



# Optimization of Ethylene – Vinyl Acetate Dosage for Rheological and Physico-Mechanical Properties of Loda Bitumen

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## ABSTRACT

Heavy reliance on road transportation, especially in developing countries, has necessitated the construction of durable roads using localized materials such as natural bitumen. However, using natural bitumen as a binder in pavement construction gave poor performance and hence, the need for its modification prior to application. This study investigated ethylene–vinyl acetate (EVA) as a modifier and optimized its dosage for improved rheological, physical, and mechanical properties of Loda natural bitumen. A D-optimal mixture design coupled with Response Surface Methodology (RSM) was deployed for evaluating the effect of EVA content (1.5–6 wt%) on penetration, softening point, ductility, viscosity, and flash point. Thirteen experimental runs were analyzed using ANOVA to develop predictive and experimentally validated models. The result showed that EVA modification reduced penetration, increased softening and flash points, enhanced ductility, and reduced the viscosity of the base Loda bitumen. Multi-objective optimization identified an optimal composition of 95.6 wt% bitumen and 4.4 wt% EVA, yielding a penetration of 17.95 mm, softening point of 59.79 °C, ductility of 117.32 cm, flash point of 290.25 °C, and viscosity of 2658.22 MPa·s. These results demonstrate that optimized EVA modification significantly enhances Loda natural bitumen, supporting its use in durable pavements and promoting sustainable utilization of local bitumen resources.

## INTRODUCTION

Approximately 95% of transportation activities in many developing nations occur on road networks; however, this dependence is accompanied by persistent pavement failures arising from material deficiencies, increased traffic loading, and adverse environmental conditions (Otuoze and Shuaibu, 2017). Several road damages have been attributed to the poor binding capacity of the binder used for binding pavement aggregates (Salawudeen et al., 2024). Binders are sourced from petroleum residue after atmospheric and vacuum distillation in oil and gas refineries. Natural bitumens that are found at shallow depth or as outcrop above the surface of the ground have also been identified with a potential for bonding aggregates in pavements (Olabemiwo et al., 2015). In most cases, limited attention has been

given to the exploitation of such large natural bitumen deposits, resulting in the continuous importation of asphaltic bitumen for road infrastructure development (Akinmosin and Olufowobi, 2017).

Specifically, natural bitumen deposits have been identified in Nigeria, particularly in the southwestern region states such as Ondo, Ogun, Lagos, Edo, and Enugu. A proven reserve estimated at 14.86 billion barrels has been reported from these states collectively (Ademila and Ojo, 2018). A major factor contributing to its low patronage by construction industries is poor adhesion performance, largely attributed to prolonged exposure to severe environmental conditions (Salawudeen et al., 2024). To address these challenges, various improvement strategies have

been explored, and different classes of polymers, including plastomers (e.g. polyethylene (PE), polypropylene (PP), ethylene–butyl acrylate (EBA)) and thermoplastic elastomers (e.g., styrene–butadiene–styrene (SBS), styrene–isoprene–styrene (SIS), and styrene–ethyl-ene/butylene–styrene (SEBS)) have been investigated (Al-Rabiah et al., 2016; Kunanusont et al., 2020).

Extensive research indicates that polymer modification markedly enhances the rheological and mechanical performance of bitumen and asphalt binders (Almusawi & Nasraldeen, 2025), leading to improved resistance to fatigue and low-temperature cracking, reduced temperature susceptibility, and increased resistance to permanent deformation (rutting) when subjected to traffic loading (Rek et al., 2014). The practice of modifying natural bitumen predates the commercial production of refined bitumen, with early studies and patents documenting the use of natural rubber as a modifier (Salawudeen et al., 2020). In recent years, synthetic polymers have gained prominence as a viable means of meeting modern pavement performance requirements (Santamar et al., 2004).

Among the various polymers used in pavement applications, Ethylene Vinyl Acetate (EVA) has attracted significant attention. EVA is a semi-crystalline copolymer widely classified as a plastomer and is commonly employed to enhance asphalt workability during construction while improving resistance to deformation during service (Kheirredine, 2019). EVA-based polymers form a relatively rigid and stable network within the bitumen matrix, which limits deformation under high service temperatures. Ethylene–vinyl acetate (EVA) copolymers exhibit physical properties intermediate between those of semi-rigid low-density polyethylene and rubber-like plasticized polyvinyl chloride, thereby making them particularly suitable for use in pavement

engineering applications. (Sengoz et al., 2009). Consequently, EVA modification has been demonstrated to enhance the resistance of bitumen to permanent deformation and thermal cracking, while significantly improving its viscoelastic behaviour.

