Influence of Polymer Type and Dosage on Binder Mix Design Considerations

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Abstract

This study investigated the influence of polymer types and dosages on binder mix design considerations utilising High-Density Polyethylene (HDPE) and Butonal (aqueous SBS polymer) as modifiers. The initial characterisation of unmodified asphalt binder involved establishing fundamental properties, namely softening point, penetration index, flash and fire point temperatures, and specific gravity, which constituted baseline parameters for subsequent analysis. Subsequently, the asphalt binders were modified through the incorporation of HDPE and Butonal at concentrations of 2%, 3%, 4%, and 5% by weight. These modified binders were subjected to a complete evaluation, examining softening point, penetration, and specific gravity to assess performance variations. Results showed that HDPE modification generally increased binder stiffness, with higher softening points and lower penetration values, enhancing high-temperature rutting resistance but risking reduced low-temperature flexibility at excessive dosages. In contrast, butonal modification resulted in improved elasticity while maintaining penetration values within moderate ranges, indicating better resistance to thermal cracking. Specific gravity was found to vary non-linearly with both polymer types and dosages, influencing binder volume and mix volumetric parameters such as Voids in Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA). The findings highlight the need for polymer- and dosage-specific calibration of mix design to balance stiffness, elasticity, and thermal stability while adjusting binder content to account for density changes."

Keywords: Polymer type, Dosage, Asphalt binder, Mix design
Word Count: 190

I. Introduction

Asphalt binders are essential in pavement construction, acting as the adhesive that holds aggregate particles together to form asphalt concrete as its performance is fundamentally governed by the engineering characteristics of the bituminous binder and its compatibility with aggregates (Huang *et al.,* 2023; Pipintakos *et al.,* 2024; Akinmade *et al.,* 2024). Their viscoelastic nature allows them to exhibit both viscous and elastic behavior, which is crucial for accommodating traffic loads and temperature variations. However, unmodified asphalt binders face several challenges that can compromise pavement performance (Malluru *et al.,* 2025). While economical and widely available, these asphalt binders fail to meet the increasingly stringent demands imposed by heavier traffic loads, higher tire pressures, and more extreme climatic conditions (Afshin & Behnood, 2025; Vigneswaran *et al.,* 2024). Conventional asphalt binders are prone to issues such as rutting, fatigue cracking, and thermal cracking, especially under extreme weather conditions and increasing traffic loads (Riyad *et al.,* 2024; Joumblat *et al.,* 2023; Osman *et al.,* 2024). Asphalt pavements are highly susceptible to temperature-induced stresses, which can lead to significant deterioration such as rutting at high temperatures and cracking at low temperatures (Riyad *et al.,* 2024). These issues can indeed lead to pavement deformation, specifically rutting, which compromises road integrity and safety (Vámos & Szendefy, 2024; Joumblat *et al.,* 2023; Osman *et al.,* 2024).

These challenges have necessitated the need for modifications of asphalt to improve the properties of the asphalt. To address these deficiencies, polymer modification has emerged as a proven approach to enhance binder rheology, thermal stability, and elastic recovery. The increasing demand for durable and resilient pavements has led to the modification of asphalt binders with polymers to enhance their performance (Hasan *et al.,* 2024). While several polymers have been investigated in the modification of asphalt, the influence of polymer dosage and type on mix design considerations of bitumen has not been extensively studied (Huang *et al.,* 2023).

Polymer-modified binders (PMBs) can be engineered using various polymer types, such as thermoplastics (e.g., high-density polyethylene (HDPE), ethylene–vinyl acetate (EVA)) and elastomers (e.g., styrene–butadiene–styrene [SBS], synthetic latex) (Yang *et al.,* 2024; Emtiaz *et al.,* 2023). Each polymer class interacts differently with the asphalt matrix, producing unique effects on properties such as viscosity, penetration, softening point, and elasticity (Yang *et al.,* 2024). Equally important is polymer dosage: insufficient polymer content may yield negligible performance gains, while excessive content can lead to workability issues, segregation, and higher production costs (Yang *et al.,* 2024; Gupta *et al.,* 2021). Thus, both polymer type and dosage must be judiciously considered to achieve the optimal balance between performance enhancement and economic feasibility. Binder mix design considerations extend beyond initial rheological characterization. The choice of polymer and its dosage influences mixing and compaction temperatures, aggregate coating quality, volumetric properties, the binder's temperature susceptibility, and other factors that directly affect hot-mix asphalt (HMA) performance (Yang *et al.,* 2024; Darshan & Kataware, 2025). For instance, highly stiffened binders may improve rutting resistance but compromise low-temperature flexibility, leading to premature cracking (Quan *et al.,* 2024; Usanga *et al.,* 2025; Malluru *et al.,* 2025). Similarly, variations in viscosity and workability can alter compaction effort requirements, thereby impacting density and in-service durability. Despite the growing body of literature on PMBs, there remains a need for systematic studies that link polymer type and dosage level to binder mix design parameters in a unified framework. This knowledge is essential for optimizing material selection, ensuring construction efficiency, and predicting field performance with greater accuracy

