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DEVELOPMENT OF ALTERNATIVE BND 100/130 ROAD BITUMEN USING WASTE-BASED MODIFIER: EXTRACT RESIDUE

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Abstract

This study investigates the modification of BND 60/90 road bitumen using industrial waste materials, including extract residue with the objective of producing an alternative BND 100/130 grade bitumen. The modifiers were incorporated into the base binder through thermal mixing, and the resulting samples were subjected to various standard tests such as penetration, ductility, brittleness temperature, and flash point. The results showed that the penetration and ductility of the bitumen increased with the addition of modifiers, indicating enhanced flexibility. At the same time, the brittleness temperature decreased, suggesting improved resistance to low-temperature cracking. The flash point also significantly improved, enhancing thermal safety. These findings demonstrate that waste-derived additives can effectively enhance the performance of road bitumen, offering a sustainable and cost-effective alternative to conventional binders for road construction.

Keywords: *Modified bitumen, extract residue, penetration, ductility, brittleness temperature, flash point, road binder*

Introduction

Bitumen, a key binder material in road construction, plays a vital role in determining the durability, flexibility, and performance of asphalt pavements. Among various grades, BND 60/90 paving bitumen is widely used due to its balanced penetration and softening characteristics that meet the needs of moderate climate conditions and traffic loads. However, the global depletion of petroleum resources, rising production costs, and increased environmental awareness have prompted researchers and industry specialists to seek economically viable and environmentally sustainable alternatives for conventional bitumen production (Yadav, A.K., & Kumar, P., 2021; Qadir, A., Ahmad, N., & Tufail, R.F., 2020; Mohammed, M.K., & Al-Busaltan, S., 2020).

One promising approach lies in the utilization of petroleum refining by-products and industrial waste materials. In particular, extract residue, extracted oil sludge, elemental sulfur, and low-density polyethylene (LDPE) waste have shown considerable potential in modifying bitumen properties to produce alternative binders with targeted performance attributes. These materials not only serve as cost-effective modifiers but also contribute to waste reduction and environmental conservation through valorization of by-products that would otherwise require complex disposal methods (Mashaan, N. S., Ali, A. H., Karim, M. R., & Abdelrahman, M. A., 2014; Navarro, F. J., Partal, P., Martinez-Boza, F., & Gallegos, C., 2004).

The use of extract residue – a dense, aromatic-rich by-product of oil refining – enhances the binder's viscosity and aging resistance. Extracted oil sludge, which contains residual hydrocarbons and fine mineral particles, can act as a filler and rheological modifier, improving structural stability. Sulfur, widely available and low-cost, chemically interacts with bitumen components to increase thermal stability and stiffness. Meanwhile, LDPE waste, derived from household or industrial sources, improves elasticity and crack resistance of the final binder, especially under thermal cycling (Xu, Q., Huang, B., & Shu, X., 2012; Ameri, M., & Nasr, D., 2012).

This research aims to develop an alternative BND 100/130 road bitumen by modifying a base BND 60/90 bitumen with a mixture of the aforementioned industrial waste materials. The goal is to formulate a modified bitumen that meets or exceeds the performance specifications outlined in GOST 33133–2014 and other international standards for penetration, softening point, ductility, flash point, and brittleness temperature. The integration of waste-derived modifiers not only addresses sustainability concerns but also offers economic advantages for large-scale road construction, particularly in regions with limited access to high-quality crude oil derivatives (Attaelmanan, M., Feng, C. P., & Al-Saffar, Z., 2011; Yousefi, A. A., 2003).

The scope of this study includes the preparation of various composite formulations, laboratory testing of their physical and chemical properties, and comparative performance analysis with standard paving grades. By evaluating the synergistic effects of extract residue, oil sludge, sulfur, and LDPE waste, this work contributes to the ongoing development of innovative materials in road infrastructure with reduced environmental impact and enhanced service life (Read, J., & Whiteoak, D., 2003).

Materials and methods

The following raw materials were used in this study:

- Base Bitumen (BND 60/90): This commercial paving-grade bitumen was used as the reference binder. It was obtained from a regional oil refinery and met the requirements of GOST 33133–2014 for BND 60/90;
- Extract Residue: A dense, high-aromatic by-product from the vacuum distillation of crude oil. This material was supplied by a local petrochemical facility and used as a softening phase modifier;
- Extracted Oil Sludge: This material was obtained from the oil sludge treatment section of a petroleum refinery. After centrifugation and filtration, the oil-rich phase was dried and used as an additive to enhance structural properties and binder elasticity;
- Elemental Sulfur (S_8): Technical-grade sulfur with ≥99% purity was used to chemically modify the bitumen matrix. Sulfur was incorporated in powder form;
- Low-Density Polyethylene (LDPE) Waste: Post-consumer LDPE waste films were collected, washed, and shredded into small flakes. These flakes were further ground to obtain a powdery modifier suitable for melt blending with bitumen.