To investigate the combined effects of these parameters, several researchers have employed Response Surface Methodology (RSM) and experimental design techniques to optimize asphalt binder performance (Abbas et al., 2024; Abdullah et al., 2018). RSM is a powerful statistical tool widely used for developing empirical models, evaluating parameter interactions, and performing process optimization. For instance, Abbas et al. (2024) applied RSM to minimize asphalt content and mixing temperature in polyethylene-modified bitumen and reported optimum performance at mixing temperature of 152.24 °C and polymer content of 10 wt%. Similarly, Muhaimin et al. (2020) utilized RSM to model and optimize mixing conditions, identifying optimum mixing temperature, speed, and time of 149 °C, 1292 rpm, and 53 minutes, respectively. Ebenezer and Hainin (2018) further confirmed that EVA modification significantly enhances the rheological properties of bitumen.

Several experimental design techniques have been explored in asphalt and bitumen modification studies (Arinkoola and Ogbe, 2015). The determination of an optimal design methodology is governed primarily by experimental cost, time limitations, and the inherent complexity of the system under study. According to this study, a D-optimal mixture design was employed for its effectiveness in addressing both mixture and process variables. By maximizing the determinant of the information matrix, the D-optimal design minimizes the overall variance of the estimated model parameters and enhances the robustness of

the optimization process. (Salawudeen et al., 2025). Analysis of variance (ANOVA) was employed to evaluate the significance of model parameters, while multi-objective optimization was used to determine the optimal formulation that yields enhanced performance characteristics suitable for durable pavement applications. Therefore, Response Surface Methodology based on a D-optimal mixture design was used in order to optimize the EVA content in Loda bitumen.

## MATERIALS AND METHOD

### Material and Equipment

50/70 penetration bitumen grade of AC-30 and Ethyl vinyl acetate were the main materials used. The latter was acquired from Sigma Aldrich Ltd in Lagos state, Nigeria. while the former came from bitumen resources in Loda (Longitudes 4°88E and Latitudes 6°65N) in Ondo State, Nigeria. The

primary instruments employed for the analysis of the modified bitumen are presented in Figure 1.

### Bitumen Characterization

The raw bitumen was characterized using the ASTM standard, and Table 1 presents the main attributes of the raw bitumen. The ethyl vinyl acetate sample provided by Sigma Aldrich Co. Ltd has the following characteristics: melting point of 150 °C, 0.925 g/cm<sup>3</sup> density and 25g/10 min MFI.

### Material Preparation

The bitumen sample was taken from a drilled oil well in Loda, Ondo state, and brought to the lab in an iron container. Following the method outlined by Salawudeen *et al.* (2020), the sample was boiled and heated in a beaker at 110°C for 30 minutes in order to remove sand and moisture. Sand and other impurities were then filtered through an iron mesh filter.



**Figure 1:** Laboratory equipment used for bitumen modification (Bitumen Laboratory, Chemical Engineering Department, LAUTECH, Ogbomoso, Nigeria): (a) LR-A018 No Motor Rheometer (b) Variable speed high shear mixer (c) Asphalt Penetration tester (d) Softening point analyser.

**Table 1:** Base Bitumen Properties

Properties	Units	Value	Limit	Standard
Ductility	Cm	101	$\geq 100$	ASTM D-113
Penetration point	0.1mm	51	50-70	ASTM D-36
Softening point	$^{\circ}\text{C}$	46	52-54	ASTM D-113
Flash point	$^{\circ}\text{C}$	210	-	ASTM D-92
Viscosity	MPa.s	2685	-	ASTM D2170-95
Fire point	$^{\circ}\text{C}$	277	-	ASTM D-92
Density	$\text{g}/\text{cm}^3$	1.19	-	ASTM D-70
Saturates	%	16.66		
Aromatics	%	18.82		
Asphaltene	%	27.56		
Resin	%	34.75		

### Experimental Design for Polymeric Bitumen

The bitumen–EVA mixture was formulated using a randomized D-optimal mixture design implemented in Experimental Design Program (version 13). Thirteen randomized runs were generated within the specified ranges of bitumen (94–98.5 wt%) and EVA (1.5–6 wt%). Among various mixture design approaches—including D-optimal, axial, simplex-centroid designs and simplex-lattice - the D-optimal design was selected to minimize the total variance of the objective functions and enhance the predictive accuracy of the model (Izzati *et al.*, 2015). Moreover, the D-optimal design necessitates few experimental runs compared to other design types, thereby minimizing both testing time and reducing costs (Carneiro *et al.*; 2020).

