Uniosun Journal of Engineering and Environmental Sciences (UJEES), Vol. 8 No. 3, March, 2026
DOI: 10.64980/ujees.v8i1.021 **Jimoh et al.**
Published: March 30, 2026

INFLUENCE OF POLYMERIC MODIFICATION ON THE CONVENTIONAL PROPERTIES OF BITUMEN SOURCED FROM AGBABU AND LODA IN NIGERIA: A STATISTICAL APPROACH

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Abstract

Natural bitumen requires modification to qualify as a binder in pavement construction. However, the effects of modifiers on bitumen vary depending on the bitumen composition, polymer type, and dosage applied. The effects of bitumen geographical location (Agbabu, L1 and Loda L2), dosage (0 - 6 wt.%) and polymer types (polypropylene (PP), polyethylene (PE), poly-ethylene-co-vinyl-acetate (PEVA), poly-styrene-co-butadiene (PSCB) and butyl acrylate (BA) were investigated on conventional properties of Nigerian bitumen. This study identified the most suitable modifier and optimum dosage levels as a preliminary attempt towards promoting Nigerian bitumen for road construction. Thermal degradation, functional groups, surface morphology and chemical composition of purified and modified bitumen were done using thermal gravimetric analyzer, Fourier Transform infrared technique, Scanning electron microscope and Thin Layer chromatography respectively. Conventional properties were analyzed using standard procedures and the results obtained were statistically analyzed using Statistical Package for Social Sciences (SPSS). Significant differences were noticed between the geographical areas, types and dosage of polymer ($p< 0.05$). Samples from L1 responded well to modification than those from L2. PSCB performed better at L1 and PP outperformed others at L2 regarding softening and penetration points. Polymeric modification improved the ductility of base bitumen regardless of location. Except PEVA, polymeric bitumen exhibits a lower fire point value compared to base samples. A dosage as low as 2 wt.% additives was found to be adequate in terms of ductility and flash point irrespective of sample location. Dosages of 4 and 6 wt% are optimum and significant ($p< 0.05$) at L1 and L2, respectively for other properties. Regarding the viscosity, only BA showed positive effect on viscosity reduction, other polymers tend to absorb oily components from bitumen and swell, resulting in higher viscosity. The findings of this study establish optimal polymer dosages for bitumen modification at Agbabu and Loda, Nigeria, providing a robust baseline for future enhancement using binary or ternary modifiers to improve road performance and pavement service life.

Keywords
Polymer additives, Nigerian bitumen, Modification, Statistical Analysis, Characterization

1. INTRODUCTION

Nigeria is the world's second-largest producer of bitumen, after Canada, with estimated reserves of 42.74 billion metric tons [1]. In southern Nigeria, the states of Ondo, Edo, Lagos, and Osun are home to substantial bitumen deposits. The greatest deposit is in Agbabu, Ondo State, and it has garnered more interest than the others since it is easy to extract, of good grade, and requires little preprocessing [2]. According to [3], International and local road construction industries have not extensively explored the utilization of Nigerian bitumen for indigenous road infrastructure development, largely due to its relatively low binding capacity and inadequate mechanical strength, which limit its engineering performance [4]. To further assess its potential, the majority of scholars and multinational corporations have, however, concentrated on the geological study and characterisation of Agbabu oil sand and/or natural bitumen [5]. Polymer modification of Nigerian bitumen is essential due to the material’s inherent susceptibility to temperature variations, rutting, and premature ageing, which compromise pavement durability under the country's harsh climatic and increasing traffic loading conditions. Conventional asphalt binders tend to exhibit viscoelastic limitations, leading to deformation at high temperatures and cracking at low temperatures, whereas polymer modification has been shown to significantly enhance elasticity, rutting resistance, fatigue life, and ageing resistance, thereby extending pavement service life [3]. Worldwide, heightened traffic volumes and diverse environmental factors have subjected road surfaces to elevated loads, resulting in continuous and extreme strain, ultimately leading to irreversible deformation [6]. As a result, natural bitumen is no longer adequate for creating pavements that satisfy the service life requirement [7] In this regard, the majority of previous research on Nigerian bitumen modification - more than 80% of them has concentrated primarily on Agbabu bitumen using various additives, including sulphur, polypropylene (PP), polyphosphoric acid (PPA), waste water sacks (WWS), crumb rubber, and waste polyethylene bottles (WPB) [1], [3], [8], [9], [10] [12].

Bitumen modification using polymers has attracted significant attention, with numerous researchers exploring various modification techniques to mitigate severe rutting and cracking problems in pavements across different regions [13], [14]. However, not all polymers are suitable for bitumen modification. Studies indicate that polymer-modified bitumen exhibits enhanced resistance to moisture damage, rutting, cracking, and fatigue, as well as decreased temperature sensitivity [15]. The selection of a suitable polymer for modifying bitumen takes into account the type, composition, and origin of the bitumen [16], [17]. Nigerian bitumen mixtures, like bitumen from other nations, are composed of several hydrocarbons, including saturates, aromatics, resins, and asphaltenes, each of which has unique physical and chemical characteristics. To comprehend their behavior and choose the right modifiers for their upgrading, it is imperative to ascertain these fractions. The proportions of saturates and asphaltenes in bitumen provide an indication of their contribution to aggregate binding within the bituminous mixture. These components significantly influence the rheological behaviour and workability of the material. Additionally, the resin content governs the adhesive properties, durability, and resistance to ageing effects [18]. Bitumen is usually mixed with silane, amine, or rubbery polymers to increase the interfacial adhesion [19]

Polymer modification of natural bitumen is often carried out using two types of polymers, namely reactive polymers and non-reactive plastomers, which are often classified as elastomers [20]. By creating a physical network between the bitumen and polymer, the nonreactive plastomers and elastomers increase the modified bitumen's elastic qualities and resistance to rutting [21], [22]. Functional groups in reactive polymers can combine with specific bitumen molecules to generate a variety of connections, such as epoxides, isocyanates, and anhydrides. [22] reported that the enhancement in bitumen properties resulting from polyolefin modification is attributed to the formation of covalent bonds, which improve polymer compatibility within bitumen. The light aromatic components in bitumen (maltenes) cause the polymer to swell when it is added to the bitumen binder, resulting in the polymer-rich phase taking up 4–10 times more volume than the added polymer [23]. On the other hand, some functional groups in reactive polymers can form chemical bonds with particular bitumen molecules, improving the bitumen's mechanical qualities, stability over time, stiffness, and temperature tolerance [24]. Plastomers are made up of two hydrogen atoms joined to a single carbon atom. They work effectively with asphalt binders designed for high traffic volumes and those built in warm to hot regions [25] . For the purpose of supporting heavy traffic loads in both slow- and fast-moving traffic scenarios, they improved the engineering properties of the asphalt and changed its phase composition. [26] reported that incorporating 2% ethylene-vinyl acetate (EVA) into bitumen increases its stiffness, as evidenced by a higher softening point and reduced penetration value. However, EVA contents exceeding 2% lead to poor compatibility, resulting in diminished storage stability of the asphalt binder. Polyethylene (PE) is another widely used polymer for bitumen modification and is available in three forms: low-density polyethylene (LDPE), high-density polyethylene (HDPE), and linear low-density polyethylene (LLDPE). [27] investigated the performance and internal structure of binders modified with PE and polypropylene (PP). Their study evaluated both pellet and powdered forms at concentrations of 2%, 4%, and 6% by weight of bitumen over mixing times of 60, 120, 210, and 300 minutes. The results showed that the rheological and physical properties improved with increasing polymer content, irrespective of the polymer type. However, PP imparted higher stiffness and reached equilibrium more rapidly compared to PE.

Similarly, [28] examined bitumen modified with PP, HDPE, and LDPE under strain- and stress-controlled conditions. The results indicated that PP-modified bitumen exhibited the lowest fatigue resistance, whereas LDPE-modified bitumen demonstrated the highest fatigue resistance at a dosage of 4% by weight. This superior performance was attributed to the improved dispersion characteristics of LDPE within the bitumen matrix.

