Euphorbia Balsamifera Gum as a Bio-Based Modifier for Bitumen: A Comparative Physicochemical Study

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ABSTRACT

This study analysed and evaluated the physical and chemical properties of bitumen and Euphorbia balsamifera gum (EBG) for potential application in flexible pavement construction. The physical properties of the binders were evaluated using penetration, softening point, viscosity, flash point, fire point, and ductility tests, while the chemical(element and compound) properties were investigated using Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Fluorescence (XRF), and Energy Dispersive X-ray (EDX) analyses. The penetration test classified the bitumen as 60/70 penetration grade, while EBG exhibited properties corresponding to 40/50 grade. The softening point test showed that bitumen softened at 48°C, whereas EBG softened at 56°C. Viscosity was found to be 150seconds and 185seconds for bitumen and EBG respectively. The flash and fire points of bitumen were 271.5°C and 282.1°C, respectively, compared with 276°C and 287°C for EBG, indicating slightly higher thermal resistance of EBG. FTIR analysis revealed the presence of functional groups associated with saturates, aromatics, resins, and asphaltenes(SARA) in EBG, indicating chemical characteristics relevant to bituminous binder. XRF analysis further contained several elements and compounds also present in bitumen. EDX showed that EBG analysis indicated a substantially higher lead concentration in bitumen (43.68%) than in EBG (1.99%), suggesting that EBG presents a comparatively lower potential environmental hazard with respect to lead content. Overall, the findings demonstrate the potential of Euphorbia Balsamifera gum as a sustainable and locally available bio-based binder and bitumen modifier for flexible pavement applications.

Keywords: Bitumen, Euphorbia Balsamifera Gum, Flexible pavement, modifier

INTRODUCTION

Bitumen is a by-products of crude oil distillation, composed of complex hydrocarbons which can be classified into saturates, aromatics, resins and asphaltenes, typically known as SARA fractions (Lili Ma et al, 2023)

The whole world is now moving from conventional materials to bio-based, renewable and other waste materials in the construction of flexible pavement. Bitumen is widely used as binder and also filled some voids within the mineral aggregate. The basic functions of aggregate in flexible pavement are to provide a structural framework to carry the imposed loads from traffic without considerable distortion. A concrete asphalt layer (Asphalt concrete) is a road construction layer made of coarse and fine aggregates, fillers, and bitumen that is mixed, distributed, and compacted at a certain temperature.(Mochamad et al, 2022). Around the world, experts are attempting to improve the qualities of these materials to ensure sustainability in the pavement construction sector(Rahman et al., 2020).

When bitumen is modified, it changes into a better quality that is needed for certain construction projects meanwhile bitumen is considered one of the oldest construction materials, dating back over 5000 years. Bitumen's three essential features are its capacity to act as a cementing agent, its waterproofing and thermoplastic properties, which make it suitable for use in flexible pavement applications and roofing (Murana et al, 2024). In order to improve the performance of asphalt mixtures and lessen the distress and deterioration impacting the pavement, researchers are currently looking for novel ways and sustainable materials. Modification is often selected as one of the simplest and most acceptable methods for obtaining the desired outcomes in conventional blends due to environmental benefits as well as low fuel use.(Yaro et al., 2023)

Euphorbia balsamifera (Aguwa in Hausa) is a flowering plant belonging to the spurge family Euphorbiaceae. The height of the plant varies widely and can be characterized as a small tree that is 2 to 5 meters tall. Meanwhile Euphorbia balsamifera (EB) is easily raise by cuttings and is considered to be one of the best hedge plants for low rainfall areas, it's requires deep sandy soil and is not eaten by termites or stock (Bramwell, 2025). In terms of output, one-year-old plants produce 10 to 20 barrels of sap per acre (1 acre = 4046.86 m^2) in a year (Gondim et al., 2016). Euphorbia balsamifera gum (Damkon aguwa in hausa) has functional groups associated with saturates, aromatics, resins, and asphaltenes (SARA) fractions which are contained in bitumen.