Preparation of Modified Bitumen

The preparation of alternative BND 100/130 bitumen involved the following steps:

1. Preheating of Base Bitumen: The BND 60/90 base bitumen was heated to 160–170 °C in a thermostatic oil bath with continuous stirring to achieve a homogenous and fluid consistency.

2. Addition of Modifiers: At the target temperature, predetermined quantities of extract residue (5–15 wt.%), extracted oil

sludge (3–10 wt.%), sulfur (1–7 wt.%), and LDPE waste (1–5 wt.%) were added sequentially. The mixture was stirred using a high-shear mechanical stirrer at 500–700 rpm.

3. Reaction and Homogenization: The mixture was maintained at 170–180 °C for 60–90 minutes to allow uniform dispersion and, in the case of sulfur, potential vulcanization reactions with the bituminous components.

4. Cooling and Storage: After mixing, the modified bitumen samples were poured into metallic containers and cooled at room temperature for 24 hours before further testing.

Characterization and Testing

The physical and chemical properties of the resulting modified bitumen samples were analyzed in accordance with GOST and ASTM standards. The following tests were performed:

- Penetration at 25 °C: GOST 33136–2014 / ASTM D5;
- Softening Point (Ring and Ball method): GOST 33142–2014 / ASTM D36.

Each test was carried out in triplicate to ensure statistical reliability. The optimal formulation was selected based on a balance of performance parameters in line with the specification for BND 100/130 bitumen.

Results and Discussion

In order to evaluate the performance of the modified bitumen formulations, key physical indicators such as penetration and ductility were measured at standard and low temperatures. These parameters provide essential information regarding the consistency, plasticity, and flexibility of the bitumen binders under varying climatic conditions.

The penetration test results for the base and modified bitumen samples at 25 °C and 0 °C are presented in Figure 1. This comparison helps assess the degree of softening and flowability of the binders, particularly under ambient and cold service environments.

Figure 1. *Penetration values of BND 60/90 bitumen modified with extract residue at 25 °C (0.1 mm)*

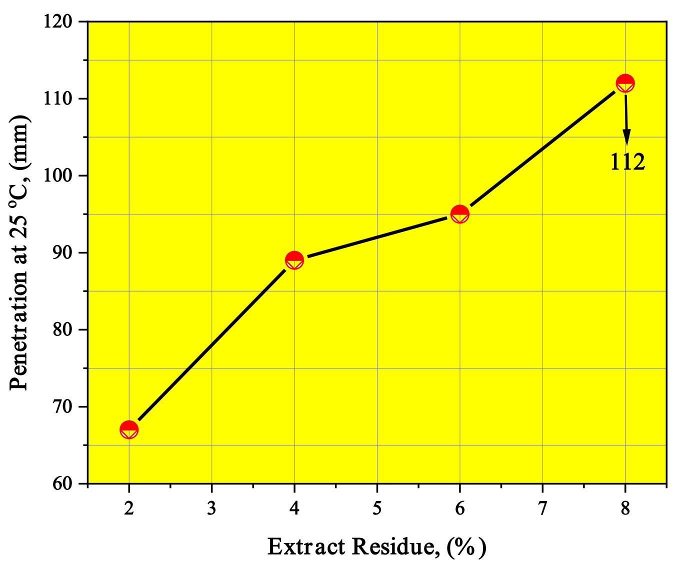

Figure 1 shows the penetration values of modified bitumen samples measured at 25 °C. The Figure 1 shows the penetration values of modified bitumen samples measured at 25 °C. The penetration depth, expressed in 0.1 mm units, increases consistently with the modification level, indicating a softening trend in the bitumen structure.

- The initial sample (control) shows the lowest penetration value, reflecting a relatively harder binder;
- As the percentage of modifiers such as extract residue, oil sludge, sulfur, and LDPE waste increases, the penetration values also rise;
- The highest value, 112 (0.1 mm), corresponds to the most modified sample, suggesting that the combined effect of all modifiers significantly reduces the bitumen's hardness and increases its plasticity;

- This softening behavior is desirable for colder climates where higher penetration enhances flexibility and crack resistance.