2. Statement of the Problem

Despite the recognized benefits of polymer modification, there is a limited number of studies addressing the influence of polymer type (SBS and PE) and concentration on the mix design considerations of asphalt binders. A systematic evaluation of these factors is necessary to optimize performance and cost efficiency. Thus, in this study the effect of polymer type and dosage concentration on the mis design considerations of asphalt binder using SBS and Polyethylene was investigated. Butonal (Aqueous Styrene-Butadiene-Styrene (SBS)) and polyethylene are among the polymers commonly used to improve the rheological properties of asphalt binders, thereby enhancing their resistance to deformation and extending pavement lifespan. Incorporating polymers such as styrene-butadiene-styrene (SBS) and polyethylene into asphalt binders has been confirmed in numerous studies to be effective in improving the rheological properties of asphalt binders (Hasan *et al.,* 2024). While SBS has been extensively studied and confirmed to be effective in modifying asphalt binders, there is limited research on the combined effects of polymer type, and dosage concentration, on the rheological properties of asphalt binders. This study aims to investigate the influence of polymer type (SBS and polyethylene), and dosage concentration on the rheological properties of asphalt binders.

3. Methodology

The study employs an experimental research design focused on the laboratory modification and testing of asphalt binders. The methodology includes evaluating unmodified asphalt binders, modifying asphalt binders with varying concentrations of SBS and polyethylene, and subjecting the samples to rheological tests.

Research Materials and Experimental Procedures

Asphalt Binder: Unmodified Penetration Grade 100/120 asphalt binder was used as the base material. The neat asphalt was obtained from a construction yard within Ibadan, Oyo State. The material was kept at a normal temperature in the laboratory in a covered container.

Polymers: Aqueous Styrene-Butadiene-Styrene (SBS) (Butonal) and aqueous polymer (Melted HDPE) served as the polymer modifiers. Butonal was obtained from BSAFE and HDPE was sourced locally. HDPE is identified by the number "2" in the triangular recycling symbol. The shredded HDPE is shown on Figure 1 while the Butonal is shown on Figure 2

Figure 1: Shredded High-Density Polyethylene HDPE

Figure 2: Aqueous Styrene-Butadiene-Styrene (SBS) (Butonal)

Specific Gravity Test on High-Density Polyethylene (HDPE)

The Aqueous Styrene-Butadiene-Styrene (SBS) polymer (Butonal) and Polyethylene (PE) polymer (Melted HDPE) was obtained and the specific gravity of the polymers was determined. Specific gravity testing on polymers is performed to determine the ratio of a polymer's density to the density of water, which is useful for quality control, material identification, and understanding a material's behavior in various applications (Al-Mg, 2023; Kumar *et al.,* 2025). This test helps in distinguishing between different types of polymers and estimating their quality (Specific Gravity ASTM D792).

The apparatus and reagent used includes; Pycnometer, Digital balance, Distilled water, and Thermometer

Procedure

A representative polymer sample was sieved to obtain the desired particle size. The empty pycnometer was cleaned, dried, and weighed (M_1). Distilled water was then added to the pycnometer, and the mass was recorded (M_2). The pycnometer was emptied and dried, and the polymer samples were added. The pycnometer was then filled with distilled water and weighed (M_3). The specific gravity of the polymer was calculated using the formula Eqn. (1)

$$\text{Specific Gravity} = \frac{Mass\ of\ Polymer\ (M_3 - M_1)}{Mass\ of\ an\ equal\ volume\ of\ water\ (M_2 - M_1)} \ldots \qquad (1)$$

Specific Gravity Test on Butonal

The specific gravity of Butonal (aqueous SBS polymer) was determined based on standard liquid-specific-gravity testing methods (ASTM D70 / ASTM D792 principles adapted for liquid polymers

Properties of Unmodified Asphalt Binder

Before modification, the base binder was tested to determine its baseline properties. The softening point test (Ring and Ball method) – ASTM D36, penetration test at 25 °C – ASTM D5, flash and fire point test (Cleveland Open Cup method) – ASTM D92, and specific Gravity – ASTM D70 was determined. The softening point and penetration served as reference values for evaluating the effect of polymer modification, while flash and fire points provided a safety margin for heating during blending.