### Preparation of Modified Bitumen of EVA

A determined amount of bitumen was poured into a beaker and was weighed in accordance with the experimental design for each experiment, and the beaker was put beneath a thermostatically controlled hot plate that was set at 160 degrees Celsius (Celauro *et al.*, 2020). A predetermined amount of EVA was added to the molten bitumen, and the resulting mixture was agitated using a high-shear mixer at 1200 rpm for 30 minutes. Each EVA-

bitumen mixture was taken out after 30 minutes and stored in a beaker at room temperature for characterization. The design matrix and test results from the experimental D—optimal design—are shown in Table 2.

### Determination of Conventional Properties

Both raw and modified samples were analyzed using standard procedures. The following is a description of the method:

### Determination of Softening Point

The softening point of the virgin and modified samples was evaluated using the ASTM D36 (ASTM D36/D36M-14, 2014). Bitumen samples weighing 50 grams were suspended on a ring in a cup of 75 millilitres of water. Glycerine was used to keep the bitumen from sticking to the metal plate beneath the hanger. The heater was switched "ON" while a ball was hanging on the ring's bitumen. The bitumen began to melt as the water's temperature rose. The ball's weight dropped through the bitumen that had melted on the plate. The ball's temperature and the moment it landed on the plate were recorded. For each sample and the modified bitumen, the process was repeated.

### **Determination of Penetration Point**

The consistency (hardness) of the bitumen mixture under particular test conditions can be ascertained empirically using the penetration test. The experiment was conducted in accordance with the ASTM-D5-97 standard (ASTMD5-97, 1998). Using a penetrometer, penetration was measured by attaching a loaded needle to a bitumen sample's surface for five seconds at 25 degrees Celsius. Each sample's penetration findings were obtained and recorded. For each of the altered samples, the sample procedure was repeated.

### **Flash Point Determination**

ASTM D 92 (ASTMD92-01, 1965) was utilized to determine the bitumen's flashpoint. A 75 ml sample of bitumen was poured to the cup and heated with a Bunsen burner powered by an external natural gas source to maintain a small open flame. A flame lighter was used to allow the flame to cross the surface of the bitumen on a regular basis. When the flash point temperature was reached, the surface of the bitumen began to burn. The flash point temperature was calculated by observing and recording the current temperature at when this occurred.

### **Viscosity determination**

Viscosity of both raw and modified bitumen was determined using ASTMD2170-95. An analytical weighing scale was used to measure a specific amount (0.3 g) of modified bitumen samples. A custom-made nylon from the manufacturer was used to wrap each sample. Rubber and polymer software was installed on a computer that was connected to the rheometer. Because of the pressure cylinder connected to it, the rheometer opens and closes in response to pressure changes. After opening the rheometer and inserting the weighed sample on the spindle, the chamber was closed. The rheometer's initial values were 130 degrees Celsius and 240 seconds. The sample was heated to the

specified temperature for 240 seconds. After then, the viscosity was measured and noted.

### **Bitumen ductility determination**

Ductility was utilized using the ASTM D-113. The process description is accessible elsewhere (Salawudeen *et al.*, 2020).

### **Statistical Analysis and Optimization study**

Analysis of variance (ANOVA) at a 95% confidence level was employed for data analysis. The statistical parameters used to identify the best-fitting model for the binary systems include coefficient of determination ( $R^2$ ), adjusted coefficient of determination (adjusted  $R^2$ ), predicted coefficient of determination (predicted  $R^2$ ), coefficient of variance (C.V), standard deviation, lack-of-fit, regression data (p and f values), and predicted residual sum of squares (PRESS) (Salawudeen *et al.*, 2020).

The degree of significance for the mean, linear factorial (2FI), quadratic, cubic, and quartic models, which show agreement between expected and experimental responses, was determined using the ANOVA and previously established correlation coefficients. The contour, 3D models, factors, and interaction graphs based on design factor correlation were provided by the Design Expert after the fitting procedure. The appropriate mathematical model that best explained the experimental data of different responses was chosen as the aim function using the ANOVA. The multi-objective functions were then optimized using a numerical approach with inequality constraints. The numerical optimization solution was experimentally verified three times.