Elastomers are natural or synthetic rubbers that exhibit elastic behaviour under compressive and tensile stresses. Examples include synthetic rubbers, commonly referred to as crumb rubber, and natural rubber latex derived from rubber trees [29]. Among elastomers used to enhance the flexibility of bitumen, styrene–butadiene–styrene (SBS) copolymers are the most widely employed. Previous studies have shown that SBS-modified bitumen demonstrates improved performance in asphalt binders and mixtures due to its unique structure, which consists of rigid styrene blocks and highly elastic butadiene blocks. Both components are compatible with the aromatic fractions of bitumen, contributing to enhanced performance [30]. [31] reported that below the glass transition temperature, the mechanical behaviour of SBS is governed by either polybutadiene (PB) or polystyrene (PS), depending on whether PS forms a continuous network within the polymer. When SBS is blended with bitumen, the PS end-blocks chemically interact and form cross-links, creating a three-dimensional network structure. Although this cross-linking can shift the system from a continuous bitumen phase to a continuous polymer phase, the PB mid-blocks maintain the material's flexibility [32] . However, [33] observed that SBS-modified bitumen at concentrations of 3-6% by weight may experience a decline in final properties within the first three days of storage due to phase separation. Phase separation remains a major challenge in these applications and has been associated with several factors, including polymer type and dosage, mixing conditions, and the intrinsic composition of the bitumen [34]. Furthermore, the stability of polymer-bitumen systems is influenced by the compatibility between asphaltenes, polymers, and the maltene phase, which can adversely affect storage stability.

Despite the growing body of research on bitumen modification, a critical knowledge gap persists in developing location-specific optimization of polymer dosage and understanding the comparative behaviour of indigenous Nigerian bitumen under uniform modification conditions. Existing studies have primarily focused on resource characterization and exploratory assessment of Nigerian bitumen deposits, with limited emphasis on performance-based modification and comparative evaluation across multiple local sources.

This study aims to evaluate five different polymers using statistical methods to identify the most suitable modifier for bitumen samples sourced from Agbabu (L1) and Loda (L2) towns in southwestern Nigeria. In addition, the study seeks to determine the optimum polymer dosage required to develop a stable three-dimensional polymer network within the binder and enhance storage stability. Furthermore, the application of statistical analysis in evaluating modifier performance is justified as it provides a rigorous and objective framework for interpreting experimental data, identifying significant relationships between variables, and optimizing modifier content. Statistical and experimental design approaches have been widely applied in asphalt research to determine optimal dosage levels, quantify performance improvements, and establish reliable correlations between material composition and engineering properties, thereby enhancing the reproducibility and reliability of findings [21]. Statistical analysis in this study is intended to (i) examine the influence of bitumen source location on its properties, (ii) identify the most effective polymer additives for samples from different geographical origins, and (iii) establish the appropriate dosage range for further detailed analysis and optimization at a 95% confidence level. Although this phase of the research is limited to conventional bitumen characterization methods, it is an essential step toward the development of indigenous Nigerian materials. It provides a foundation for subsequent, more comprehensive investigations involving advanced rheological characterization using sophisticated testing techniques.

2. MATERIALS AND METHOD

2.1 Study Area

Two bitumen samples collected from two geographical locations, Agbabu (L1) and Loda (L2) towns served as the base material for the modification of the blends evaluated in this study. Agbabu and Loda are prominent bitumen-bearing communities situated in the southwestern region of Nigeria, specifically within Ondo State, Nigeria. Agbabu is in Odigbo Local Government Area, while Loda falls within Irele Local Government Area of Ondo State (Figure 1). Agbabu and Loda are geographically proximate but exhibit notable differences in geological formation and compositional characteristics, which influence their physical and chemical behaviour. The climate of the region is typically tropical, characterized by high temperatures, seasonal rainfall, and humidity, conditions that are critical in assessing the performance of bituminous materials used in pavement construction [8]. Agbabu bitumen is generally associated with higher bitumen content and improved mechanical properties, while Loda bitumen often presents relatively higher impurity levels and compositional variability. These differences make the two sites suitable for comparative evaluation in this study, as they provide a representative basis for understanding the behaviour of indigenous Nigerian bitumen under varying modification conditions. Consequently, the selection of these study areas enables a comprehensive assessment of the influence of source-dependent characteristics on polymer modification performance and supports the development of location-specific optimization strategies for road construction applications.

2.2. Bitumen binder

Bitumen samples obtained from Agbabu, L1 were semi-solid in nature and contained minor impurities, primarily in the form of bituminous sand and fine particles. In contrast, samples from Loda, L2 were predominantly bituminous sand, necessitating further processing steps such as bitumen extraction, removal of sand (de-sanding), and moisture reduction prior to analysis.

Sample from L1 was dehydrated by boiling for 30 minutes at 160 °C in a beaker after which the molten bitumen was filtered to remove sand and other impurities. Bituminous sand samples from L2 were subjected to size reduction, after which they were placed in a metallic container and saturated with petroleum ether. The mixture was manually agitated to form a two-phase system consisting of a bitumen–sand slurry. The containers were then sealed to minimize solvent evaporation and maintained under ambient conditions for 24 hours. Phase separation was achieved through gravity settling, and the continuous phase was subsequently decanted. The resulting bitumen-ether mixture was heated in a reflux system for 30 minutes to recover the solvent, after which the remaining sand and stones were separated. Both extracted samples were characterized as having penetration grades within the 50/70 range. The physical characteristics of the purified samples of bitumen are presented in Table 1.

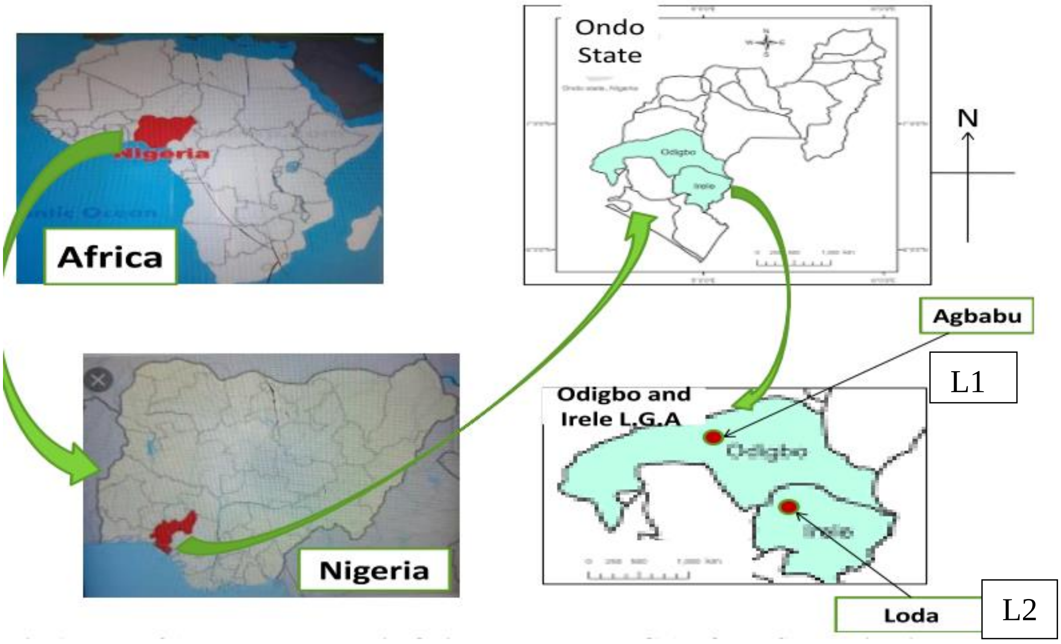


Figure 1: Map of Agbabu and Loda in Odigbo and Irele, Ondo State, Nigeria [9]

Table 1: Conventional properties of the pristine bitumen from locations L1 and L2

Physical properties	Location	Penetration	Softening point	Flash point	Density	Ductility	Viscosity
Units		0.1 mm	(°C)	(°C)	g/cm^3	(mm)	MPa.s
Standard		ASTM D5-06e1	ASTM D-36	ASTM D-92	ASTM D-70	ASTM D-113	ASTM D2170-95
Test value	L1	53	48	279	1.16	110	
	L2	51	46	277	1.19	101	
Standard value		50-70	52-54	-	-	≥ 100	

2.3. Polymer Additives

The additives used in this study were procured from Sigma Aldrich Co. Ltd. and are presented in Table 2 along with selected properties. They were chosen to evaluate the effects of different polymer types characterized by varying morphologies, densities, and chemical structures.

