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Physicochemical Characterization of BND 60/90 Bitumen Modified with Extracted Oil Sludge for Road Applications

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ABSTRACT: This study investigates the impact of modifying BND 60/90 road bitumen with varying concentrations (1%, 3%, 5%, and 7%) of extracted oil sludge – a petroleum refinery by-product. The goal was to enhance the binder's physicochemical properties and evaluate its performance for road construction applications. Modified bitumen samples were prepared through thermal mixing and analyzed for penetration, softening point, ductility, brittleness temperature, and flash point in accordance with GOST and ASTM standards. The results showed a consistent increase in penetration and ductility values with sludge content, indicating improved flexibility. The softening point and flash point also increased, reflecting enhanced thermal stability and safety. Additionally, the brittleness temperature decreased significantly, confirming better low-temperature resistance. These findings suggest that oil sludge is a viable modifier for producing high-performance, cost-effective, and environmentally sustainable road binders, aligning with circular economy principles in the asphalt industry.

KEY WORDS: Modified bitumen, oil sludge, road binder, penetration, ductility, softening point, flash point, brittleness temperature.

I. INTRODUCTION

Bitumen is a critical binder material used extensively in road construction due to its excellent viscoelastic properties, water resistance, and adhesive capabilities. However, traditional bitumen—particularly paving grades like BND 60/90—faces several limitations in extreme climate conditions, such as brittleness at low temperatures, softening at high temperatures, and susceptibility to aging and oxidative degradation. These shortcomings have driven research toward the development of modified bitumen that offers enhanced performance and durability [1-2].

One promising solution is the incorporation of petroleum-based industrial by-products, such as oil sludge, into bitumen formulations. Oil sludge, a semi-solid waste material generated during crude oil refining, tank bottom cleaning, or wastewater treatment processes, contains a mixture of residual hydrocarbons, water, and mineral particles. Rather than disposing of this environmentally hazardous material through incineration or landfilling, researchers have investigated its reuse as a binder additive due to its organic composition and binding characteristics [3-4].

Adding oil sludge to bitumen has shown potential to improve the rheological behavior, thermal resistance, and elasticity of the binder. The presence of residual oils enhances the flexibility and softening point of the bitumen, while the fine mineral particles can function as active fillers, improving structural integrity and stability [5-6]. Moreover, the recycling of oil sludge into bitumen contributes to waste minimization, resource efficiency, and circular economy practices in the petroleum and construction industries [7].

This study focuses on the modification of BND 60/90 road bitumen using extracted oil sludge, aiming to evaluate its effect on key physicochemical properties, including penetration, ductility, softening point, flash point, and brittleness temperature. The research also seeks to identify an optimal oil sludge-to-bitumen ratio that achieves performance improvements while ensuring compliance with technical standards such as GOST 33133-2014 and relevant ASTM methods [8-10].

II. RELATED WORK

Currently, scientists around the world are considering the possibility of using oil sludge as a secondary raw material for various purposes [11-13]. It is known, that the current methods for processing some oil waste are not economically efficient. The use of oil sludge as a secondary raw material seems to be one of the main directions in their use in the modification of bitumen and is of great practical importance [14-16].

III. SIGNIFICANCE OF THE SYSTEM

This article reviews the investigates the impact of modifying BND 60/90 road bitumen with varying concentrations (1%, 3%, 5%, and 7%) of extracted oil sludge – a petroleum refinery by-product. The Related works of other scientists are presented in section II, Methodology and Discussion are presented in section IV, section V covers the experimental results of the study, and section VI discusses the future study and conclusion.