Physical property tests help to determine the quality and performance of materials intended for construction and manufacturing purposes. On the other hand, chemical property tests provide information about the chemical composition of materials and help to assess their suitability for use as alternatives to, or in combination with, existing materials.

Bitumen modification is promoted in order to enhance bitumen's viscoelastic characteristics, nevertheless the bitumen is modified to enhance the pavement's performance under service circumstances and to function better within a particular serviceability temperature range.(Yaro et al 2023). Issues like global warming, greenhouse gas emissions, population growth, resource depletion, and the need to expand urban infrastructure have sparked intense debate about sustainable development and the development of environmentally friendly technologies worldwide and in light of these developments, it is becoming more and more crucial to find renewable resource based products that are less damaging to the environment and can replace petroleum-based asphalt (Gondim et al., 2016)

1. MATERIALS AND METHODS

All the physical property tests were conducted at the civil engineering department of the Ahmadu Bello University (ABU), Zaria. The Fourier Transform Infrared (FTIR) test, was conducted at Chemistry Department ABU Zaria, Energy dispersive X-Ray (EDX) test and X-ray fluorescent test (XRF) was conducted at National steel raw materials exploration agency malali, kaduna

1.1 Materials

The materials used in this study were Bitumen and Euphorbia Balsamifer Gum.

2.2 Methods

2.2.1 Physical and Chemical property tests conducted on Bitumen and EBG

The bitumen used in this study was 60/70 penetration grade of bitumen obtained from mother cat construction company, Zaria. The laboratory tests carried out on bitumen include penetration test, flash and fire point test, ductility test, Softening point test, viscosity test, X-ray fluorescent test (XRF), Fourier Transform Infrared (FTIR) test, and energy dispersive X-Ray (EDX) test. Table 2.1 shows the type of test and standard used.

Table 2.1 : Physical and Chemical Properties Test on bitumen and EBG

Test	Test Method
Penetration @ 25^{O}C (mm)	ASTM D5/D5M –20, 2020
Softening point (^{O}C)	ASTM D36/D36-14, 2020
Flash point (^{O}C) and Fire point (^{O}C) min	ASTM D92 – 18
Ductility at 25^{O}C (mm)	ASTM D113 (2017)
Viscosity (@60^{O}C) Sec.	**IS 1206 (Part 1)**
X-Ray fluorescent (XRF)	
Energy Dispersive X-ray analysis (EDX)	**ASTM E1508-12a(2019)**
Fourier Transform Infra-Red (FTIR)	ASTM D6348-12. 2020).

2.2.2 Euphorbia Balsamifera Gum (EBG)

The Euphorbia Balsamifera gum was obtained from Argungu Local Govt. Area of kebbi State at Badariya location; it was extracted from the stem of Euphorbia Balsamifera tree. All laboratory test carry out on bitumen was carryout on Euphorbia Balsamifera gum to compare their similarities.