Table 2: Characteristics of polymer used in this work

Polymer	MFI, g/10 min	Density (g/cm^3)	Melting point (°C)
Polypropylene (PP)	12	0.90	160
Polyethylene (PE)	25	0.925	150
Butyl Acrylate (BA)	-	0.894	145
Poly (Styrene-co-Butadiene) PSCB	6	1.04	240
Poly (Ethylene-co-Vinyl Acetate) PEVA	57	0.93	87

*Vinyl Acetate content = 40 wt%; Butadiene content = 4wt%

2.4. Instrumental Characterization

Thermal degradation of the purified bitumen samples were carried out TGA and the DSC techniques. This test is particularly important to study changes in properties of bitumen with temperature especially for road pavements in temperate regions. The operation of the TGA is based on the measurement of the sample weight loss due to oxidation of volatiles and decomposition of heavy components. Functional groups were determined using Fourier Transform Infrared Spectroscopy technique (BRUKER ALPHA II) at a scan rate of 4 cm^{-1} between 4000 and 400 cm^{1}. Functional groups present in these samples influences their oxidative behaviour while undergoing thermal aging or chemical treatment. Surface morphology of the purified and modified bitumen samples was obtained using a high-performance variable pressure scanning electron microscope (PHENOM pro-X) with a resolution of 4.0 nm. Samples were gold coated to achieve high resolution images.

2.5. SARA Fractionation

Thin Layer Chromatography (TLC) using a Latroscan MK 5 was applied to fractionate the bitumen samples to analyse the chemical composition of pure binders from different geographic sources (L1 and L2), based on differences in polarity and solubility. The purpose of this fractionation was to better understand the chemical changes in bitumen associated with oxidative ageing [35]. The analysis separates bitumen into four SARA fractions: saturates, aromatics, resins, and asphaltenes, arranged in order of increasing polarity, with asphaltenes being the most polar. Separation was carried out on silica-coated rods, and the relative proportions of each fraction were quantified using flame ionization detection.

To prepare the samples, the bitumen was dissolved in peroxide-free tetrahydrofuran to obtain a 2% (w/v) solution. The saturated fraction was separated by immersing the rod in n-heptane, while the aromatic fraction was eluted using a 4:1 mixture of toluene and n-heptane. Resins were subsequently extracted using a solvent mixture of 95% dichloromethane and 5% methanol, leaving the asphaltenes retained at the base of the rods.

2.6. Preparation of polymer-modified binders

To enable flow, the reference bitumen samples from location L1 were heated to 160 ˚C at 1200 rpm for 30 minutes in a high-shear mixer [36]. The modification was performed at 160 ˚C, 2000 rpm for 30 minutes using a high shear mixer with various additives at the dosage of 2, 4 and 6% by weight of bitumen in agreement with previous studies [8]. The procedure was repeated for bitumen samples sourced from location L2. However, due to relatively high melting point (240 – 250 ˚C) of PSCB, it was first dissolved in xylene before introduced into the bitumen. A total of 65 samples were prepared to study the effects of five different additives on the properties of bitumen samples sourced from the two geographical locations. The following properties of the modified bitumen were evaluated using standard testing procedures: softening point [37], penetration value [41], kinematic viscosity [38], flash and fire points [40], and ductility [39]

2.7. Statistical Analysis

The experimental data obtained were subjected to both one-way and two-way analysis of variance. One-way ANOVA was carried out using the General Linear Model procedure to investigate the effects of polymer levels used during the treatment. Four polymer levels used were 0, 2, 4 and 6 wt.%. Significant mean differences were determined using the Duncan Multiple Range Test of the SPSS. The experimental model for one-way ANOVA was evaluated using equation 1:

$$Y_{ij} = \mu + T_i + \varepsilon_{ij} \tag{1}$$

Where: Y_{ij} = Observed value of the dependent variable, μ = Population mean, T_i = Effect of treatment and ε_{ij} = Experimental error assumed to be evenly distributed.

On the other hand, the two-way analysis of variance was used to show comparisons between populations based on various properties or variables. The two variables taken into account in this study are bitumen location and polymer concentrations used in the modification of bitumen samples.

2.8. Determination of Optimum Dosage

To determine the optimum dosage of polymers for the modification of bitumen samples, bitumen samples and polymers were randomized in a D - Optimal Mixture Design. A total of thirteen (13) samples were prepared for each polymer which gives a total of 65 samples. The range of value of bitumen is 94 - 98.5 % while each of the polymers was maintained in the range between 1.5 - 6% by weight of the bitumen based on observations from the statistical analysis and previous studies [42], [8]. For each of the experimental runs, the bitumen was prepared as described in section 2.4 and polymers were mixed with the molten bitumen under a high-speed shear mixer operating at 2000 rpm for 30 min. The specimens were tested for penetration, softening point, ductility, viscosity, and flash point. Figure 2 shows a flow chart for sample preparation and testing for modified samples from L1 and L2.

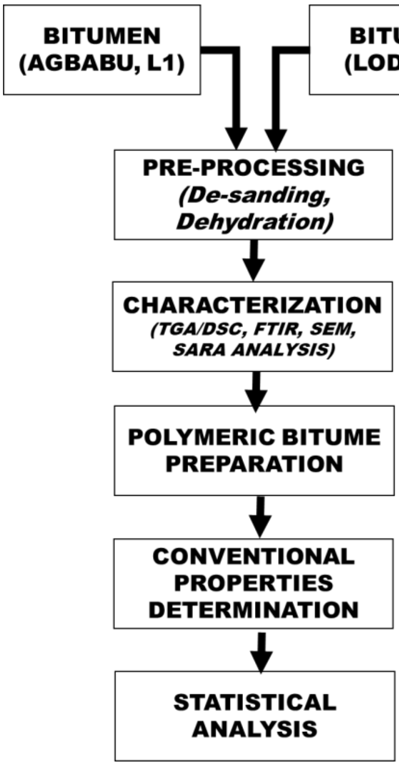


Figure 2: Illustration of the Testing Process Flow

3. RESULTS AND DISCUSSION

3.1. Characterization

3.1.1. TGA/DSC Analyses

Thermal stability of the base bitumen from locations 1 and 2 was determined using TGA and DSC analyses, the thermographs are displayed in Figures 3 and 4. These curves can be used for two purposes: for determining the initial and final temperatures of the thermal events for every stage of weight change and for determining the amount of the weight loss for each stage of weight change (%). From the TGA curve, it can be noted that bitumen sample from L1 location loses about 12.1% weight in the temperature range from 100 to 200°C, while the weight loss of the bitumen obtained from L2 is about 18.5%. L1 sample loses less weight, which indicates lower evaporation and higher stability against heat. From the DSC curve, the maximum peak indicates the melting temperature of sample L1 and L2 and was found to be 97.7 °C and 103.68 °C, respectively. The lower mass loss observed for L1 bitumen in the TGA analysis indicates superior thermal stability and reduced volatility compared to L2, suggesting a lower susceptibility to short-term thermal ageing. Although L2 exhibited a higher melting temperature, its greater weight loss implies a higher proportion of thermally unstable components. Overall, L1 bitumen demonstrates a more favourable balance between thermal stability and workability, making it more suitable for high-temperature processing and polymer modification.

3.1.2. FTIR Analysis

Figure 5 shows the FTIR spectra recorded between 400 and 4000 cm^{-1} for purified bitumen samples obtained from L1 and L2. The two samples have shoulder peaks at 1000 cm^{-1} which is prominent in L2 sample than the L1. The FTIR spectrum revealed some prominent peaks at 1480, 1493, 2696, 2943, 2957 and 3500 and 3654 cm^{-1}. The spectrum trends for the samples are similar regardless of geographical locations. However, there was a variation in their peaks values which suggest the two samples react differently to various modifiers [11] . The shoulder peak observed at 1000 cm^{-1} is more prominent in sample from L1 and it is attributed to C-O hydroxyl group whose development dependent on the concentration of oxygen [43]. The presence of the C=C function group in the two samples was also supported by an absorption peak with bending at a wavelength of 1480 and 1493 cm^{-1} [44]. The FTIR spectrum also showed strong absorbance at 2696, 2943 and 2957 cm^{-1} which correspond to C-H stretch in alkane related absorption bands (CHSp^3). The spectrum showed peak which appeared as shoulder at 3,300 cm^{-1} and may be attributed to C-H stretch aromatic carbon. The absorption band observed between 3500 and 3654 cm^{-1} in both samples is attributed to the O–H stretching vibration associated with alcohol functional groups.