Modification of Asphalt Binder

Asphalt binder will be modified with different types of polymers (Butonal and Melted HDPE] at the optimum temperature as determined by SEM analysis.

Modification Procedures

Based on the empirical evidence, this research adopted polymer dosages within the effective ranges identified in previous studies. Specifically, SBS and Polyethylene was incorporated at dosages of 2%, 3%, 4%, and 5% by weight of the binder to assess the incremental benefits and determine the best concentration. The required amount of asphalt binder was weighed using a digital balance and transferred into the mixing container. The desired quantity of Butonal and HDPE was measured based on the specified dosages (2% 3%, 4%, and 5% by weight of binder). The asphalt was heated to the target temperature of 70°C. The temperature was monitored using a thermometer to ensure consistent heating. The polymer (SBS or PE) was then gradually added to the heated asphalt binder at a steady pace to prevent clumping. The target temperature was maintained throughout the mixing process to ensure proper blending of the polymer and asphalt binder. After mixing, the modified binder was cooled, then transferred into clean, labeled sample containers for further testing.

Properties of Modified Asphalt Binders

For each polymer type and dosage, softening point tests, penetration tests and specific gravity tests were conducted. These tests were performed in triplicate to ensure repeatability, and results were expressed as mean values. Changes in softening point and penetration relative to the control were used to assess binder stiffness and temperature susceptibility, while variations in specific gravity were analyzed in relation to mix design considerations

Softening Point Test

The asphalt binder softening test was conducted in accordance with the ASTM D36-2000 standard specifications (De Medeiros *et al.,* 2024).

Penetration Test

The asphalt binder penetration test was conducted in accordance with the ASTM D5 / AASHTO T49 standard specifications. It was performed at a temperature of 25°C ± 0.1°C, using a needle of 100 grams in weight, with penetration time of 5 seconds.

Specific Gravity of Asphalt Binder

Specific gravity is dimensionless (ratio of asphalt binder density to water density) (Kumar *et al.,* 2025). The specific gravity of the asphalt binder was conducted in accordance with Standard Reference ASTM D70 / AASHTO T228. The specific gravity determined at 25°C ± 0.1°C. The data was analyzed to identify performance trends under varying conditions; polymer dosage and type. Specific attention will be given to how these treatments influence the performance of the modified asphalt binder. The trends were illustrated using bar charts for clarity, showcasing the relationships between key treatment factors and the rheological properties.

4. Results And Discussion

Specific Gravity of Styrene Binder and Polyethylene

The Styrene-Butadiene-Styrene (SBS) polymer and Polyethylene (PE) polymer was inspected to ensure they are free from visible contamination. The specific gravity of the binders was determined to determine the physical specifications of the modifier. Reflecting their inherent material properties, the specific gravity values obtained for the two polymer modifiers show clear variations. High-Density Polyethylene (HDPE) and Aqueous Butonal, a type of Styrene-Butadiene-Styrene, have distinct specific gravity values that reflect their inherent material properties. HDPE had a specific gravity of 0.91 (Table 1), which is normal for materials made of polyethylene, which are known for being lightweight and having a relatively low density. Given their low specific gravity, HDPE-modified binders may be less dense, which could enhance workability and provide advantages in applications where weight reduction is crucial. HDPE is known to reduce the density of the asphalt binder, improving workability and making it beneficial in lightweight pavement designs (Ma *et al.,* 2021).

Table 1: Specific Gravity of Modifiers

Modifier (Polymer)	Specific Gravity
High Density Polyethylene	0.91
Aqueous Butonal	1.04

Studies also confirmed similar values for recycled HDPE used in asphalt (HDPE ranging from 0.935 g/cm^3 to 0.96 g/cm^3) emphasizing its cost-effectiveness and ease of blending at moderate temperatures (Begum *et al., 2020;* Abhilash *et al.,* 2020). Aqueous Butonal, on the other hand, had a higher specific gravity (1.04) than HDPE. This suggests a substance that is denser and has a more intricate molecular structure. Studies also reported SBS-specific gravity values around 0.93–1.1, which is consistent with the findings of this study (Sheng *et al.,* 2020). This reflects SBS's more complex and denser structure, which contributes to higher stiffness and improved high-temperature performance in modified asphalt (Sheng *et al.,* 2020). Studies have shown that SBS increases binder density slightly but significantly improves elasticity and rutting resistance, which correlates with its higher molecular mass and structure (Aurilio *et al.,* 2021; Lee *et al.,* 2023). Better stiffness and greater binder stability may result from a higher specific gravity, especially at high temperatures. This characteristic is in line with the performance requirements for SBS-type polymers, which are utilized to improve the elasticity and deformation resistance of asphalt binders.