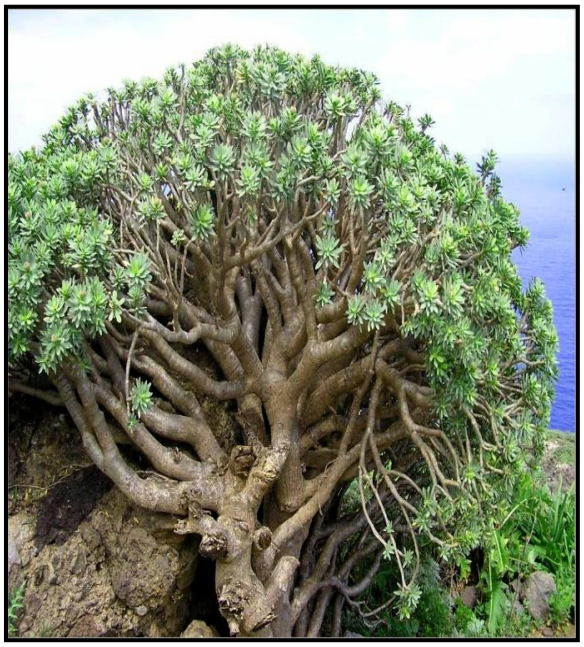


Plate I: Euphorbia Balsamifera Tree



Plate II: Euphorbia Balsamifera gum

3.0 RESULTS AND DISCUSSIONS

3.1 Results of Physical Properties Test Conducted On Bitumen and EBG

All tests conducted on bitumen were also conducted on EBG. Table 3.1 displays the findings of the different physical property tests that were performed on bitumen and EBG. The penetration value was 65mm and 50mm for bitumen and EBG respectively. This indicated that bitumen is 60/70 grade while EBG is 40/50 grade of bitumen which shows that EBG is harder than the bitumen. The softening point was found to be 48^{O}C and 56^{O}C for bitumen and EBG respectively which indicated that EBG has a higher melting temperature than the bitumen, the values are within the code specifications of 60/70 bitumen grade and 40/50 bitumen grade respectively. Ductility was measured at 110 cm for bitumen and 110cm for EBG the values conform to code specifications, Viscosity was 150seconds and 185seconds for bitumen and EBG respectively, which indicated

that EBG is more viscous than Bitumen also flash and fire points conform to the code specifications. Every physical property that was assessed performed satisfactorily.

Table 3.1: Physical Properties test on Bitumen and EBG compared with the Specifications

Test conducted	ASTM Code	Result (Bitumen)	Code (Bitumen)	Result (EBG)
Penetration at 25^{O}C,	ASTM D5-97	68	60-70	50
Softening point (^{O}C)	ASTMD36-12	48	47–52	56
Ductility at 25^{O}C, cm	ASTM D113	110	Min.100	110
Viscosity (@60^{O} C) Sec.	**IS 1206 (Part 1)**	150		185
Flash point (Cleveland open cup) ^{O}C	ASTM D92-02	271.5	Min.232	276
Fire point (Cleveland open cup) ^{O}C	ASTM D92-02	282.1	Min.232	287

3.2 Chemical Property tests conducted on Bitumen and EBG

3.2.1 X-Ray fluorescent (XRF) test on Bitumen and Euphorbia Balsamifera Gum (EBG)

The high concentration of SiO_2 (silicon dioxide) in EBG indicated that EBG can resist high temperature than Bitumen (EBG =15.078, Bitumen 5.643) as shown on the XRF analysis in table 3.2 and 3.3 respectively. The viscosity and temperature sensitivity of bitumen were improved by adding nano SiO_2.(Ahmad, and Alaa, 2023)

SO_3 (sulphur trioxide). Sulfur trioxide (SO_3) is a colorless to white crystalline solid that forms white fumes when exposed to air. This fuming is due to its rapid reaction with water in the air, producing sulfuric acid (H_2SO_4) and releasing heat. When SO_3 is exposed to air, it rapidly absorbs water and forms white fumes. Bitumen has a higher concentration of SO_3 (74.7) table 3.2 than EBG (17.1), table 3.3. Therefore EBG when used in asphalt can reduce cracking in asphalt pavement because it absorb water lower than Bitumen it is therefore less porous than bitumen and is less hazardous , less toxic than bitumen because of its less concentration of SO_3.

Generally, bitumen consists of about 85 % carbon, 10 % hydrogen, heteroatoms in lesser amounts such as nitrogen (0–2 %), oxygen (0–2 %), sulfur (0–9 %), and traces of metals such as vanadium, iron and nickel (Lu et al., 2017).

EBG contained the major component of bitumen such as carbon(C), nitrogen (N), oxygen (O), vanadium (V) , iron(Fe) and Nickel(Ni), as shown on table 3.4

Based on the X-Ray fluorescent (XRF) analysis carried out at National steel, raw materials exploration agency at Malali, Kaduna EBG contain all the compound and element in bitumen.