IV. METHODOLOGY AND DISCUSSION

Materials
In this study, BND 60/90 road bitumen was used as the base binder. It was obtained from a regional petroleum refinery and met the specifications of GOST 33133-2014 for conventional paving bitumen. The modifying agent used was extracted oil sludge, a semi-solid waste product collected from the oil refining process. The sludge was first dried, filtered, and homogenized to remove water and large impurities, ensuring consistent quality for use in bitumen modification.
Preparation of Modified Bitumen Samples
To evaluate the effect of oil sludge on bitumen performance, four modified bitumen samples were prepared by incorporating 1%, 3%, 5%, and 7% oil sludge by weight into the base BND 60/90 bitumen. The modification process was carried out as follows:
Heating: The base bitumen was heated to 160–170 °C in a thermostatically controlled oil bath under continuous stirring to achieve a uniform fluid state.
Incorporation of Oil Sludge: Pre-weighed amounts of oil sludge were gradually added to the hot bitumen while stirring at 600 rpm using a high-shear mechanical stirrer.
Mixing Duration: Each blend was mixed for 60 minutes at a stable temperature of 170 °C to ensure complete dispersion of the oil sludge and homogeneity of the modified binder.
Cooling and Storage: After mixing, the samples were poured into metallic molds and allowed to cool at room temperature (25 °C) for 24 hours before further testing.
Testing Procedures
The physical and thermal properties of the control and modified bitumen samples were evaluated in accordance with GOST and ASTM standards. The following tests were conducted:
Penetration at 25 °C: Determined using GOST 33136-2014 / ASTM D5 to assess the consistency of the bitumen.
Softening Point (Ring and Ball method): Conducted as per GOST 33142-2014 / ASTM D36 to evaluate the temperature at which the bitumen softens.
Ductility at 25 °C: Measured using GOST 11505-75 / ASTM D113 to determine the elongation capacity before breaking.
Brittleness Temperature: Evaluated using GOST 11507-78 / ASTM D3111 to determine the temperature at which the bitumen becomes brittle under stress.
Each test was carried out in triplicate, and the average values were used to ensure accuracy and reliability of the results.

V. EXPERIMENTAL RESULTS

To evaluate the effect of oil sludge modification on the performance of BND 60/90 bitumen, a series of physical tests were conducted, including penetration, softening point, ductility, and brittleness temperature. These parameters are critical in assessing the binder's consistency, flexibility, and temperature sensitivity, especially for road pavements exposed to varying climatic conditions.

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The penetration values of the modified bitumen samples at 25 °C are presented in Figure 1. These results illustrate how increasing the content of oil sludge (1%, 3%, 5%, and 7%) affects the consistency of the bitumen. Penetration is a key indicator of binder softness and workability, and changes in this property can provide insight into the structural influence of the added sludge on the base binder.

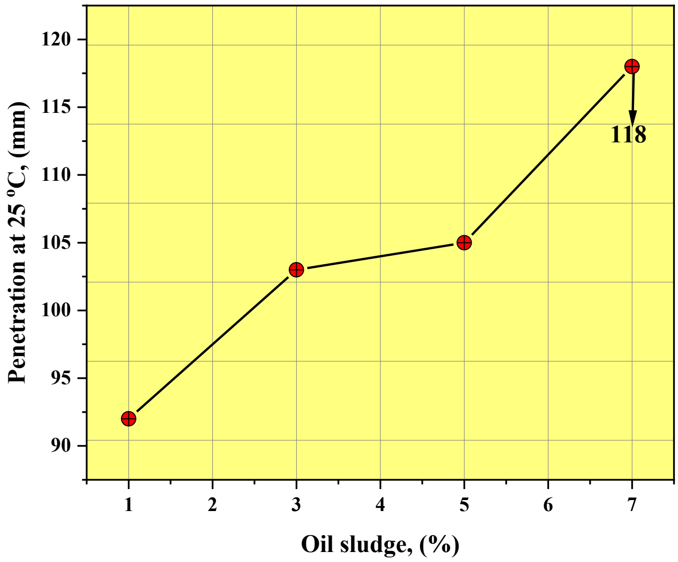

Figure 1. Penetration of BND 60/90 bitumen modified with oil sludge at 25 °C (0.1 mm)