Properties of the Unmodified Asphalt Binder

The unmodified binder was tested to determine its fundamental properties (Table 2). The softening point, penetration value, specific gravity, and flash and fire point were recorded. These values served as the baseline for comparative analysis with modified binders. The binder's capacity to tolerate high temperatures before softening is demonstrated by its softening point of 39℃. Given its low value, it appears to have little resistance to thermal deformation at high temperatures. Likewise, the high penetration of the unmodified asphalt binder (111 pens) indicated that the binder is very soft making it prone to rutting under repeated traffic loading. In pavement construction, particularly in hotter climates, such high penetration could compromise structural integrity. The softening point and penetration values suggest that the binder is soft and lacks high-temperature deformation resistance, which makes it unsuitable for hot climates or high-load pavements without modification (Olalekan *et al.,* 2024).

The specific gravity of the unmodified was 1.05 which is consistent with expected value of specific gravity for bitumen of paving grade, indicating sufficient density and the absence of any notable contamination or compositional irregularities. It is also used to calculate the volume of bitumen required in a hot mix aaphalt (HMA) design, as well as reflecting the binder composition where higher values may suggest the presence of denser fractions, which influences stiffness, aging susceptibility, and thermal cracking resistance. The specific gravity is normal, which suggests no significant impurity affecting the bulk composition. The flash point and fire point were determined to be 95.1℃ and 102℃ respectively, indicating the temperatures in which the binder may emit flammable vapours (flash point) and sustain combustion. Given that the binder becomes volatile at moderate heating temperatures, the rather low values indicate the need for caution during mixing and application. The very low flash and fire points are far below standard (230°C to 250°C), indicating oxidation, or volatility issues (Huo *et al.,* 2020). This presents serious safety concerns during mixing or field application (Huo *et al.,* 2020).

Standard Specification for Asphalt Cement (ASTM D946 / AASHTO M20) (Table 2) recommends 60–70 penetration grade to have penetration: 60–70 dmm, softening point: 45–

52□°C, flash Point: Min. 230□°C. These properties of the unmodified binder shows that the binder does not perform at its best, thus, justifying the need for modification with HDPE and Butonal polymers to improve its rheological qualities.

Table 2: Properties of Unmodified Binder

Properties of Bitumen	Average Values	Standard Requirements
Softening Point	39	≥ 45
Penetration Values	111	60 – 70
Specific Gravity	1.05	-
Flash Point	95.1℃	Min 230 °C
Fire Point	102℃	Min 240 °C

Studies emphasize the need for binder modification when properties fall outside optimal ranges, especially for use in high-temperature zones or under repetitive loading (Duarte and Faxina, 2021).

Modification of Asphalt Binders with Polymers

Asphalt binders were modified using SBS and HDPE at concentrations of 2%, 3%, 4%, and 5% by weight at a mixing temperature of 60°C. Each blend was subjected to the same set of rheological tests to determine the influence of polymer addition.

Softening Point Test

The effect of polymer type and dosage on the softening point of the asphalt binder is presented in Table 3 and Figure 3. The control binder (unmodified) exhibited a softening point of 39.0 °C for both HDPE and Butonal reference samples, which falls within the acceptable range for 60/70 penetration-grade asphalt.