Table 3.2: XRF Test on Bitumen showing the compound in Bitumen

Sample Layer	Table Component	Type	Concn.
1	SiO2	Calc	5.643
1	V2O5	Calc	1.132
1	Cr2O3	Calc	0.227
1	MnO	Calc	0.051
1	Fe2O3	Calc	1.255
1	CoO	Calc	0.000
1	NiO	Calc	0.236
1	CuO	Calc	0.219
1	Nb2O5	Calc	0.116
1	WO3	Calc	0.000
1	P2O5	Calc	0.000
1	SO3	Calc	74.686
1	CaO	Calc	3.082
1	MgO	Calc	2.086
1	K2O	Calc	0.728
1	BaO	Calc	0.000
1	Al2O3	Calc	3.555
1	Ta2O5	Calc	0.000
1	TiO2	Calc	0.435
1	ZnO	Calc	0.209
1	Ag2O	Calc	0.131
1	Cl	Calc	5.076
1	ZrO2	Calc	0.022
1	SnO2	Calc	0.000
1	PbO	Calc	1.086
1	Rb2O	Calc	0.015
1	Cs2O	Calc	0.006
1	SrO	Calc	0.001

Table 3.3: XRF Test on EBG showing the compound in EBG

Sample Layer	Table Component	Type	Concn.
1	SiO2	Calc	15.078
1	V2O5	Calc	0.081
1	Cr2O3	Calc	0.044
1	MnO	Calc	0.665
1	Fe2O3	Calc	2.932
1	CoO	Calc	0.095
1	NiO	Calc	0.026
1	CuO	Calc	0.709
1	Nb2O5	Calc	0.321
1	WO3	Calc	0.043
1	P2O5	Calc	0.108
1	SO3	Calc	17.119
1	CaO	Calc	14.383
1	MgO	Calc	12.275
1	K2O	Calc	6.893
1	BaO	Calc	0.000
1	Al2O3	Calc	11.846
1	Ta2O5	Calc	0.034
1	TiO2	Calc	1.457
1	ZnO	Calc	0.123
1	Ag2O	Calc	0.311
1	Cl	Calc	14.902
1	ZrO2	Calc	0.070
1	SnO2	Calc	0.000
1	PbO	Calc	0.190
1	Rb2O	Calc	0.086
1	Cs2O	Calc	0.101
1	SrO	Calc	0.107

Table 3.4 Element in Bitumen and EBG

	BITUMEN		**EBG**		
Elements	Intensity(c/s)	Conc (wt. %)	Element	Intensity	Concentration
O	0	52.682	O	0	36.127
Mg	0.142	1.258	Mg	0.444	7.403
AI	2.42	1.881	AI	3.774	6.27
Si	19.313	2.638	Si	22.277	7.048
P	0	0	P	0.461	0.047
S	1193.69	29.912	S	124.991	6.856
Cl	146.889	5.076	Cl	286.546	14.902
K	25.102	0.604	K	125.78	5.722
Ca	138.679	2.203	Ca	297.672	10.279
Ti	35.164	0.261	Ti	46.733	0.873
V	116.522	0.634	V	3.298	0.045
Cr	37.152	0.155	Cr	2.831	0.03
Mn	11.737	0.039	Mn	60.83	0.515
Fe	317.111	0.878	Fe	292.883	2.051
Co	0	0	Co	12.53	0.075
Ni	89.183	0.185	Ni	3.677	0.02
Cu	97.496	0.175	Cu	119.082	0.567
Zn	103.756	0.168	Zn	23.163	0.099
Rb	8.642	0.104	Rb	20.655	0.079
Sr	0.71	0.001	Sr	20.851	0.09
Zr	7.79	0.017	Zr	9.993	0.052
Nb	33.554	0.081	Nb	38.173	0.225
Ag	4.765	0.122	Ag	4.571	0.29
Sn	0	0	Sn	0	0