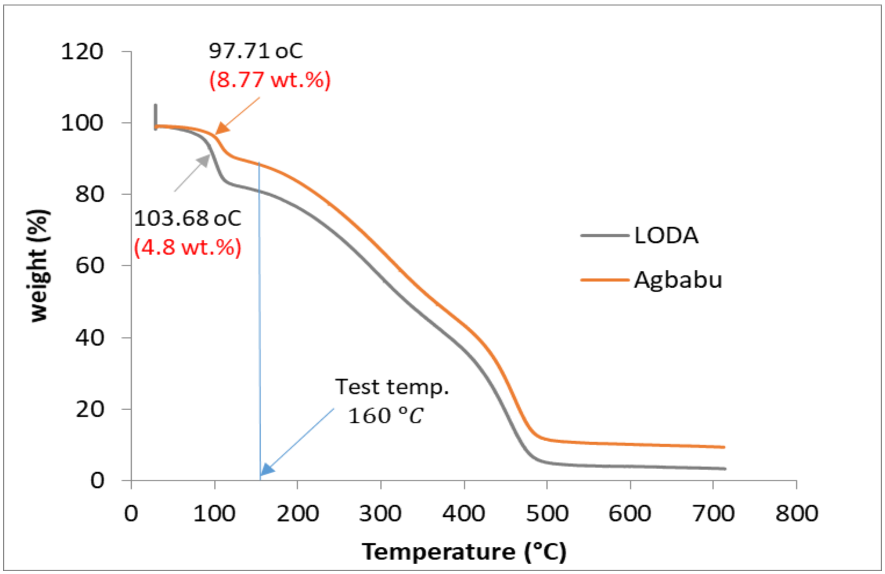


Figure 3: TGA Curves under Air Gas Flow for Two Nigerian Bitumen Samples

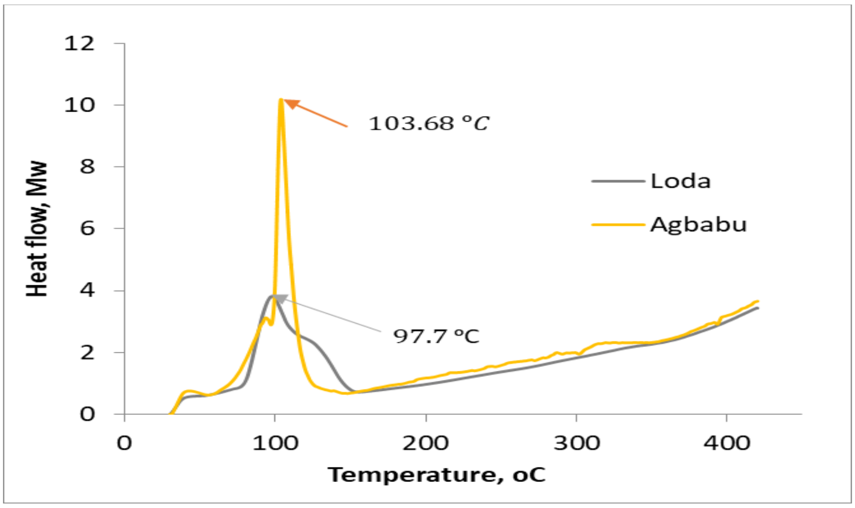


Figure 4: DSC Heat Flow Curves for the Melting Temperatures of Two Bitumen Samples

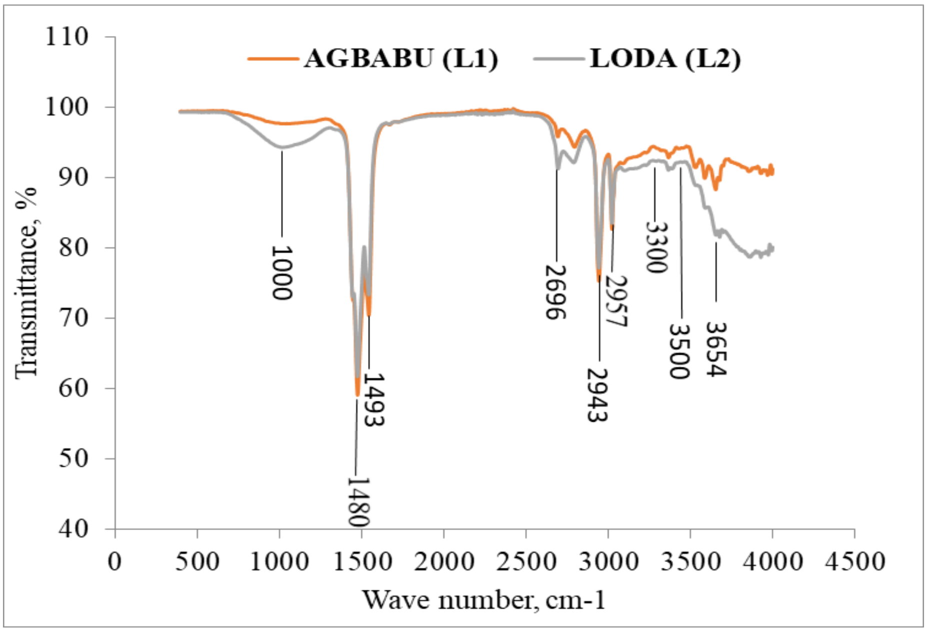
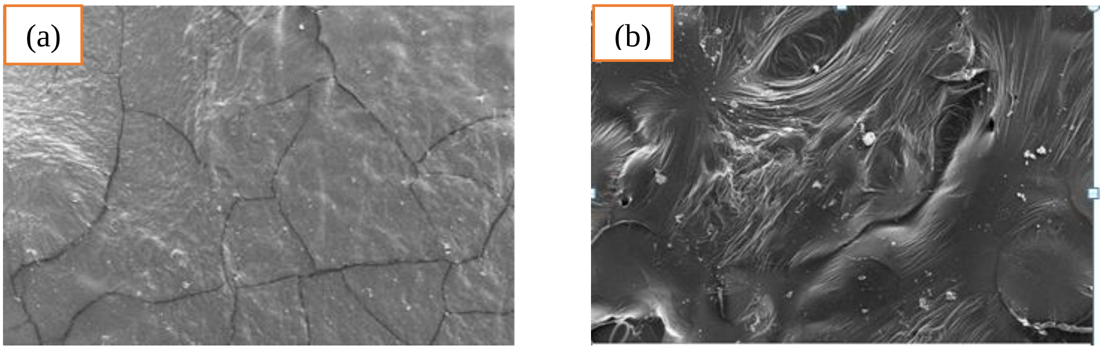


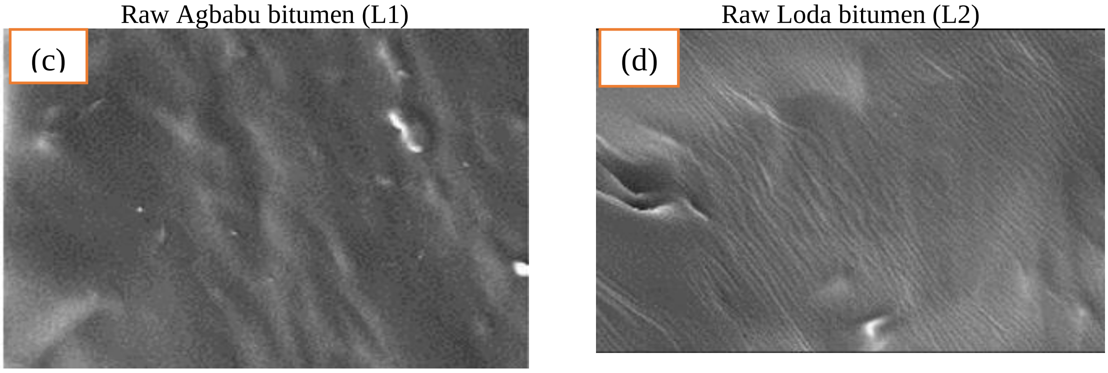
Figure 5: FTIR Spectra of Purified Bitumen from Location (a) L1 (Agbabu) and (b) L2 (Loda)