Table 3: Softening Point (°C) of HDPE- and Butonal-Modified Binders

Dosage (% by wt. of binder)	HDPE	Butonal
0% Control	39	39
2%	38.3	38.5
3%	39.5	40.7
4%	43.0	37.5
5%	52.7	41.3

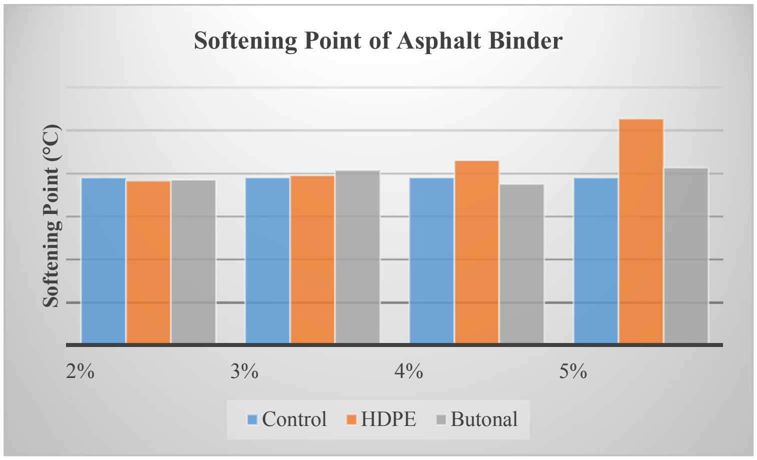

Figure 3: Softening Point of Asphalt Binder

For HDPE-modified binders, the softening point showed a consistent upward trend with dosage, except for a slight drop at 2% concentration (38.3 °C compared to 39.0 °C for the control). This initial reduction may be due to incomplete polymer dispersion at low dosage, which can temporarily disrupt the binder's structural homogeneity. Beyond 2%, the softening point increased progressively, reaching 43.0 °C at 4% and peaking at 52.7 °C at 5% dosage. This substantial improvement at higher concentrations indicates that HDPE, being a stiff thermoplastic, significantly enhances the binder's resistance to softening at elevated temperatures (Olalekan *et al.,* 2024; Nguyen *et al.,* 2025). The increase is attributed to the crystalline structure of HDPE, which increases binder stiffness and reduces susceptibility to permanent deformation under high service temperatures (Ghani *et al.,* 2022; Zhao *et al.,* 2021).

The Butonal-modified binders displayed a more variable trend. The softening point rose slightly at 2% (38.5 °C) and more notably at 3% (40.7 °C), suggesting an initial enhancement of high-temperature stability. However, a sharp decline occurred at 4% dosage (37.5 °C), dropping below the control value. This decline could be due to phase separation or over-saturation of the binder with the latex polymer, leading to reduced homogeneity and weakened structural integrity at elevated temperatures. At 5%, the softening point recovered to 41.3 °C, indicating partial improvement but still less pronounced than the HDPE-modified binder at the same dosage.

Polymer Type Comparison

At low dosages (2–3%), both polymers had relatively minor effects on softening point, with Butonal showing a slightly higher improvement at 3%. At moderate dosage (4%), HDPE provided a significant increase (+4.0 °C, over control), while Butonal unexpectedly reduced the softening point, suggesting that SBS latex may have a dosage threshold beyond which its thermal performance is compromised. At high dosage (5%), HDPE outperformed Butonal by a wide margin (+13.7 °C vs. +2.3 °C, over control), highlighting HDPE's superior capability to improve high-temperature performance when used at higher concentrations.

Implications for Mix Design

From a binder mix design perspective, the choice of polymer and dosage must balance high-temperature rutting resistance with workability and low-temperature flexibility (Li *et al.,* 2022). HDPE at higher dosages (>4%) is highly effective in raising the softening point, making it suitable for hot climates and heavily trafficked pavements (Işık and Baş, 2025). However, the corresponding increase in stiffness may require adjustments to compaction temperatures to avoid construction difficulties. When asphalt pavement materials exhibit increased stiffness due to factors like temperature changes or mix design adjustments, it can lead to difficulties in achieving proper compaction during construction. This can result in issues like inadequate air voids in the pavement, impacting its long-term performance. To compensate, adjustments to compaction temperatures may be necessary to ensure sufficient workability and density (Luxman *et al.,* 2019). Butonal performs better at low to moderate dosages (2–3%), where it offers modest improvements without significantly altering binder workability. At higher concentrations, its inconsistent effect on softening point suggests potential issues with phase compatibility, which could influence volumetric design parameters and long-term performance (Issa *et al.,* 2025).

Penetration Test

The penetration values for the control binder and polymer-modified binders are presented in Table 4 and Figure 4. The control (unmodified) binder had a penetration of 111 (0.1 mm), typical for a 100/120 penetration-grade asphalt. Lower penetration values indicate a harder (stiffer) binder, while higher values indicate a softer binder.