Cs	0.164	0.006	Cs	1.085	0.095
Ba	0	0	Ba	0	0
Ta	0	0	Ta	1.613	0.028
W	0	0	W	2.104	0.034
Pb	246.948	1.008	Pb	16.408	0.176

3.2.2 Energy Dispersive X-ray analysis (EDX) on Bitumen and EBG

As presented in Tables 3.5 and 3.6, the concentration of lead in EBG (1.99) is considerably lower than that in bitumen (43.68). This finding suggests that EBG may present a lower potential risk of lead-related health effects than bitumen. The results also show that EBG has higher concentrations of carbon, nitrogen, oxygen, iron, and chlorine than bitumen, while silicon is present at a higher concentration in bitumen. These differences indicate variations in the elemental composition of the two materials

Table 3.5: Bitumen EDX Analysis

Elemt NO.	Elemt Symbl	Element Name	Atomic Conc.	Wt Conc.
82	Pb	Lead	5.37	43.68
6	C	Carbon	70.51	33.26
14	Si	Silicon	5.28	5.82
8	O	Oxygen	7.92	4.98
20	Ca	Calcium	1.43	2.25
13	Al	Aluminium	1.88	2.00
7	N	Nitrogen	3.30	1.82
17	Cl	Chlorine	1.28	1.78
26	Fe	Iron	0.77	1.69
19	K	Potassium	1.06	1.62
11	Na	Sodium	0.82	0.74
12	Mg	Magnesium	0.39	0.37

Table 3.6: EBG EDX Analysis

Elemt NO.	Elemt Symbl	Element Name	Atomic Conc.	Wt Conc.
82	Pb	Lead	0.15	1.99
6	C	Carbon	80.38	63.39
14	Si	Silicon	2.05	3.80
8	O	Oxygen	5.18	5.45
20	Ca	Calcium	0.91	2.41
13	Al	Aluminium	0.83	1.48
7	N	Nitrogen	4.64	4.28
17	Cl	Chlorine	1.58	3.70
26	Fe	Iron	1.03	3.79
19	K	Potassium	0.91	2.35
11	Na	Sodium	0.83	1.25
12	Mg	Magnesium	0.22	0.35

3.2.3 Fourier Transform Infrared (FTIR) Analysis (Fourier transform infrared (FTIR) spectroscopy is a quick and powerful technique in characterizing the chemical composition of bitumen and its SARA fractions (Lili Ma et al, 2023), (Mirwald *et al*., 2020) and (Pipintakos *et al*.,2021). FTIR test was conducted in order to investigate the Saturate, aromatic, resin and asphaltene (SARA), which are the major component element in bitumen.

3.2.3.1 Saturates:

Saturated hydrocarbons are generally identified by C–H stretching vibrations within the wavenumber range of approximately 2,850–3,000 cm^{-1}. As shown in Figure 4.1, the bitumen sample exhibits distinct absorption peaks at 2,920.4 cm^{-1} and 2,851.4 cm^{-1}, while the EBG sample shows peaks at 2,927.8 cm^{-1} and 2,855.1 cm^{-1}, as presented in Figure 4.2. These absorption peaks fall within the characteristic range of aliphatic C–H stretching vibrations, suggesting the presence of saturated hydrocarbon groups in both materials. The distinct peaks indicate noticeable absorption at these wavenumbers;

3.2.3.2 Aromatics

Aromatic oils help the binder stay flexible over time by increasing its resistance to aging. Exhibit characteristic peaks associated with aromatic rings, such as C=C stretching around 1600 cm^{-1} and 1500 cm^{-1}, and out-of-

plane bending vibrations below 1000 cm^{-1}.The bands ranges are observed in bitumen and EBG and peaks are strong (sharp bends) as shown on fig.4.1 and 4.2 respectively.