## **RESULTS AND DISCUSSION**

### **Effects of EVA Dosage on Penetration Point**

EVA dosage effects on the modified bitumen's penetration point is presented in Figure 2(a). According to this study, all of the modified samples

have penetration values between 16.00 and 21.90 mm, which is less than the 51 mm found in the raw bitumen. Penetration value decreased compared to raw bitumen value, indicating that the bitumen becomes stiffer and less prone to deformation as EVA content increases. This stiffening is typical of EVA-modified binders and is associated with improved rutting resistance under traffic loads (Ebenezer et al., 2018). The penetration point is a key indicator of bitumen hardness and softness (Adeyemi et al., 2021). Higher penetration value indicates a softer bitumen, while a lower penetration shows a harder bitumen. The result showed a

penetration value of 19.25 mm under optimal conditions. This value, when compared with standard specifications, was lower, which further confirms the efficiency of modified bitumen. This finding is consistent with the report of Guo et al. (2020), when asphalt is modified by EVA and other polymers, a notable decrease was also observed in the penetration value.

### Effects of EVA Dosage on Softening Point

EVA dosage effects of the modified bitumen on the softening point is shown in Figure 2 (b).

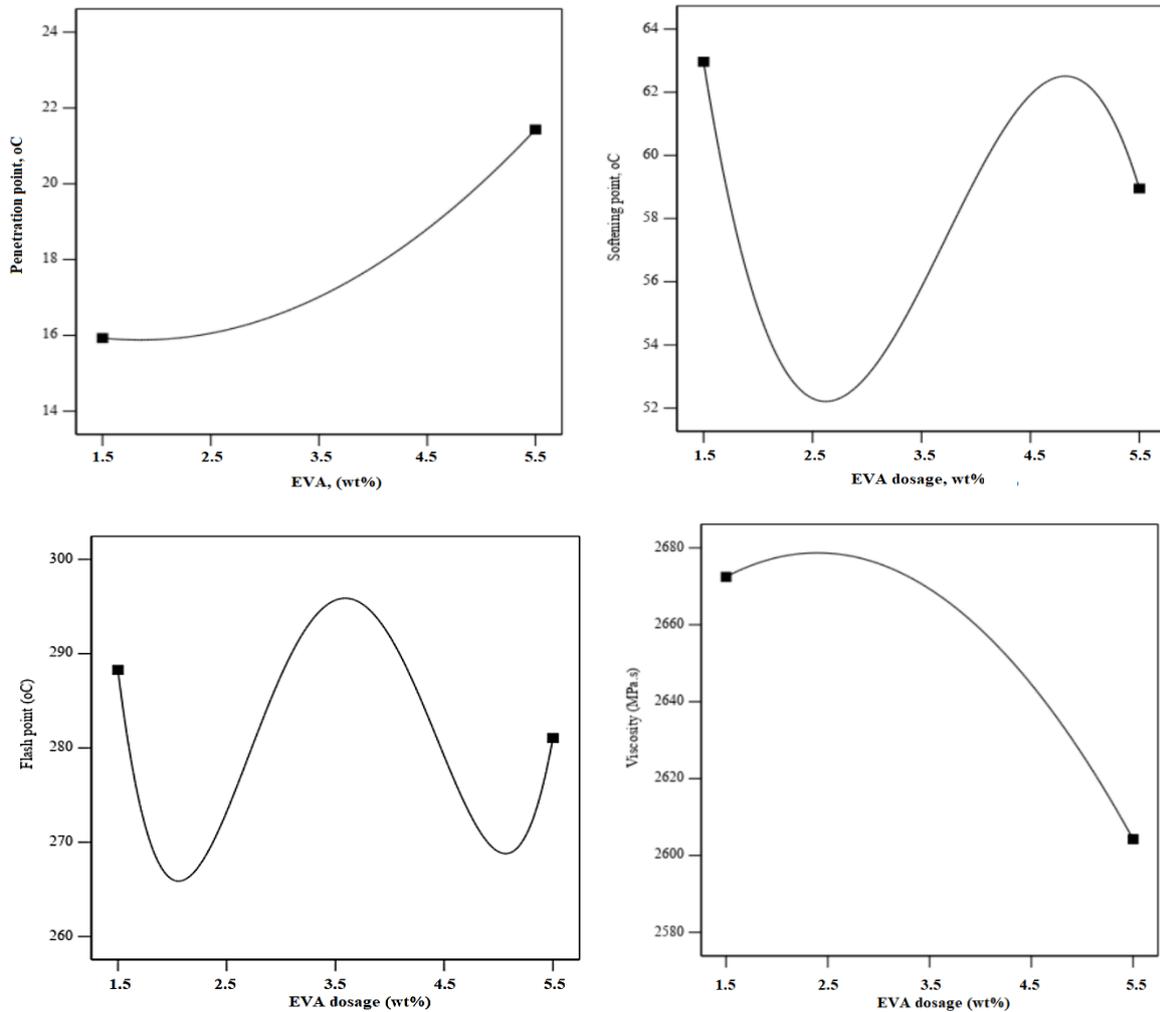


Figure 2: EVA dosage sensitivity to (a) Penetration point (b) Softening point (c) Flash point and (d) Viscosity