Table 4: Penetration (0.1 mm) of HDPE- and Butonal-Modified Binders

Dosage (% by wt. of binder)	HDPE	Butonal
0% (Control)	111	111
2%	97	177
3%	84	133
4%	139	80
5%	56	72

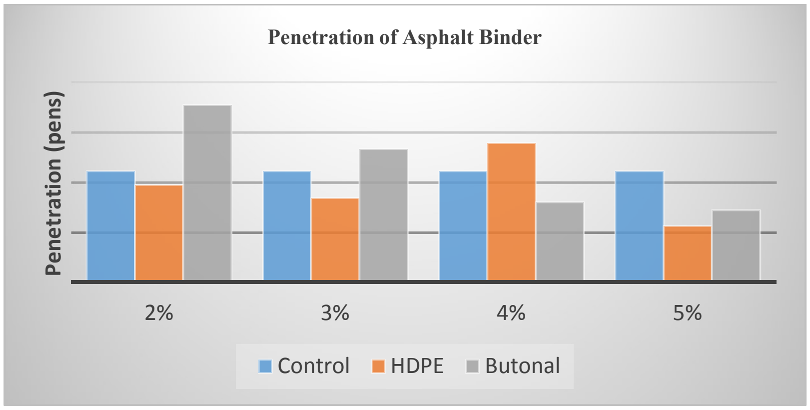

Figure 4: Penetration Test of Asphalt Binder

The HDPE-modified binders showed a general trend of increased stiffness with increasing polymer dosage, except at 4% dosage where penetration unexpectedly spiked to 139, indicating a temporary softening effect. At 2% dosage, penetration dropped from 111 to 97, suggesting improved hardness and reduced susceptibility to deformation under loading. At 3% dosage, the reduction was more pronounced (84), consistent with HDPE's thermoplastic crystalline nature, which increases binder rigidity. The anomaly at 4% (139) may be due to incomplete blending or localized agglomeration of polymer particles, which could interfere with the binder's structural uniformity and soften certain phases. At 5% dosage, penetration reached its lowest value (56), indicating significant hardening and a strong potential for rutting resistance in high-temperature conditions, albeit with possible implications for low-temperature cracking resistance.

Butonal (aqueous SBS latex) displayed a more erratic penetration pattern, suggesting that its elastomeric nature responds differently to increasing dosage. At 2% dosage, penetration increased sharply to 177, indicating a much softer binder. This is consistent with SBS's ability to improve elasticity and flexibility, which can be beneficial for low-temperature performance but reduces stiffness at high temperatures. At 3% dosage, penetration dropped to 133, showing partial recovery in stiffness but still higher than the control. At 4% dosage, penetration fell further to 80, indicating a considerable hardening effect, likely due to better polymer–binder network formation at this dosage. At 5% dosage, penetration decreased slightly again to 72, maintaining a stiffer structure while still softer than the equivalent HDPE-modified binder.

Polymer Type Comparison

HDPE consistently promoted binder stiffening at most dosages, with penetration values decreasing from the control (111) to as low as 56 at 5% dosage. This indicates that HDPE, being a thermoplastic with high crystallinity, effectively restricts binder molecular movement, thus improving high-temperature rutting resistance (Zhao *et al.,* 2011). However, the anomaly at 4% dosage (penetration 139) suggests that excessive polymer agglomeration or blending inconsistencies can temporarily reduce stiffness, emphasizing the need for optimized mixing protocols (Alexandre-Franco *et al.,* 2024; Olalekan *et al.,* 2024).

Butonal, an aqueous SBS elastomer, demonstrated a contrasting initial effect. At 2% dosage, penetration rose sharply to 177, indicating significant softening due to increased elastic phase content and reduced internal friction within the binder (Issa *et al.,* 2025; Tejeshwini *et al.,* 2025). While this can be advantageous for low-temperature flexibility and fatigue resistance, it compromises rutting resistance (Issa *et al.,* 2025; Tejeshwini *et al.,* 2025). As dosage increased, penetration progressively decreased, 133 at 3%, 80 at 4%, and 72 at 5%, reflecting improved polymer network formation and compatibility with the asphalt matrix.