Figure 1 presents the penetration results of bitumen samples modified with varying contents of extracted oil sludge (1% to 7%) measured at 25 °C, expressed in 0.1 mm units. The test evaluates the softness and consistency of the binder, which are important factors in determining its workability and flexibility during mixing and paving operations.
The unmodified BND 60/90 bitumen showed the lowest penetration value, indicating a harder and stiffer binder.
As oil sludge content increases, the penetration value rises steadily, reaching a maximum of 118 (0.1 mm) at 7% sludge addition.
This trend clearly demonstrates that oil sludge contributes to the softening of the binder, due to the presence of residual hydrocarbons and light oil fractions in the sludge that reduce internal friction within the bitumen matrix.
Notably, the increase from 5% to 7% sludge leads to a sharper rise in penetration, suggesting a threshold effect beyond which the structure becomes significantly more fluid and plastic.
Such behavior is particularly beneficial for cold or temperate climate applications, where higher penetration values correspond to greater flexibility and resistance to cracking. However, excessively soft binders may risk deformation at high temperatures, which would need to be evaluated in softening point analysis.

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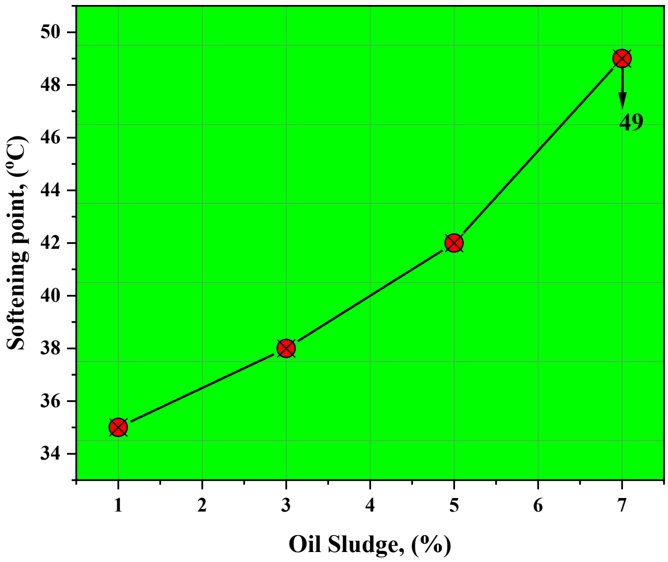

Figure 2. Softening point of BND 60/90 bitumen modified with oil sludge (°C)

Figure 2 presents the softening point values of BND 60/90 bitumen samples modified with increasing amounts of oil sludge (1%, 3%, 5%, and 7%). The softening point indicates the temperature at which bitumen transitions from a semi-solid to a viscous liquid state, and is crucial for assessing the binder's resistance to deformation at elevated temperatures. As the oil sludge content increases, the softening point rises gradually from the lowest to the highest concentration, with a peak value of 49 °C at 7% sludge content.
This upward trend suggests that oil sludge enhances thermal stability of the binder, likely due to the interaction of heavy hydrocarbons and mineral residues present in the sludge with the bituminous matrix.
The inclusion of sludge appears to promote higher cohesion and stiffness, reducing the susceptibility of the binder to flow or rut under high temperature conditions.
Overall, the results demonstrate that the addition of oil sludge has a beneficial effect on the high-temperature performance of bitumen, making it more suitable for use in warm climates or under heavy traffic loads.