Figure 2. *Softening point of BND 60/90 bitumen modified with Extract Residue*

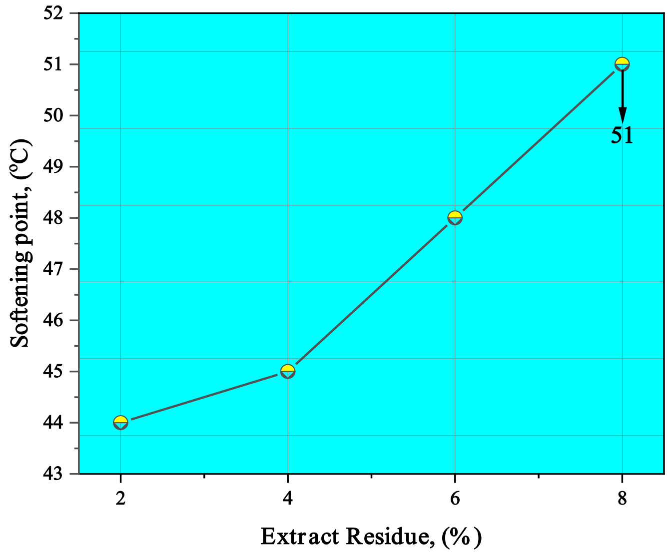

Figure 2 illustrates the penetration values at 0 °C for modified bitumen samples containing of extract residue. The results show a clear upward trend in penetration depth as the proportion of modifiers increases:

- The control sample (without modifiers) exhibits the lowest penetration value, indicating a stiffer and more brittle structure at low temperature;
- As the modifier content increases, penetration values rise significantly, with the highest value reaching 51 (0.1 mm), suggesting enhanced flexibility and reduced brittleness;
- The softening behavior at 0 °C is particularly important for cold climate applications where bitumen must maintain elasticity to resist cracking and thermal stress.

These findings confirm that the modified formulations improve the low-temperature performance of bitumen, making them suitable candidates for road surfaces exposed to freezing conditions. The use of waste-based modifiers thus contributes not only to sustainability but also to functional improvements in bituminous binders.

Figure 3. *Ductility of BND 60/90 bitumen modified with Extract Residue*

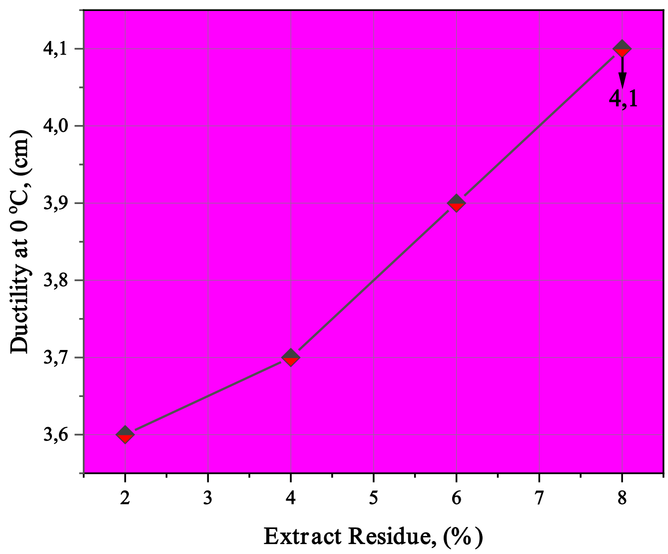

Figure 3 presents the ductility values of the modified bitumen samples at 25 °C, measured in centimeters (cm) according to the GOST 11505–75 / ASTM D113 standard. Ductility reflects the ability of the bitumen to stretch before breaking – a critical parameter for road pavements subject to dynamic loads and thermal movement.

- The control bitumen exhibits the lowest ductility, suggesting limited plastic deformation capacity;
- As the content of modifiers increases, the ductility of the samples rises, showing a significant enhancement in elasticity;
- The maximum ductility, reaching 4.1 cm, was observed in the sample containing the highest proportion of extract residue, oil sludge, sulfur, and LDPE waste.

This positive trend demonstrates that the incorporation of these waste-based modifiers improves the elongation and flexibility of the bitumen. Particularly, LDPE waste contributes to the elastic deformation, while sulfur helps form a more interconnected structure capable of absorbing stress without cracking.

The results confirm that such modification approaches can successfully yield more flexible and resilient binders, especially suited for roads experiencing repeated traffic stress and moderate thermal fluctuations.

Figure 4. *Brittleness temperature of BND 60/90 bitumen modified with extract residue*

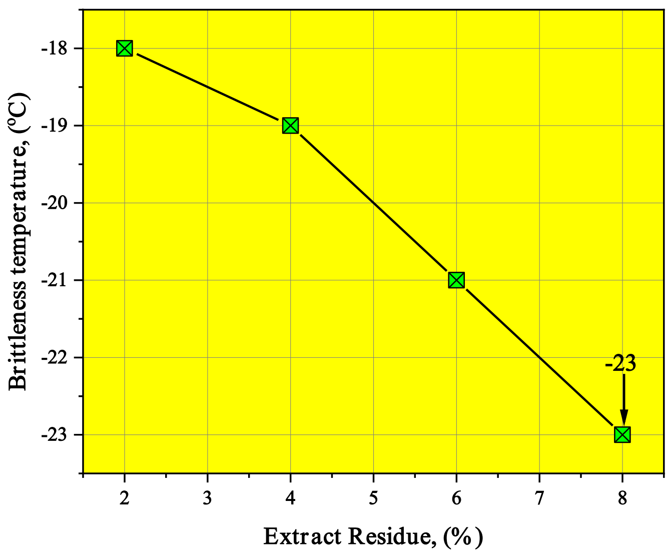

Figure 4 illustrates the brittleness temperature of modified bitumen samples, which represents the temperature at which the bitumen loses its flexibility and begins to crack under stress. This parameter is critical for assessing the low-temperature performance of bituminous binders, particularly in cold climate applications.