Implications for Mix Design

For binder mix design, penetration values influence the choice of compaction temperature, expected rutting resistance, and low-temperature flexibility (Do *et al.,* 2025). HDPE is most effective for applications where high stiffness is desirable, especially at 5% dosage, though care must be taken to avoid blending anomalies such as seen at 4%. Butonal can enhance flexibility at lower dosages but achieves optimal stiffening at 4–5%, where it can still maintain some elastic recovery properties. Designers must consider that an overly stiff binder may reduce fatigue life, while an overly soft binder may compromise rutting resistance, meaning polymer selection should be based on specific climate and traffic conditions

Specific Gravity of Asphalt Binder

The consistency, mixing behaviour, and possible compatibility of additives or modifiers with the base binder are all assessed using specific gravity, a basic property that shows the density of the asphalt binder in relation to water. Modifier agglomeration, dispersion, or chemical interaction within the binder can also be indicated by a change in specific gravity. The specific gravity for the asphalt binder is shown in in Table 5, and illustrated in Figure 5. The unmodified asphalt binder had a specific gravity of 0.99, providing a baseline for comparison.

At 2% HDPE, the specific gravity of the modified asphalt binder increased to 1.02, suggesting a slight densification that is probably caused by the polymer's uniform distribution. At 3%, HDPE, it further increases to 1.07, indicating better HDPE particle incorporation. At 4% HDPE, the modified asphalt binder achieved the highest density of any HDPE sample, 1.13, indicating a peak that may indicate optimal dispersion or potential agglomeration at this stage. However, at 5% HDPE, the specific gravity of the modified asphalt binder was 1.00, which could suggest phase separation or poor dispersion at higher concentrations. The upward trend from 2% to 4% indicates efficient mixing and integration, whereas the downward trend at 5% might indicate that too much polymer leads to binder instability or separation. For asphalt binder modified with Butonal, at 2%, there was a slight increase to 1.00 in the specific gravity. At 3%, Butonal, the specific gravity of the modified asphalt binder was 1.11, indicating a strong chemical bond or interaction with the bitumen. The specific gravity at 4%, Butonal was 2.09, and at 5%, was 1.10. At higher dosages, Butonal-modified binders exhibit more stable and consistent density values, suggesting good compatibility with the base bitumen.

A study reported that HDPE increases the specific gravity of asphalt binder with dosage increase due to its uniform blending at lower concentrations and dense polymer structure (Murana *et al.,* 2024). However, beyond a threshold (~4%), dispersion issues can occur, reducing homogeneity (Emtiaz *et al.,* 2023). A study also noted that HDPE-modified binders typically peaked in specific gravity at 3%–4%, after which overloading caused density reductions, likely due to phase separation or entrapped air (Dulaimi *et al.,* 2023). It was also found that SBS-based modifiers like Butonal generally lead to moderate increases in specific gravity, indicating good polymer-bitumen compatibility (Li *et al.,* 2024). SBS shows more thermodynamic stability across dosages due to its ability to form elastic networks with the binder (Li *et al,* 2025). This study showed that Butonal modified asphalt binder showed consistent increases from 1.00 to 1.11, reflecting effective integration. Specific gravity remained relatively stable at higher dosages, suggesting no severe phase separation.

Table 5: Specific Gravity of Modified Asphalt Binder

	Specific Gravity	
	HDPE	Butonal
Control	0.99	
2%	1.02	1.00
3%	1.07	1.11
4%	1.13	1.09
5%	1.0	1.10

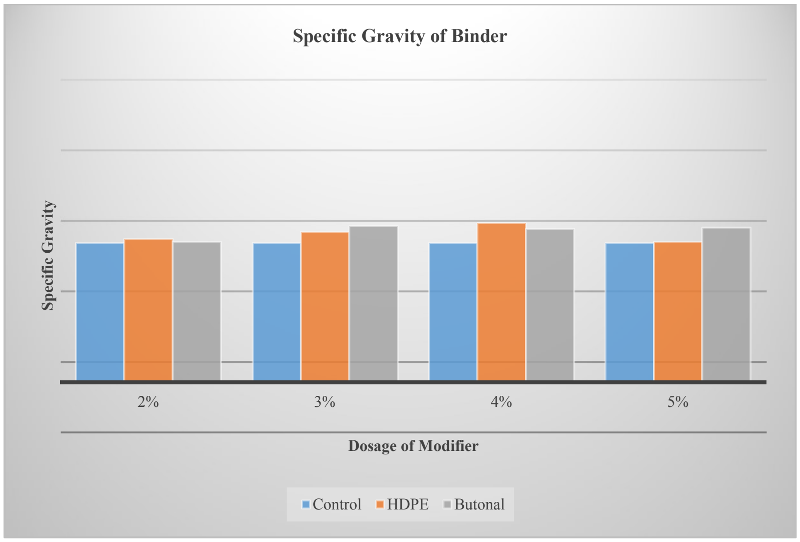

Figure 5: Specific Gravity of Asphalt Binder

The specific gravity of HDPE modification exhibits a non-linear trend, with an ideal increase at 4% and a decrease at 5%, most likely as a result of inadequate dispersion or oversaturation (Emtiaz *et al.,* 2023). Butonal-modified binders show more consistent increases, indicating improved compatibility at all dosages and more uniform mixing (Dulaimi *et al.,* 2023). Denser, more structured binders are typically implied by higher specific gravity; while this may increase stability, workability and flexibility should be balanced (Dulaimi *et al.,* 2023).