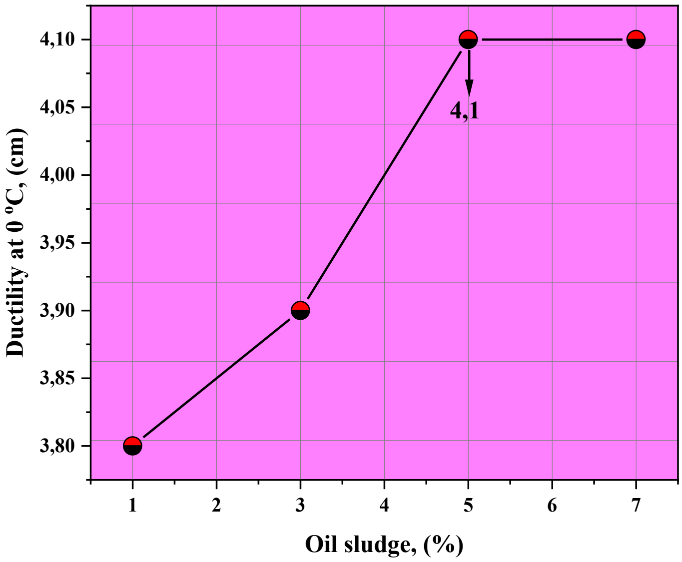

Figure 3. Ductility of BND 60/90 bitumen modified with oil sludge at 0 °C (cm)

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Figure 3 illustrates the ductility values of BND 60/90 bitumen samples modified with various concentrations of oil sludge (1%, 3%, 5%, and 7%), tested at 25 °C in accordance with standard methods (e.g., GOST 11505-75 / ASTM D113). Ductility represents the binder's ability to elongate before breaking, which is critical for evaluating its flexibility and resistance to cracking under mechanical or thermal stress.

The results show a progressive increase in ductility from lower sludge contents up to 5%, reaching a peak value of 4.1 cm.

Interestingly, increasing the sludge content beyond 5% (i.e., to 7%) does not further improve ductility, and the value plateaus, indicating a saturation effect where additional sludge no longer contributes to flexibility.

The improvement in ductility can be attributed to the residual hydrocarbons and semi-fluid components in the oil sludge, which act as softening agents within the bitumen matrix.

However, the plateau suggests that excess sludge may reach a limit in terms of its plasticizing effect, or possibly begin to interfere with the cohesive structure of the binder.

These results confirm that oil sludge—when used in optimal amounts—can enhance the elastic and deformative capacity of bitumen, making it more resilient to cracking in service conditions. The 5% content appears to be the optimal level for maximizing ductility without compromising material stability.

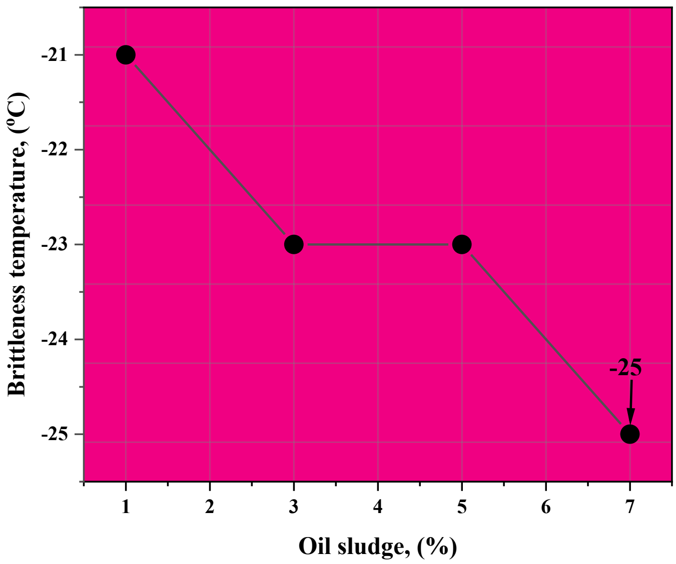

Figure 4. Brittleness temperature of BND 60/90 bitumen modified with oil sludge (°C)

Figure 4 presents the brittleness temperature values of BND 60/90 bitumen modified with different dosages of oil sludge. Brittleness temperature is defined as the temperature at which bitumen loses flexibility and begins to crack under mechanical stress — a crucial parameter for evaluating performance in cold climates.

The data show a consistent downward trend: as the oil sludge content increases, the brittleness temperature decreases, reaching a minimum of –25 °C at the highest level of modification.

This indicates that bitumen modified with oil sludge retains greater flexibility at lower temperatures, delaying the onset of cracking.

The effect can be attributed to the softening components in oil sludge (such as light hydrocarbons and lubricating residues), which reduce the internal stiffness of the binder and enhance its elasticity.