3.1.3. SEM analysis

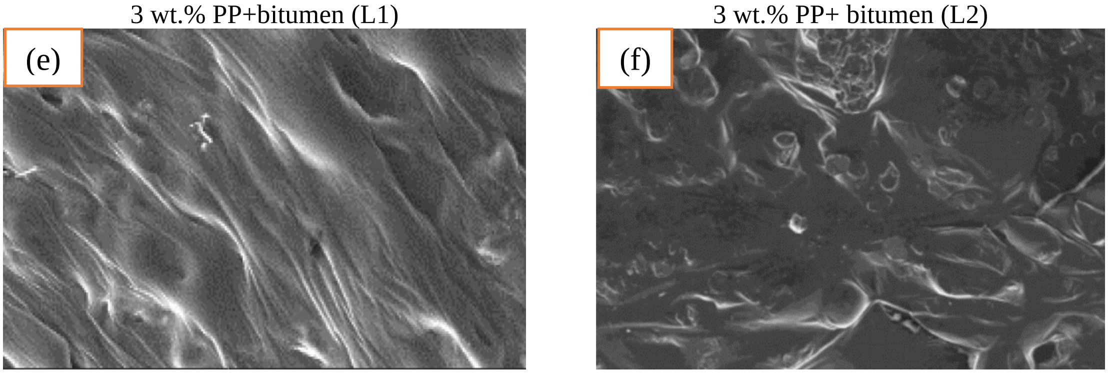
The images shown in Figures 6 (a) and 6 (b) illustrate SEM images of the raw bitumen samples obtained from locations L1 and L2, respectively. Both images can be used as the control to bench-mark the changes in microstructure of the various samples after modification with polymers at varying contents. Figures 6(c) and 6(d) show SEM images of the samples at L1 and L2 mixed with 3 wt% PP, respectively. It is obvious that the PP dispersed better at these concentrations in the samples regardless of geographical location previous study [4] has indicated a good PP dispersion in Agbabu bitumen at a dosage of 2.5 wt%. This study has also shown that 3 wt% PP dispersed is in line with previous research. The SEM images of samples from sites L1 and L2, modified with 4 weight percent PSCB are displayed in Figures 6(e) and 6(f). Certain surface texture properties of the polymer and binder were changed by the addition of PSCB to the raw samples, as seen by the irregular and swollen surface texture patterns seen in these samples especially on Figure 6e [36]. The dispersion and physical characteristics of changed bitumen can also be affected by changes in temperature, time, and agitation requirements during modification [22].



Raw Agbabu bitumen (L1) Raw Loda bitumen (L2)



3 wt.% PP+bitumen (L1) 3 wt.% PP+ bitumen (L2)



4 wt% PSCB+ bitumen (L1) 4 wt% PSCB+ bitumen (L2)

Figure 6: SEM images of (a) raw sample from location L1 (b) raw sample from location L2 (c) modified L1 sample with 3 wt% PP (d) modified L2 sample with 3 wt% PP (e) modified L1 sample with 4 wt% PSCB and (f) modified L2 sample with 4 wt% PSCB

3.1.4. SARA analysis

The SARA content of the refined bitumen samples from locations L1 and L2 is shown in Table 3. The value of the saturate, aromatic, and resin fractions recorded from the two locations did not differ much. The asphaltene fractions is higher in sample from L2 than the L1. According to [35], the asphaltene content of bitumen reflects its propensity for molecular aggregation and self-assembly, as described by the colloidal model, leading to the formation of micelle-like aggregate structures [45]. These structures are distributed into the continuous phase, which is mostly made up of the saturate and aromatic oil fractions (maltene). Assuming bitumen to be a colloidal suspension, it was believed that asphaltenes would scatter throughout maltenes and resins serving as a peptizing agent for saturates, aromatics, and asphaltene micelles. This mechanism produces a continuous phase that is intermicellar. This approach offers a rapid technique to investigate a successful polymer-modified bitumen [46]. Equation 2 was used to estimate the colloidal index (CI), which is the ratio of flocculated fractions to dispersed ones.

$$CI = \frac{\%_{ASPHALTENE} + \%_{SATURATES}}{\%_{AROMATICS} + \%_{RESINS}} \tag{2}$$

A higher colloidal index indicates that the asphaltenes are more effectively peptized by resins within the oil medium, suggesting improved dispersion of polymer additives in the bitumen. Typically, the colloidal index for most bitumen grades falls within the range of 0.5 to 2.7. The CIs for the two samples are 0.75 and 0.83 for the L1 and L2 samples, respectively. Thus both samples exhibit typical sol-type behaviour and are therefore highly suitable for the production of polymer-modified bitumen [46].

Table 3: SARA fraction in Agbabu and Loda bitumen

Fraction	Polarity	Percentage (%) L1	L2	Characteristics	Colour
Saturates	Non-polar	17.61	16.66	Viscous oil	White
Aromatics	Non-polar	19.14	18.82	Viscous liquid	Brownish
Resins	Polar	35.98	34.75	Semi-solid	Dark brown
Asphaltenes	Polar	23.45	27.56	solid	Black

3.2. One-Way ANOVA

The descriptive statistics for all experiments conducted in this study are summarized in Table 4. The p-value (probability value) at 95% confidence internal ($p<0.05$) is considered significant in the analysis. A small p-value (typically ≤ 0.05) indicates that the observed effect or difference is statistically significant. Conversely, a large p-value (> 0.05) implies weak evidence against the null hypothesis, meaning that any observed difference is likely due to random variation rather than a true effect. As shown in Table 5, the General Linear Model of SAS (2012) and Duncan Multiple Range Test on the four levels of polymers reveals that the means difference between locations L1 and L2 for the measured softening point, penetration point, ductility, flash point and viscosity, are highly significant ($p<0.001$). The basis for comparison was the polymer content (called a factor) and geological location of bitumen called groups, the L1 and L2. Prior research [47] revealed that the effects of modification on the modified bitumen depend on the type, origin and, chemical properties of the bitumen. Thus, the selection of the right modifier would depend on these factors.

The ANOVA results evaluating the effects of polymer contents on the measured properties are summarized in Table 6. The effects of different polymer contents (0, 2, 4, and 6 wt%) on penetration, softening point, ductility, flash point, and viscosity were summarized. Since p-values are less than 0.05, adding polymers to bitumen affects several parameters significantly. The effects on all the independent variables are statistically significant ($p<0.001$) since the sum of squares and mean square errors between the groups are always greater than the values obtained within the groups. This indicates that the mean difference observed in the properties at L1 and L2 are because of different levels (0, 2, 4 and 6 wt.%) of additives used to modify the samples as described in the following sections.

3.3. Effects of Polymer Type and Dosage on Softening Point

After modification, the softening point of bitumen samples from L1 and L2 ranged from 51.81 to 68.79 ˚C, which differed significantly ($p<0.05$) from their unmodified counterpart with softening point of 46 to 48 ˚C from L1 and L2, respectively. It is anticipated that when different additives are added to virgin bitumen, its softening point would rise. [49] reported softening point of 40 ˚C for a conventional bitumen from Malasia. [1] also reported softening point of 47 ˚C for unmodified Agbabu bitumen from Nigeria. The result obtained for the pristine bitumen sample in this study (48 ˚C) is consistence with that from [42], [48] The values of softening points reported are quite low for typical value of bitumen standard [37] used for road pavement construction [47], [49] . Based on the analysis performed in this study, it is obvious all the additives investigated were able to enhance the softening point irrespective of the location. However, the highest softening point observed corresponds with 6 wt% PSCB at L1 (81.17 ˚C) and 6 wt% PP at L2 (63.67 ˚C). It was however observed that there was no significance difference between softening point of 61.67 ˚C when 4 wt.% PP compared to using 6 wt.% PP at L2. Nigeria specification limits for softening Point are 52 and 56 ˚C for the 80/70 and 60/100 grades, respectively [50]. It is obvious that for L1, about 2 wt% PE, 4 wt% (PP, PEVA or BA) and 6 wt% PSCB would significantly increase the softening point from 46 to between 55.33 to 81.17 ˚C ($p<0.001$). On the other hand, 2 wt% (PE, BA or PSC) and 6 wt% (PP or PEVA) will be required to significantly increase the softening points of bitumen samples at L2 (p<0.001). Thus, the softening point is sensitive to different polymers and modified bitumen from different geological areas yielded softening points higher than the unmodified values.