The softening point ranged from 52 to 64 °C was presented in Table 2, which was significantly different from the raw sample's 46 °C. Mixing of EVA to bitumen produced an unstable system as indicated by non-linear response of the curve. This trend implies that the proper dosage of EVA increases the bitumen's thermal resistance and raises the temperature at which the binder softens. In warm climatic regions, a higher softening point is preferred since it postpones deformation under load. (Zhihua *et al.*, 2023).

The softening point attained a value of 57.25 °C under optimal condition. This indicates a strong resistance to softening under elevated pavement temperatures. It was observed from the graph that the softening point increases with EVA content. However, the sharp peak observed at the dosage of 1.5 – 2.0 wt%, followed by a drop, suggests a potential limit to the benefit of EVA addition. Beyond this point, additional EVA reduce homogeneity or promotes phase separation, leading to less predictable performance.

#### **Effects of EVA Dosage on Ductility**

The degree to which bitumen stretches under typical conditions (5 cm/min at 25 °C) is measured by a mechanical property called ductility. Additionally, it shows the viscoelasticity of bitumen under deformation. A minimum of 100 is required for binders according to ASTM D113. The ductility of unmodified samples obtained ranged from 101 to 110 cm, as shown in Table 1, which satisfied the minimum requirement. Following adjustment, a maximum ductility value of 120 cm was noted (Run 3). This demonstrates how bitumen's mechanical properties were improved by employing an EVA modifier. However, it has been noted that EVA modifiers are adequate/sufficient in the range. Previous research (Desideriy and Lanotte, 2021) has

indicated that EVA significantly increases ductility, as demonstrated by this study.

#### **Effects of EVA Dosage on Viscosity**

The effects of EVA dosage on the bitumen sample's viscosity is presented in Figure 2 (d). The results demonstrate a noticeable variation in viscosity with decrease EVA content. The SARA composition, particularly the bitumen's resin percentage in relation to its asphaltene concentration, can be connected to the variations in viscosities (Cui *et al.*, 2024; Salawudeen *et al.*, 2024). It was shown that adding EVA significantly decreased viscosity, thereby improving bitumen's workability (Siddiq *et al.*, 2024). According to earlier research, EVA increases compatibility while maintaining the presence of polymer-rich particles. Under some circumstances, these phase-separated domains are softer and more malleable, which create low flow resistance (Yuhao *et al.*, 2023).

#### **Effects of EVA Dosage on Flash Point**

The bitumen temperature at which vapours ignite momentarily when exposed to an ignition source is called the flash point (Salawudeen *et al.*, 2020). For paving-grade binders, minimum flash point requirements of 250 °C and 225 °C are specified for penetration grades 60/70 and 80/100, respectively (Osuolale and Agbalaya, 2012). When EVA was added to base bitumen, there was a noticeable difference in the flash points. The maximum flash point of about 295 °C was recorded at 3.5 wt% dosage of EVA; there was an increase in flash point when compared with the base bitumen. Mixing of EVA to bitumen produced an unstable system as indicated by the non-linear response of the curve.

#### **OPTIMIZATION STUDY**

Getting the right dosage of EVA is crucial as sensitivity analysis indicated. Efforts was made to optimize the dosage through a systematic approach described as follows

**Model Selection**

Several regression equations were evaluated on the basis of statistical parameters, including lack of fit, Correlation coefficient and adjusted correlation coefficient. Table 3 shows the selected correlations for developing proxy models for various properties of modified bitumen.

The correlation coefficients are approximately equal to one, and the lack of fit is not statistically significant ( $p>0.05$ ). Polynomial models were therefore recommended after regression models' suitability for each of the measured responses was

confirmed using the regular coefficient of determination.