The curve flattens slightly between mid-level dosages, then drops significantly again, suggesting that 7% oil sludge content provides the most substantial improvement in cold resistance.

These results confirm that oil sludge is an effective modifier for improving the low-temperature flexibility of bitumen, making it suitable for roads exposed to freeze–thaw cycles and subzero environments.

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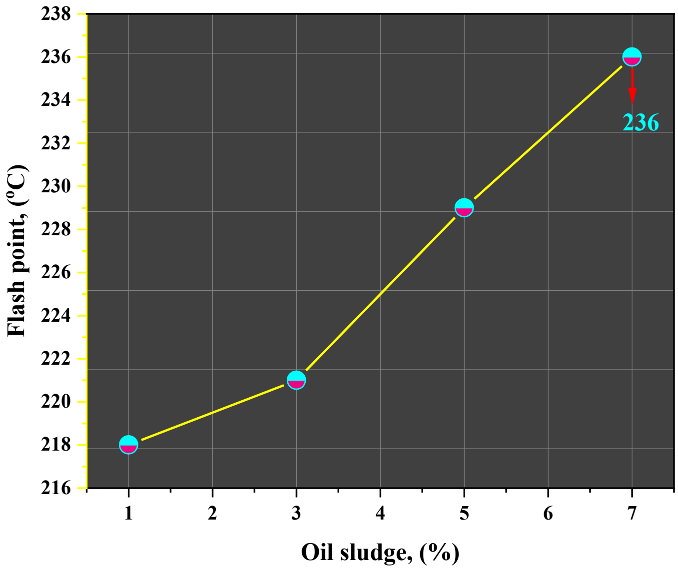

Figure 5. Flash point of BND 60/90 bitumen modified with oil sludge (°C)

Figure 5 illustrates the flash point values of BND 60/90 bitumen modified with increasing concentrations of oil sludge. The flash point is a critical safety indicator representing the lowest temperature at which vapors above the bitumen surface can ignite in the presence of an open flame.
The results show a steady increase in flash point values with the addition of oil sludge, reaching up to 236 °C at the highest sludge content.
This trend indicates that the modified binders are thermally more stable and less volatile, reducing the risk of ignition during storage, transport, and application at elevated temperatures.
The increase may be due to the high boiling components in oil sludge, which dilute the more volatile fractions of the base bitumen and increase the temperature required for vapor ignition.
Additionally, the incorporation of oil sludge seems to enhance molecular cohesion, contributing to the binder's resistance to volatilization.
From a practical standpoint, these results demonstrate that oil sludge not only improves mechanical performance but also significantly enhances the thermal safety of the bituminous binder, which is essential for hot mix asphalt applications and industrial-scale paving operations.

VI. CONCLUSION AND FUTURE WORK

The modification of BND 60/90 road bitumen with extracted oil sludge in varying proportions (1%, 3%, 5%, and 7%) demonstrated significant improvements in both physical and thermal performance characteristics. The findings from penetration, softening point, ductility, brittleness temperature, and flash point tests can be summarized as follows:
- Penetration increased progressively with oil sludge content, indicating enhanced softness and better workability of the binder at 25 °C.
- Softening point also increased, suggesting improved resistance to flow and deformation at elevated temperatures.
- Ductility improved sharply up to 5% sludge content, then plateaued, confirming that optimal sludge dosage contributes to better elasticity and stretchability.
- Brittleness temperature decreased notably, with the lowest value reaching −25 °C, showing superior flexibility at low temperatures and resistance to cracking.
- Flash point rose significantly, up to 236 °C, indicating improved thermal stability and operational safety during mixing and application.

Overall, the use of oil sludge as a bitumen modifier proved to be an effective and sustainable approach to enhancing the physicochemical properties of paving-grade bitumen. The results support the feasibility of incorporating petroleum waste into road construction materials, aligning with principles of resource recovery, cost-efficiency, and environmental responsibility.

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