Table 4: Overall Descriptive Statistics

	N	**Mean**	**Std. Deviation**	**Std. Error**	**Minimum**	**Maximum**	**95% Confidence Interval for Mean**	
							Lower Bound	**Upper Bound**
Softening point								
PP	24	54.92	7.93	1.62	40.00	66.00	51.57	58.27
PEVA	24	54.33	6.10	1.25	43.00	64.00	51.76	56.91
PE	24	54.29	6.13	1.25	44.00	65.00	51.71	56.88
BA	24	52.57	10.33	2.11	35.25	72.35	48.21	56.93
PSCB	24	61.06	13.39	2.73	42.00	83.50	55.41	66.72
Penetration point								
PP	24	30.35	19.85	4.05	3.87	53.10	21.97	38.73
PEVA	24	29.64	15.84	3.23	10.57	53.00	22.95	36.32
PE	24	25.06	16.55	3.38	10.34	53.50	18.07	32.05
BA	24	30.18	18.34	3.74	6.47	54.50	22.44	37.92
PSCB	24	19.46	21.07	4.30	0.00	54.50	10.57	28.36
Ductility								
PP	24	113.92	7.35	1.50	95.00	122.00	110.81	117.02
PEVA	24	127.43	21.82	4.45	96.00	169.51	118.21	136.64
PE	24	119.97	12.45	2.54	99.21	151.94	114.72	125.23
BA	24	132.07	44.82	9.15	98.00	257.04	113.14	150.99
PSCB	24	92.85	36.59	7.47	15.38	127.42	77.40	108.30
Flash point								
PP	24	285.29	10.88	2.22	263.00	302.00	280.70	289.89
PEVA	24	286.63	8.86	1.81	269.00	298.00	282.88	290.37
PE	24	287.50	7.66	1.56	274.00	301.00	284.27	290.73
BA	24	279.20	9.35	1.91	265.70	295.00	275.25	283.15
PSCB	24	288.27	14.40	2.94	272.76	321.50	282.19	294.35
Viscosity								
PP	24	1391.21	1018.27	207.85	478.00	2720.00	961.23	1821.19
PEVA	24	1390.42	1004.82	205.11	530.00	2703.00	966.12	1814.72
PE	24	1428.38	1017.67	207.73	531.00	2755.00	998.65	1858.10
BA	24	1321.83	1052.84	214.91	509.60	2700.00	877.26	1766.41
PSCB	24	1332.87	1070.23	218.46	505.30	2790.00	880.95	1784.79

Table 5: ANOVA Showing A Significant Level of Property Mean Differences in Locations L1 and L2

Dependent variable	**Polymer additives**	**I**	**J**	**Mean Difference (I-J)**	**Std. Error**	**Sig.^{b}**	**95% Confidence Interval for Difference^b**	
							Lower Bound	**Upper Bound**
	PP	1	2	-3.333*	0.745	0.000	-4.913	-1.753
Softening point	PEVA	1	2	-3.500*	0.759	0.000	-5.109	-1.891
	PE	1	2	-4.917*	1.027	0.000	-7.095	-2.739

	BA	1	2	-1.52	0.782	0.070	-3.178	0.138
	PSCB	1	2	15.458*	0.835	0.000	13.689	17.228
	PP	1	2	25.452*	0.515	0.000	24.36	26.543
Penetration point	PEVA	1	2	9.807*	0.843	0.000	8.02	11.593
	PE	1	2	2.720*	0.511	0.000	1.637	3.803
	BA	1	2	19.586*	0.659	0.000	18.189	20.983
	PSCB	1	2	-11.638*	0.436	0.000	-12.561	-10.714
	PP	1	2	-0.667	0.878	0.459	-2.528	1.195
Ductility	PEVA	1	2	28.853*	2.641	0.000	23.253	34.452
	PE	1	2	5.613	4.203	0.200	-3.296	14.522
	BA	1	2	41.637*	2.65	0.000	36.02	47.254
	PSCB	1	2	-39.631*	3.011	0.000	-46.014	-33.249
	PP	1	2	-5.083*	1.837	0.014	-8.978	-1.189
Flash point	PEVA	1	2	-0.25	1.876	0.896	-4.228	3.728
	PE	1	2	-7.167*	1.893	0.002	-11.18	-3.154
	BA	1	2	-14.106*	1.251	0.000	-16.757	-11.454
	PSCB	1	2	0.038	1.236	0.976	-2.583	2.66
	PP	1	2	-1492.750*	10.493	0.000	-1515	-1470.51
Viscosity	PEVA	1	2	-1478.000*	11.668	0.000	-1502.73	-1453.27
	PE	1	2	-1482.083*	6.937	0.000	-1496.79	-1467.38
	BA	1	2	-1607.503*	11.371	0.000	-1631.61	-1583.4
	PSCB	1	2	-1635.600*	12.536	0.000	-1662.18	-1609.03

** The mean difference is significant at the 0.05 level*
b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 6: ANOVA Results for Effects of Different Additives Levels (0, 2, 4 and 6 wt%) on Mean of Various Properties of Bitumen Sourced from Locations L1 and L2.

			Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
	PP	Between Groups	1394.500	7	199.214	59.764	0.000
		Within Groups	53.333	16	3.333		
		Total	1447.833	23			
	PEVA	Between Groups	800.000	7	114.286	33.046	0.000
		Within Groups	55.333	16	3.458		
		Total	855.333	23			
	PE	Between Groups	761.625	7	108.804	17.180	0.000
Softening point		Within Groups	101.333	16	6.333		
		Total	862.958	23			
	BA	Between Groups	2393.562	7	341.937	93.185	0.000
		Within Groups	58.711	16	3.669		
		Total	2452.274	23			
	PSCB	Between Groups	4056.616	7	579.517	138.64	0.000
		Within Groups	66.880	16	4.180		
		Total	4123.496	23			
	PP	Between Groups	9041.408	7	1291.630	812.282	0.000
		Within Groups	25.442	16	1.590		
		Total	9066.850	23			
	PEVA	Between Groups	5701.841	7	814.549	191.087	0.000
		Within Groups	68.203	16	4.263		

		Total	5770.045	23			
	PE	Between Groups	6275.816	7	896.545	572.207	0.000
Penetration point		Within Groups	25.069	16	1.567		
		Total	6300.885	23			
	BA	Between Groups	7690.528	7	1098.647	421.754	0.000
		Within Groups	41.679	16	2.605		
		Total	7732.207	23			
	PSCB	Between Groups	10196.543	7	1456.649	1279.642	0.000
		Within Groups	18.213	16	1.138		
		Total	10214.756	23			
	PP	Between Groups	1169.833	7	167.119	36.134	0.000
		Within Groups	74.000	16	4.625		
		Total	1243.833	23			
	PEVA	Between Groups	10285.363	7	1469.338	35.100	0.000
		Within Groups	669.780	16	41.861		
		Total	10955.143	23			
	PE	Between Groups	1866.671	7	266.667	2.516	0.060*
Ductility		Within Groups	1695.579	16	105.974		
		Total	3562.25	23			
	BA	Between Groups	45531.420	7	6504.489	154.41	0.000
		Within Groups	673.998	16	42.125		
		Total	46205.418	23			
	PSCB	Between Groups	29921.333	7	4274.476	78.586	0.000
		Within Groups	870.275	16	54.392		
		Total	30791.609	23			
	PP	Between Groups	2398.958	7	342.708	16.924	0.000
		Within Groups	324.000	16	20.250		
		Total	2722.958	23			
	PEVA	Between Groups	1467.625	7	209.661	9.925	0.000
		Within Groups	338.000	16	21.125		
		Total	1805.625	23			
	PE	Between Groups	1004.000	7	143.429	6.671	0.001
Flash point		Within Groups	344.000	16	21.500		
		Total	1348.000	23			
	BA	Between Groups	1862.146	7	266.021	28.338	0.000
		Within Groups	150.196	16	9.387		
		Total	2012.342	23			
	PSCB	Between Groups	4623.961	7	660.566	72.012	0.000
		Within Groups	146.768	16	9.173		
		Total	4770.729	23			
	PP	Between Groups	23837573.300	7	3405367.613	5154.441	0.000
		Within Groups	10570.667	16	660.667		
		Total	23848144	23			
	PEVA	Between Groups	23209195.200	7	3315599.310	4059.296	0.000
		Within Groups	13068.667	16	816.792		
		Total	23222263.800	23			
	PE	Between Groups	23815281.600	7	3402183.089	11782.452	0.000
Viscosity		Within Groups	4620.000	16	288.750		
		Total	23819901.600	23			
	BA	Between Groups	25482572.900	7	3640367.558	4692.063	0.000
		Within Groups	12413.703	16	775.856		
		Total	25494986.600	23			
	PSCB	Between Groups	26329112.700	7	3761301.817	3988.981	0.000
		Within Groups	15086.767	16	942.923		
		Total	26344199.500	23			

Polypropylene = PP; polyethylene = PE; poly-ethylene-co-vinyl-acetate = PEVA; poly-styrene-co-butadiene = PSCB) and butyl acrylate = BA

