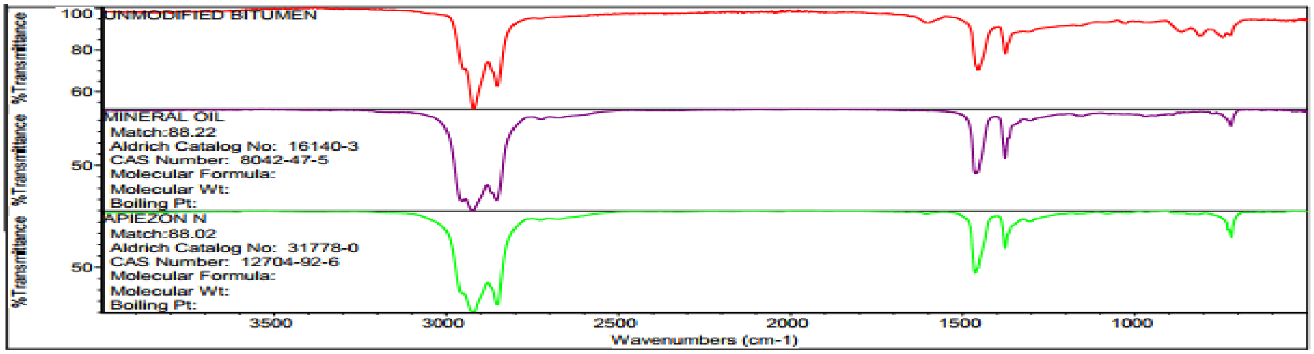


Fig. 14: FTIR Spectrum of Modified Bitumen and PVC

4. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

(i)The aggregate crushing value, specific gravity, aggregate impact value, elongation and flakiness index test result showed satisfactory performance and was within the limits specified by [18]. Hence can be used for production of hot mix asphalt.

(ii) The strength properties of the hot mix asphalt modified with PVC performed better than the control and also satisfies [18], requirement for use as base course.

(iii) The micrograph analysis on the asphalt mixture for the modified and unmodified hot mix asphalt indicates an improvement in interlocking of aggregate, increase in the atomic concentration of the elements in the mixture

RECOMMENDATIONS

(i)For an improved performance of asphalt pavement, hot mix asphalt should be produced with 10% PVC modified bitumen
(ii) The production of hot mix asphalt with 10% addition of PVC modified bitumen be use for high strength value of 9.57KN increase in Marshall stability.

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