**Model Development**

The ANOVA table for each property's developed models is presented in Table 4. The F-value, p-values, and lack of fit displayed for different responses suggest that the associated models are reasonably right with a 95% confidence level because noise is unlikely to produce an F-value bigger than 0.01%. Moreover, there is no significant lack of fit ( $p>0.05$ ). Equations 1 through 5 present the final models, with A and B standing for bitumen EVA, respectively.

Table 2: Design Matrix and response for binary EVA-bitumen mix

	<b>A:Bitumen</b>	<b>B:EVA</b>	<b>Flash point</b> °C	<b>Ductility</b> Mm	<b>Penetration point</b> °C	<b>Softening point</b> °C	<b>Viscosity</b> MPa/s
1	98.5	1.5	287	120	15.63	57	2673
2	94	6	279	115	20.55	59	2688
3	97.375	2.625	271	120	16.3	59	2600
4	95.125	4.875	281	117	18.3	61	2691
5	94	6	281	117	23	60	2611
6	98.5	1.5	288	119	16.2	64	2703
7	96.25	3.75	284	118	17.1	58	2664
8	94	6	283	115	21	58	2596
9	97	3	286	118	15	52	2675
10	95.5	4.5	286	117	17.3	61	2660
11	96.25	3.75	297	116	18	56	2663
12	98.5	1.5	290	120	16	62	2673
13	96.25	3.75	294	119	18	54	2678

Table 3: Statistics summary for penetration, softening, flash point, and viscosity

Properties	Source	Sequential p-	Lack of Fit p-	R <sup>2</sup>	Adjusted R <sup>2</sup>	Predicted R <sup>2</sup>
		value	value			
Pen. Point	Linear mixture-					
	Quartic process	< 0.0001	0.8268	0.9581	0.9070	0.7429
Soft. Point	Quartic mixture-					
	linear process	< 0.0001	0.1708	0.9036	0.8393	0.7235
Flash point	Linear mixture-					
	Quartic process	< 0.0001	0.1265	0.9967	0.9894	0.7505
Viscosity	Quartic mixture-					
	Factorial process	0.0018	0.6649	0.9409	0.8660	0.7915

Penetration point = 0.170601A + 31.8487B + -0.329252AB (**R2 = 0.877**) 4.1

Softening point = 1.19309 A + -12022.8B + 187.629AB - 0.679793 + AB(A - B) 4.2

Ductility = 1.21346A + 0.298864B(**R2 = 0.892**) 4.3

Flash point = 7.49596 \* A + 2.97694e + 06 \* B + -53226.3 \* AB + 321.568  
AB(A - B) + -0.87061AB(A - B)<sup>2</sup> (**R2 = 0.927**) 4.4

Viscosity = 26.4014A + -554.49B + 6.11603AB 4.5

Table 4: ANOVA of developed models for binary EVA – bitumen properties

	Sum of Squares	Df	Mean Square	F-value	p-value	
<b>Penetration point</b>						
Model	526.68	11	47.88	18.73	< 0.0001	Significant
Linear Mixture	13.36	1	13.36	5.23	0.0481	
AC	1.44	1	1.44	0.5648	0.4715	
AD	18.05	1	18.05	7.06	0.0261	
BC	64.85	1	64.85	25.37	0.0007	
BD	2.77	1	2.77	1.08	0.3254	
ACD	4.68	1	4.68	1.83	0.2091	
BCD	82.90	1	82.90	32.43	0.0003	
AC <sup>2</sup>	15.40	1	15.40	6.03	0.0365	
AD <sup>2</sup>	79.22	1	79.22	30.99	0.0003	
BC <sup>2</sup>	70.73	1	70.73	27.67	0.0005	
BD <sup>2</sup>	306.70	1	306.70	119.99	< 0.0001	
Residual	23.00	9	2.56			
Lack of Fit	17.98	8	2.25	0.4473	0.8268	not significant
Pure Error	5.02	1	5.02			
Cor Total	549.69	20				

**Softening point**

Model	833.60	8	104.20	14.05	< 0.0001	Significant
Linear Mixture	107.28	1	107.28	14.47	0.0025	
AB	285.98	1	285.98	38.57	< 0.0001	
AC	6.31	1	6.31	0.8507	0.3745	
AD	40.94	1	40.94	5.52	0.0367	
BC	0.9236	1	0.9236	0.1246	0.7303	
BD	273.56	1	273.56	36.89	< 0.0001	
ABC	54.86	1	54.86	7.40	0.0186	
ABD	2.73	1	2.73	0.3685	0.5552	
Residual	88.98	12	7.42			
Lack of Fit	81.05	9	9.01	3.41	0.1708	not significant
Pure Error	7.93	3	2.64			
Cor Total	922.58	20				