3.4. Effects of Polymer Type and Dosage on Penetration Point

The penetration value is a measure of the consistency and relative hardness of bitumen at a specified temperature. When evaluated in conjunction with the softening point, it provides a reliable indication of the thermal susceptibility of bitumen, describing how its consistency changes with temperature. Together, these parameters are commonly used to assess the binder's sensitivity to temperature variations and its expected performance under different thermal conditions. The penetration point also quantifies bitumen stiffness and rheological behaviour [51]. The analysis in this study shows that all the modified samples exhibited low penetration value because the addition of polymers stiffens the bitumen [52], [53]. However, bitumen sourced from L1 and L2 exhibited significant differences in response to polymers type and dosage. This is an indication that different polymers interacted with the bitumen in different ways [54] . As presented in Table 7, the penetration points of modified samples ranged from 11.61- 47.10 mm at L1 and 6.75 - 42.86 mm at L2. When compared with the value of 52.17 - 53.40 mm for the pristine samples, a significant reduction in penetration occurred upon modification using different polymers ($p< 0.05$). All the polymer additives show a significant reduction of penetration points irrespective of bitumen locations. Except with the PSCB, the penetration value reduces at L1 as the dosage increases between 2 - 6 wt%. The application of PSCB indicates no significant difference in penetration between 4 - 6 wt%. The highest penetration value of modified bitumen at L1 is 47.10 mm using 2 wt% BA, and the lowest value of 11.61 mm corresponded to 6 wt% PE. The resistance to penetration is an indication of improved rigidity of the binder at 25 °C [55], [56]. It was observed that bitumen sourced from L2 only required as low as 2 wt% dosages of PP, PE, BA, PEVA and PSCB to cause a significant reduction of penetration value. PSCB however, produced the highest value of 30.64 mm while PP gave the lowest at equal dosage of 2 wt% in the bitumen. Thus, a much lower quantity of polymer additive is required at L2 relative to L1 perhaps due to geographical origin. Apart from the source of bitumen, the dosage of additives influenced the penetration point. An increase in dosage at L1 caused a significant reduction in penetration value whereas a further increase of additives beyond 2 wt% to bitumen samples at L2 caused penetration value to increase which indicates poor compatibility as the dosage of additives increases. This observation that at certain concentration, the dispersal of polymer additives in the mix reduces causing agglomeration [1], [3]. Previous authors have also observed that, in addition to geographical location and environmental conditions, the chemical composition (SARA fraction) of bitumen had also a significant effect on penetration and other properties of bitumen [57].

3.5. Effects of Polymer Type and Dosage on Ductility

The ductility test measures the length the standard bitumen stretches without breaking under stress at standard conditions (5 cm/min at 25 °C). It indicates adhesive properties and influences pavement performance in service [58]. It is also an indicator of bitumen viscoelasticity when undergoing deformation. The ASTM specification recommended a minimum limit of 100 [39] for binder. As shown in Table 1, the ductility of unmodified samples obtained from the two geographical locations L1 and L2 ranged from 101-110 mm which satisfied the minimum requirement according to [39]. The statistical analysis of the modified bitumen, however, showed a significant difference in ductility of bitumen at L1 and L2 ($p<0.05$) with respect to type of modifier and dosage. The ductility values of the modified bitumen from L1 and L2 are in the range 96.62 - 244.52 mm and 112.33-122.67 mm, respectively. The maximum ductility values of 244.52 and 122.67 mm were observed at L1 and L2 when 2 wt% BA and 6wt% PE was applied, respectively. The minimum values of ductility of 96.62 and 112 mm corresponded with 4 wt% PSCB and BA at L1 and L2, respectively were recorded. It is obvious that modifiers as low as 2 wt% are adequate irrespective of geographical location when compared with the minimum requirement. A significant reduction in ductility was observed when modifier dosage increased from 2 to 4 wt.% using PEVA, PE, A and PSCB. On the contrary, the ductility of bitumen keep increasing with the addition of PP. Previous research [27] has indicated a disproportionate increase in ductility with polymer additives as observed in this study regarding PEVA, PP and PE [24]. The results of this study indicate that, for samples obtained from location L2, there was no statistically significant difference in ductility when polyethylene (PE) was added at 2 wt.% and 6 wt.%. This suggests that a PE dosage of 2 wt.% may be sufficient to achieve the desired modification effect. Furthermore, no significant variation in average ductility was observed across different polypropylene (PP) dosages for L2 samples, indicating that ductility was largely insensitive to PP content. Polypropylene is classified as a plastomer, a polymer group known to enhance the strength and stiffness of bitumen through the formation of thermodynamically stable structures within the binder matrix, even at relatively low polymer concentrations [54]. Previous study by [59] have reported a decrease in binder deformation under load when the concentration of another plastomer, PE is kept below 1 wt%. According to [25], the bitumen's elastic recovery won't greatly improve. According to authors, PE at a higher concentration form a weak intermolecular connection that induces agglomeration and deterioration of mechanical properties. Based on the result of the statistical analysis carried out as presented in Table 7, it suffices to state that 2 wt% modifier dosage may be required to preserve the minimum required ductility at both geographical locations considered in this study. However, holistic consideration of bitumen properties often requires a tradeoff of certain properties which may lead to usage of modifier dosage higher than 2 wt%. The analysis showed a degradation of ductility with dosage but generally resulted to ductility values higher than the value recorded for pristine samples except for PSCB in location L1 which yielded a value (96.62 and 98.56 mm at 4 and 6 wt.%) lower than the minimum threshold (100 mm) at higher dosage.

3.6. Effects of Polymer Type and Dosage on the Flash Point

The flash point of bitumen is the temperature at which the bitumen flashes in the presence of an open fire [4]. The ASTM specification recommended a minimum limit of 230 ˚C for bitumen binder grades while a standard in Nigeria also specified a minimum flash point of 250 and 225 ˚C for 60/70 and 80/100 penetration grades, respectively [50]. The average flash point measured for raw samples obtained from locations L1 and L2 ranged between (277-279 ˚C). However, the flash point of modified bitumen sourced from L1 using PEVA and PSCB polymers was observed to increase with dosage with PSCB yielding the highest value of 320 ˚C (12% higher than the unmodified sample) and PEVA with flash point of 291.67 ˚C (5% higher than the unmodified sample) at dosage of 6 wt%. Similarly, an increase in dosage of PE and PP marginally caused an increase in flash point of the bitumen. However, addition of BA resulted in decrease in flash point. Thus, PSCB and PEVA are better fire retarding additives in the binder than PP and PE. Though, excess BA in the mix could reduce the flash point thereby causing fire hazards. On the other hand, all the additives exhibited positive effects on the flash point at location L2 with no significant difference as a result of increasing dosage. Thus, a small additive quantity as low as 2 wt% addition is sufficient to cause a significant improvement of flash point at this location. Similar observation was made by [61] but with 14 wt% PEVA which increased the flash point to 303 ˚C. Another study regarding PSCB, indicated that the thermal stability performance of PSCB up to about 400 ˚C depended on the styrene composition [60]. Therefore, styrene content is attributed to excellent performance of PSCB as observed in the present study on flash point. Furthermore, both PEVA and PSCB are copolymers of different monomers generally having higher thermal stability, better flame retardancy and barrier properties [3][4].

3.7. Effects of Polymer Type and Dosage on Viscosity

Statistical analysis (Table 7) revealed a significant difference in the mean viscosities of bitumen samples obtained from the two geographical locations ($p < 0.05$). In addition, polymer dosage had a statistically significant effect on the viscosity of samples from location L1, whereas this effect was less pronounced for samples sourced from L2, as shown in Table 7. The observed variations in viscosity may be attributed to differences in climatic conditions, particularly temperature, as well as variations in chemical composition, notably the SARA fractions and the asphaltene content of the bitumen [47] . Crude oil is a complex mixture of various substances including waxes, resins, saturates, asphaltenes, naphthenics, dissolved gases, water, and salts. It is obvious from Table 7 that the various polymer investigated in this study increased the viscosity further from their control samples except the BA and PSCB especially, at L1. As earlier reported, the presence of and quantity of asphaltenes in bitumen influences the polymeric wax formation inhibitors and pour point depressants [62]. Thus, asphaltenes interfering with inhibitor crystal modification mechanism. The performance of the additives BA in this present study, especially in location L1 can be attributed to its phase. The BA was used in its liquid phase, which facilitated good miscibility and effective dispersion within the bitumen, as well as enhanced its ability to inhibit crystallization and paraffin deposition [63]. Also, Acrylic acid and its derivatives are one of the prominent employed pour point depressants due to their high-performance proficiency to hinder wax deposition [63]. The poor performance of PEVA copolymers may be attributed to its higher content of vinyl acetate (40 wt%), paraffin wax content in the SARA fraction and carbon number content [64]. Generally, workability remains a potential serious issue since the additives performance on viscosity reduction is less efficient irrespective of the geographical locations.