3.2.3.3 Resin

Resins are the stablizing agent which enable the bitumen to disperse uniformly & enhance bonding. Polar functional group (hydrogen bonding). contained; O, N, H & C (Alcohol,O-H) 3200-3550cm^{-1} & 3584-3700cm^{-1}**.** Hydrogen bonding are found in EBG (3200-3550cm^{-1}) which is absent in bitumen but 3584-3700cm^{-1} peak are found in bitumen but are all polar functional group region(alcohol O-H).

3.2.3.4 Asphaltenes:

Asphaltenes control the stiffness and viscosity of the Bitumen. Is a combination of Aromatic and aliphatic (C-H, 2850-2860cm^{-1}). Bitumen has a sharp peak at 2851.4 cm^{-1} while EBG has a sharp peak 2855.1 cm^{-1} which are withing the range of 2850-2860cm^{-1} wavenumber

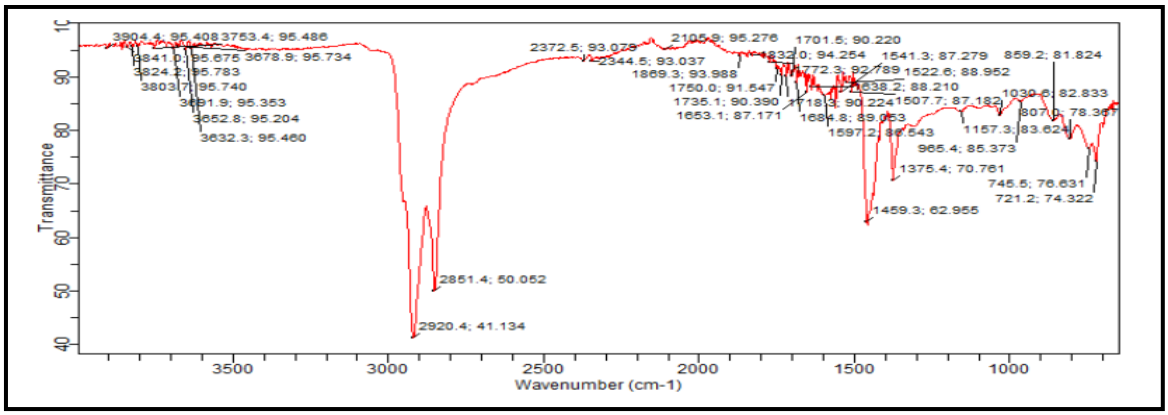


Fig.4.1: Bitumen Fourier Transform Infrared (FTIR) spectrum

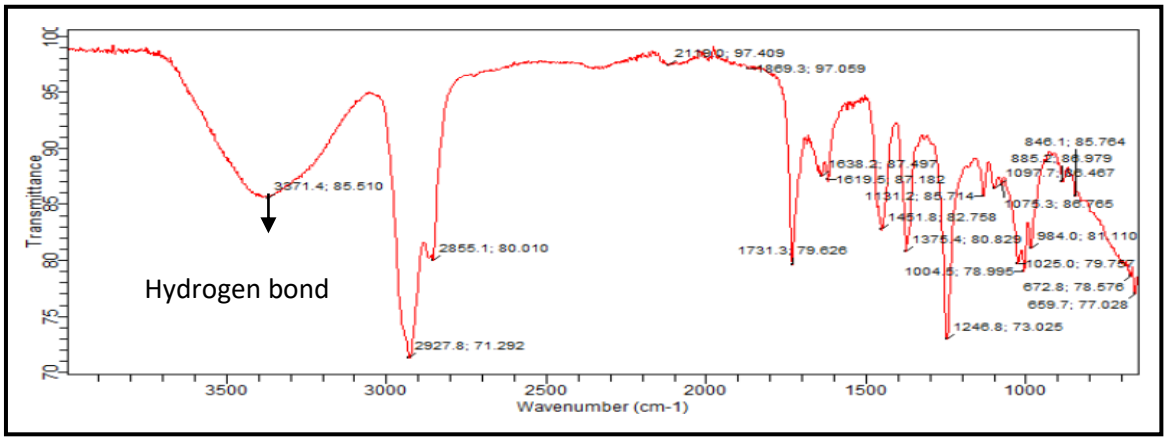


Fig 4.2: EBG Fourier Transform Infrared (FTIR) Spectrum

3.3 Physical property test Conducted on EBG modified bitumen

Fig. 4.3 shows the results of physical properties test conducted on EBG modified bitumen and compared with pure bitumen (0 % EBG). The penetration decrease with increase in EBG %, this is as a results of stiffness of EBG. The ductility also increases with increase in EBG this shows how ductile the EBG was. The Ductility test measures the tensile strength and cohesive ability of a materials .The softening point (ball and ring) temperature also increase with increase in the percentage of EBG this was due to the hardness of EBG, the viscosity values are increasing with increase in EBG this was as a result of higher viscosity of EBG.