**Flash point**

Model	9267.55	11	842.50	136.23	< 0.0001	Significant
Linear Mixture	449.57	1	449.57	72.69	0.0004	
AC	612.51	1	612.51	99.04	0.0002	
AD	1143.18	1	1143.18	184.85	< 0.0001	
BC	1046.55	1	1046.55	169.23	< 0.0001	
BD	1225.15	1	1225.15	198.10	< 0.0001	
ACD	235.02	1	235.02	38.00	0.0016	
BCD	214.99	1	214.99	34.76	0.0020	
AC <sup>2</sup>	1415.41	1	1415.41	228.87	< 0.0001	
AD <sup>2</sup>	1328.55	1	1328.55	214.82	< 0.0001	
BC <sup>2</sup>	1356.01	1	1356.01	219.26	< 0.0001	
BD <sup>2</sup>	1151.60	1	1151.60	186.21	< 0.0001	
Residual	30.92	5	6.18			
Lack of Fit	28.26	3	9.42	7.06	0.1265	not significant
Pure Error	2.67	2	1.33			
Cor Total	9298.47	16				

**Viscosity**

Model	44470.70	11	4042.79	11.57	0.0018	Significant
Linear Mixture	10423.48	1	10423.48	29.83	0.0009	
AB	5937.35	1	5937.35	16.99	0.0044	
AC	2244.40	1	2244.40	6.42	0.0390	
AD	494.95	1	494.95	1.42	0.2728	
BC	15.06	1	15.06	0.0431	0.8414	
BD	2.42	1	2.42	0.0069	0.9360	
ABC	1346.19	1	1346.19	3.85	0.0904	

ABD	895.26	1	895.26	2.56	0.1535	
ACD	6863.77	1	6863.77	19.64	0.0030	
BCD	42.52	1	42.52	0.1217	0.7375	
ABCD	659.31	1	659.31	1.89	0.2119	
Residual	2445.76	7	349.39			
Lack of Fit	1579.44	5	315.89	0.7293	0.6649	not significant
Pure Error	866.33	2	433.16			
Cor Total	46916.46	18				

### Numerical Optimization

Regression equations are used in a method that simultaneously considers the influence of numerous factors at different levels; it is feasible to choose a combination of multiple designs. In this instance, the Design Expert Software's single optimization framework takes equations 1 through 5 into account. Subject to a chosen set of restrictions, in order to maximize or minimize the objective functions, the optimization problem was designed (Baghaee *et al.*, 2015). The goal functions are represented by equations 1 through 5, and the ranges of variables utilized in the experiment constitute the set of constraints. These formulas are used to find factor combinations that meet the restrictions imposed on each response. The answer was reached by concurrently minimizing the penetration point and viscosity and optimizing the flashpoint, ductility, and softening point. By converting each regression equation into a desirability function, Design-Expert carried out multi-objective function optimization (Arinkoola *et al.*, 2022).

After the predetermined number of iterations, the overall desirability (D) was determined by taking the geometric mean of each desirability (Equation 6).

$$D = \left[ \prod_{i=1}^n d_i \right]^{\frac{1}{n}} \quad (6)$$

Where (d<sub>i</sub>) represents the desirability of different realizations and (n) denotes the number of random samples. At the optimum conditions of A (95.5978 wt%) and B (4.4022 wt%), the predicted flash point,

ductility, penetration, softening point, and viscosity are 290.25 °C, 117.32 cm, 17.95 mm, 59.79 °C, and 2658.22 MPa·s, respectively. The Design-Expert software shows these optimization results shown in Figure 3 in the ramp diagram.

The validity of the results was verified experimentally using three independent batches of bitumen blends prepared with 95.5878 wt% bitumen and 4.4022 wt% EVA. The mean properties of the modified mixtures were 229 ± 0.57 °C (flash point), 115 ± 1.10 cm (ductility), 23 ± 0.25 mm (penetration), 88.5 ± 1.21 °C (softening point), and 2016 ± 3.57 MPa·s (viscosity). These values fall within the range of typical bitumen properties (Table 1) and show good agreement with values reported in the literature (Salawudeen *et al.*, 2020).

### CONCLUSION

Polymer modification significantly improved the rheological, physical, and mechanical properties of the base bitumen, enhancing its resistance to deformation and temperature-related distress. Optimization using response surface methodology identified an optimal polymer dosage that provided a balanced improvement in penetration, softening point, ductility, viscosity, and flash point. The modified binder exhibited improved compatibility and structural stability, indicating effective polymer dispersion within the bitumen matrix.