Implications for Mix Design

Specific gravity is critical in volumetric mix design calculations (e.g., determining binder content, VMA, and air voids). The denser binders from Butonal modification may require adjustments in aggregate gradation to maintain target air voids, while HDPE's lower density at high dosages could impact stability if not balanced with proper gradation.

Compatibility and Workability Considerations

The specific gravity of the modified asphalt binders showed notable variation with both polymer type and dosage, which carries important implications for binder mix design considerations. The specific gravity trends indicate that Butonal integrates more uniformly across dosages, potentially leading to more stable mix designs. In contrast, HDPE's density drop at 5% suggests potential phase separation or inadequate polymer–bitumen bonding at higher content.

These observations agree with Lushinga *et al.,* (2020), who emphasized the importance of polymer compatibility to prevent storage instability and segregation. The control binder recorded a specific gravity of 0.99, while the incorporation of HDPE resulted in increases up to 1.13 at 4% dosage before dropping to 1.00 at 5%. Similarly, Butonal modification produced specific gravity values ranging from 1.00 at 2% dosage to 1.11 at 3%, maintaining relatively high values up to 1.10 at 5% dosage. These changes indicate that polymer modification alters the density of the binder, which in turn affects the binder volume available for coating the aggregate at a given binder mass (Olalekan *et al.,* 2024).

From a mix design perspective, a higher specific gravity means that for the same binder mass, there will be less binder volume in the mix (John *et al.,* 2021; Gardete *et al.,* 2022). Since the volume of binder directly influences volumetric parameters such as voids in mineral aggregate (VMA) and voids filled with asphalt (VFA), an increase in specific gravity without adjusting the binder mass can lead to lower VMA and VFA values (Omranian *et al.,* 2020; Brohomo *et al.,* 2025). This reduction in binder volume could produce mixes that are too dry, potentially compromising durability, reducing film thickness, and increasing susceptibility to raveling and moisture damage (Osman *et al.,* 2024; John *et al.,* 2021). Therefore, in cases where specific gravity rises significantly, such as with HDPE at 4% (1.13) or Butonal at 3–5% (1.09–1.11), it becomes necessary to increase the binder content by mass to restore target volumetric properties.

The observed trends also highlight that specific gravity does not always increase proportionally with polymer dosage. For instance, the HDPE-modified binder peaked at 4% dosage before dropping sharply at 5%, while Butonal maintained relatively high values from 3% to 5%. This non-linear behavior reinforces the need for actual measurement of specific gravity for each modification level rather than relying on assumed values. In practical terms, this means that mix designers should recalculate volumetric parameters such as effective binder content (Pbe), absorbed binder (Pba), and theoretical maximum specific gravity (Gmm) using the measured specific gravity values for each polymer dosage.

5. Conclusion

Based on the results, this study concludes thus;

i. Polymer modification significantly affects binder properties, with HDPE and Butonal producing distinct performance trends.

ii. HDPE generally increases stiffness, raises softening points, and lowers penetration values, enhancing high-temperature rutting resistance but potentially reducing low-temperature flexibility at high dosages.

iii. Butonal provides a more elastic modification effect, improving flexibility and crack resistance while maintaining moderate stiffness levels.

iv. Specific gravity changes caused by polymer type and dosage directly influence mix volumetrics (binder volume, VMA, VFA) and require binder content adjustments during mix design.

v. Optimal performance requires dosage-specific calibration, balancing stiffness, elasticity, and thermal stability while recalculating volumetric parameters for each polymer type and dosage

6. Recommendations

i. Further research should explore dual modification (HDPE + Butonal) to assess synergy and balance between flexibility and stiffness.

ii. Optimization techniques such as Response Surface Methodology (RSM) or regression modeling is recommended to be used in future work to define optimal dosage-temperature-performance windows.

iii. Long-term aging and field validation studies are recommended to confirm laboratory results under real-world conditions

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