All the results obtained conform with either 60/70 or 40/50 grade of bitumen

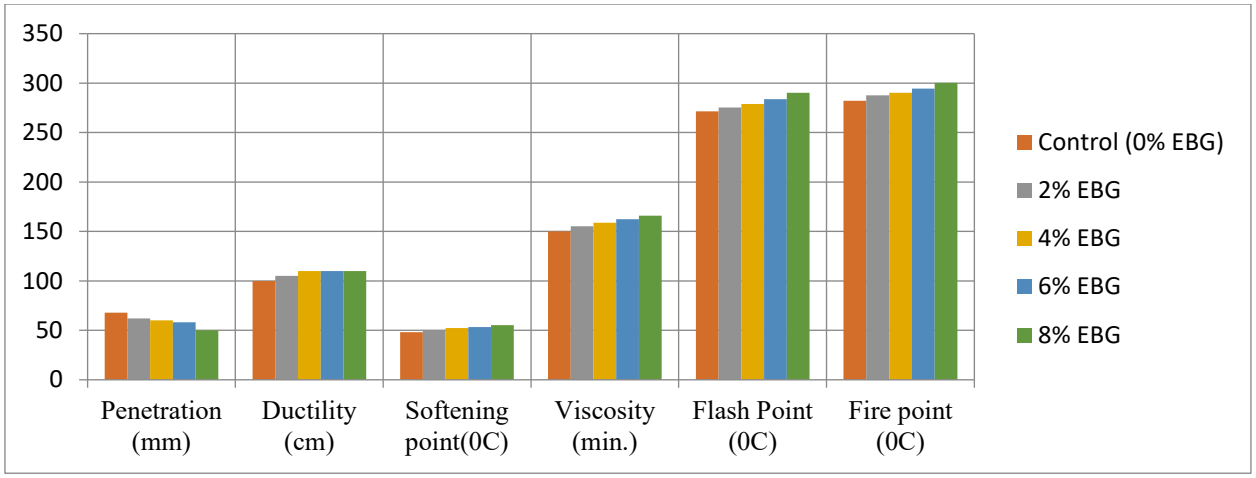


Fig. 4.3: EBG modified Bitumen test results

CONCLUSION

XRF analysis revealed similarities and differences in the elemental composition of EBG and bitumen. EBG recorded a higher reported silicon oxide value (15.078) than bitumen (5.643), indicating a difference in their elemental composition. EBG contained all the element and compound that bitumen possess.

EDX analysis recorded lead values of 1.99 for EBG and 43.68 for bitumen. EBG had a lower reported lead concentration than bitumen;

FTIR analysis revealed differences in the functional groups of EBG and bitumen. EBG showed an absorption band associated with hydrogen-bonded O–H groups, which was not clearly observed in the bitumen FTIR spectrum

The physical property tests indicated that the bitumen conformed to the 60/70 penetration grade, while EBG recorded a penetration value within the 40–50 range. This difference reflects variations in the consistency of the two materials and provides a basis for investigating the potential of EBG as a bitumen modifier in HMA.

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