Overall, the optimized polymer-modified bitumen demonstrates strong potential for durable and sustainable pavement applications. The following conclusions were therefore made:

The study developed regression models for the different binary-modified bitumen properties. The

strong agreement established between the predicted and experimental values indicated that the developed models were reliable for forecasting properties of EVA-modified bitumen.

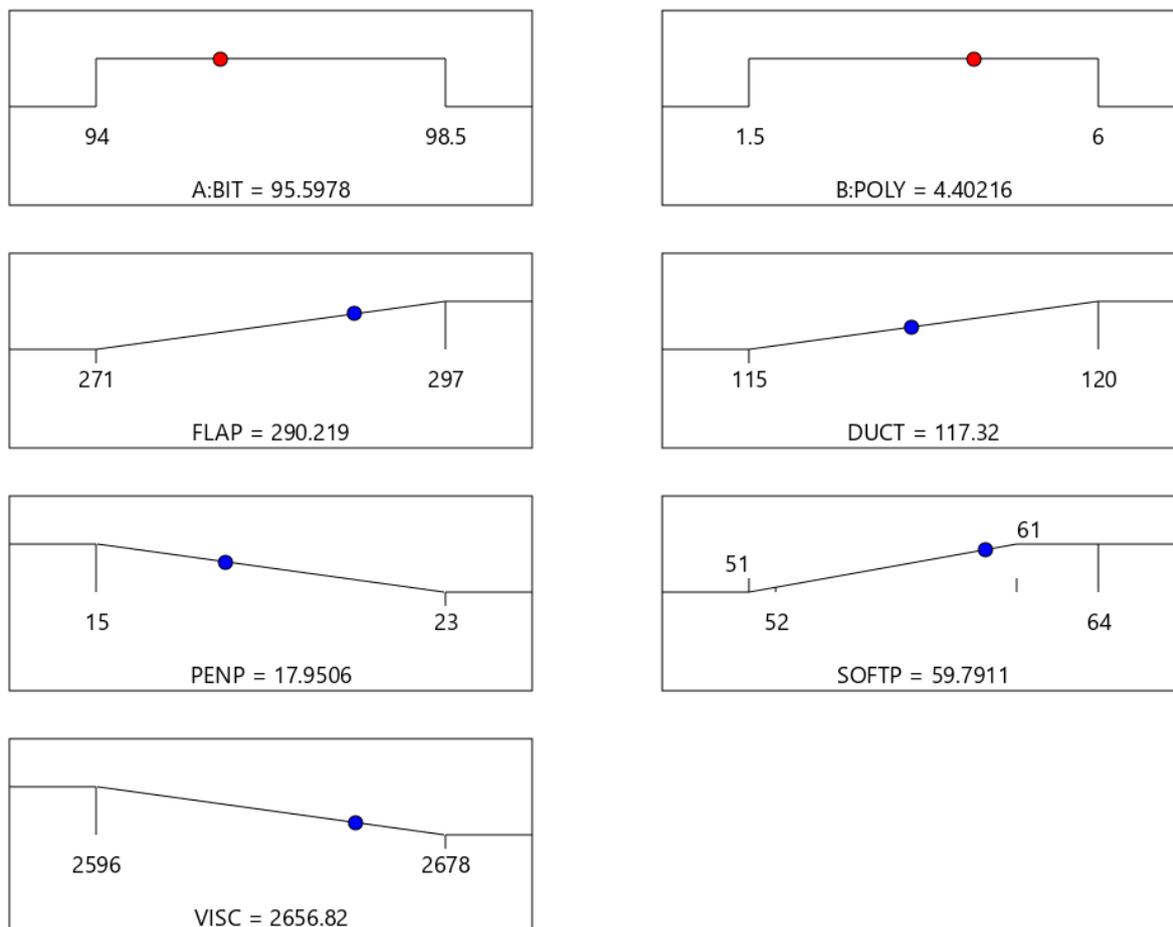


Figure 3: The optimal conditions of the ramp diagram

The study developed regression models for the different binary-modified bitumen properties. The strong agreement established between the predicted and experimental values indicated that the developed models were reliable for forecasting properties of EVA-modified bitumen. The study also showed that adding 4.4 wt% EVA to 95.6 wt% raw Loda bitumen is optimum to enhance the softening point, ductility, penetration point, flash point and viscosity properties of the raw Loda bitumen.

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