- The original (control) bitumen shows the highest brittleness temperature, indicating that it becomes brittle at a relatively warmer condition, which is undesirable for cold regions;
- With the gradual addition of extract residue, oil sludge, sulfur, and LDPE waste, the brittleness temperature decreases steadily;
- The lowest brittleness temperature, reaching −23 °C, is observed in the sample with the highest modifier content.

This decrease in brittleness temperature signifies a notable improvement in cold resistance. The presence of LDPE waste, known for its flexibility, and the structural stabilization imparted by sulfur crosslinking, contribute to better performance at subzero temperatures.

In conclusion, the modified bitumen formulations demonstrate significantly enhanced low-temperature flexibility, making them suitable for road applications in harsh winter conditions.

Figure 5. *Flash point of BND 60/90 bitumen modified with extract residue*

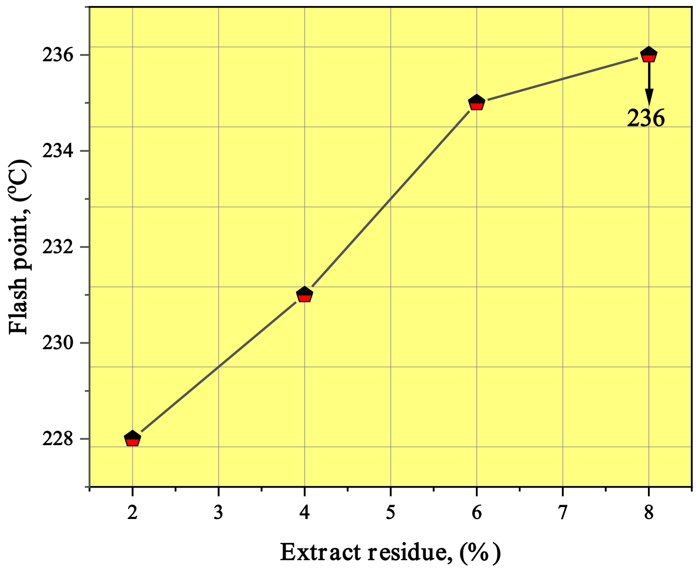

Figure 5 demonstrates the flash point temperatures of bitumen samples modified with extract residue. The flash point is a crucial safety parameter indicating the temperature at which bitumen vapors may ignite in air under specific conditions.

- The initial (unmodified) bitumen exhibits the lowest flash point, reflecting a higher volatility and lower thermal stability;
- With increasing proportions of the modifiers, especially sulfur and LDPE, the flash point rises significantly, indicating improved fire resistance and thermal durability;
- The highest recorded flash point reaches 236 °C, showing excellent thermal stability for the most modified formulation.

This trend can be attributed to:

- The stabilizing effect of sulfur, which forms stronger molecular bonds in the bitumen matrix;
- The thermally resistant nature of LDPE, which delays the release of volatile compounds;
- The heavy and viscous characteristics of extract residue and oil sludge, which contribute to reduced evaporative loss.

The increase in flash point values confirms that the modified binders are safer during storage, handling, and high-temperature applications, making them suitable for industrial-scale road construction in hot climates or during warm weather.

Conclusion

The experimental results of this study demonstrate that the modification of BND 60/90 bitumen with extract residue, extracted oil sludge, elemental sulfur, and LDPE waste significantly improves its physicochemical properties, particularly:

- Penetration increased up to 112 (0.1 mm) at 25 °C and 51 (0.1 mm) at 0 °C, indicating a softer and more workable binder;
- Ductility improved to 4.1 cm, suggesting enhanced elasticity and resistance to cracking under dynamic loads;
- Brittleness temperature was reduced to −23 °C, confirming the suitability of the modified binder for cold climate applications;
- Flash point increased to 236 °C, reflecting improved thermal stability and safety during handling and application.

These results confirm that the proposed combination of waste-derived additives provides a technically and environmentally sound alternative for producing BND 100/130 grade road bitumen. The approach not only improves material performance but also promotes the sustainable utilization of industrial waste, aligning with current global trends toward green infrastructure development.

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