3.8. Summary of Statistical Analysis

The observations from statistical analysis carried out on the modified samples from geographical locations L1 and L2 using PP, PE, PSCB, PEVA and BA show that the means difference between softening point, penetration point, ductility, flash point and viscosity measured at the two geographical locations L1 and L2 are highly significant ($p<0.001$).

3.8.1. Softening point

All the additives investigated enhanced softening points regardless of geographical location. The maximum softening point (81.17 °C) for 6 wt% PSCB and (63.67 °C) for 6 wt% PP were observed at L1 and L2, respectively. The minimum softening points of 51.67 °C and 55 °C at 2 wt% PP and 4 wt.% PSCB recorded for modified samples from L1 and L2, respectively showed statistically significant difference ($p<0.05$) from their unmodified samples. In fact, 2 wt% PSCB at L2 yielded a softening point value of 58.33 °C. Thus, additives dosage between 2 - 6 wt % is adequate to modify samples from both locations.

3.8.2. Penetration point

Significant differences in penetration occur at different locations upon modification ($p < 0.05$). PSCB between 2 - 6 wt% and PP between 2 - 4 wt% performed better at L1 and L2, respectively. At L1, the other polymers (PEVA, PE, PP and BA) other than PSCB require 6 wt.% dosage to yield a significant difference in penetration point. At L2, aside the PP, the other additives (PSCB, PEVA, PE and BA) also required the dosage at 6 wt% dosage to cause a significant reduction of penetration value.

3.8.3. Ductility

The analysis showed significant differences in ductility between the bitumen samples from different geographical locations ($p<0.05$). The maximum polymer dosage required for a significant ductility is 2 wt% irrespective of geographical location.

Table 7: Interaction effect of location and concentration levels on polymer properties after modification using different additives.

	L1 (AGBABU)				**L2 (LODA BITUMINOUS SAND)**					
INTERACTION	**0.00**	**2.00**	**4.00**	**6.00**	**0.00**	**2.00**	**4.00**	**6.00**	**SEM**	**P. val**
Softening Point										
PP	46.00^{d}	51.67^{c}	60.67^{ab}	54.67^{c}	41.00^{e}	60.00^{b}	61.67^{ab}	63.67^{a}	1.62	0.00
PEVA	47.00^{c}	54.33^{b}	55.33^{b}	53.67^{b}	44.00^{c}	61.67^{a}	58.67^{a}	60.00^{a}	1.25	0.00
PE	46.33^{d}	55.33^{bc}	52.00^{c}	53.67^{c}	46.00^{d}	62.00^{a}	58.67^{ab}	60.33^{a}	1.25	0.00
BA	48.67^{c}	36.48^{e}	71.32^{a}	50.79^{c}	42.33^{d}	58.67^{b}	55.33^{b}	57.00^{b}	2.11	0.00
PSCB	46.00^{e}	71.93^{c}	76.07^{b}	81.17^{a}	43.33^{e}	58.33^{d}	55.00^{d}	56.67^{d}	2.73	0.00
Penetration Point										
PP	52.29^{a}	42.64^{b}	37.41^{d}	39.97^{c}	52.08^{a}	6.05^{f}	4.12^{f}	8.25^{e}	4.05	0.00
PEVA	52.17^{a}	34.71^{b}	35.74^{b}	15.53^{d}	52.00^{a}	11.05^{e}	15.55^{d}	20.33^{c}	3.23	0.00
PE	52.57^{a}	24.05^{b}	17.47^{c}	11.61^{e}	52.00^{a}	11.08^{e}	17.51^{c}	14.22^{d}	3.38	0.00
BA	53.40^{a}	47.10^{b}	31.57^{c}	27.83^{d}	52.00^{a}	6.75^{f}	10.96^{e}	11.85^{e}	3.74	0.00
PSCB	53.33^{a}	21.07^{e}	20.05^{e}	20.13^{e}	52.00^{a}	30.64^{d}	35.63^{c}	42.86^{b}	4.30	0.00
Ductility										
PP	107.67^{c}	114.67^{b}	115.00^{b}	117.00^{ab}	98.33^{d}	120.33^{a}	118.67^{ab}	119.67^{a}	1.50	0.00
PEVA	108.67^{bc}	154.87^{a}	149.01^{a}	154.87^{a}	99.00^{c}	117.67^{b}	115.33^{b}	120.00^{b}	4.45	0.00
PE	110.00^{b}	127.04^{ab}	116.79^{b}	137.29^{a}	107.67^{b}	120.33^{ab}	118.00^{ab}	122.67^{ab}	2.54	0.00
BA	109.33^{ad}	244.52^{a}	121.42^{c}	136.28^{b}	101.00^{d}	114.67^{c}	112.33^{cd}	117.00^{c}	9.15	0.00
PSCB	108.33^{ab}	118.63^{a}	96.62^{c}	98.56^{c}	100.67^{c}	116.67^{a}	114.33^{a}	119.00^{a}	7.47	0.00
Flash point										
PP	278.00^{c}	288.33^{b}	275.00^{cd}	289.67^{ab}	267.33^{d}	290.67^{ab}	297.67^{a}	295.67^{ab}	2.22	0.00
PEVA	278.33^{b}	288.33^{a}	287.67^{a}	291.67^{a}	270.00^{c}	293.67^{a}	294.33^{a}	289.00^{a}	1.81	0.00
PE	280.67^{c}	286.33^{bc}	287.00^{bc}	281.67^{c}	279.33^{c}	296.33^{a}	297.00^{a}	291.67^{ab}	1.56	0.00
BA	278.00^{b}	275.69^{b}	266.82^{c}	268.07^{c}	277.00^{b}	290.67^{a}	291.33^{a}	286.00^{a}	1.91	0.01
PSCB	282.33^{c}	273.29^{d}	277.20^{d}	320.33^{a}	279.00^{c}	292.67^{b}	293.33^{b}	288.00^{b}	2.94	0.00
Viscosity										
PP	531.67^{d}	928.67^{b}	483.67^{e}	635.33^{c}	548.00^{d}	2685.67^{a}	2646.33^{a}	2670.33^{a}	207.85	0.00
PEVA	531.00^{d}	825.67^{b}	679.00^{c}	570.00^{d}	552.67^{d}	2668.33^{a}	2643.00^{a}	2653.67^{a}	205.11	0.00
PE	533.00^{d}	826.33^{a}	570.33^{c}	819.67^{b}	556.00^{cd}	2713.67^{a}	2698.33^{a}	2709.67^{a}	207.73	0.00

BA	534.33^{b}	511.92^{b}	511.25^{b}	514.81^{b}	546.33^{b}	2665.33^{a}	2640.00^{a}	2650.67^{a}	214.91	0.00
PSCB	532.33^{c}	510.42^{c}	506.38^{c}	511.13^{c}	548.33^{c}	2651.00^{b}	2718.67^{a}	2684.67^{ab}	218.46	0.00

**superscripts a,b,c,d,e indicate decreasing values across the row*

3.8.4. Flash point

The statistical analysis indicates no significant difference in fire point when polymers are added beyond 2 wt% to samples from L1 and 4 wt% to samples at L2.

3.8.5. Viscosity

The analysis showed a significant difference of the mean bitumen viscosities between the geographical locations ($p<0.05$). The viscosities of samples at L1 are lower than that at L2 perhaps owing to bitumen composition. Upon modification, the viscosity increased further except with the Butyl Acrylate (BA) additives when applied between 2 - 4 wt% dosage regardless of geographical location. Both PSCB and PP demonstrate capabilities for improving properties of bitumen regardless of geographical origin and it is recommended to optimize them. It is however obvious the polymers showed little effect on rheology, a key consideration in pavement design especially at L2. Butyl Acrylate nevertheless, demonstrates potential in this regard perhaps because of its physical state and chemical properties which allow it to disperse homogenously in the bitumen mix.

4. CONCLUSION

The geographical location, the SARA composition, the state condition of samples and degree of exposure to climatic conditions (rainfall, temperature and humidity) has a significant effect on the physico-chemical properties and viscosity of bitumen. Samples at L1 exhibited higher property improvement when modified with PSCB and that at L2 performed better with PP as an additive. Both statistical analysis, numerical optimization and SEM images supported the fact that PP as low as 1.71 wt% or PSCB at a dosage concentration of 1.5 wt% is sufficient to modify samples at geographical location L2 while 2.75 wt% PP or 4.25 wt% PSCB are satisfactory for samples at location L1. Although the additives, especially the Butyl Acrylate additive show potential for reducing the viscosity, the workability of the samples regardless of geographical location still requires further attention. This study recommends an investigation of grafted or co-polymerized additives using PP and Butyl Acrylate precursor.

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