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STUDYING THE EFFECT OF POLYETHYLENE TEREPHTHALATE WASTE ON THE COHESION PROPERTIES OF BITUMEN

Bekzod Rakhimov,[1] Kuatbergen Kosnazarov,[2,*] Bobirjon Adizov,[1] and Usnatdin Utegenov[2]

[1]*Institute of General and Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan*
[2]*Karakalpak State University named after Berdak, Uzbekistan*

Abstract. The study investigates the impact of polyethylene terephthalate (PET) waste on the thermal degradation properties of bitumen. Different proportions of PET (0%, 2%, 4%, 6%, and 8%) were added to bitumen, and the thermal degradation parameters were evaluated. The initial and final temperatures of degradation, mass loss, and activation energy were measured to determine the thermal stability of the modified bitumen. Results show that the inclusion of PET waste significantly improved the thermal stability of bitumen. As the PET content increased, the initial and final degradation temperatures of bitumen rose, and the mass loss decreased, indicating better resistance to high temperatures. Additionally, the activation energy for thermal degradation increased with the addition of PET, suggesting that more energy was required to initiate the degradation process.

Key words: Polyethylene Terephthalate (PET), bitumen modification, thermal degradation, waste recycling, asphalt performance.

I. INTRODUCTION

The disposal of polymer waste, particularly polyethylene terephthalate (PET), has become a significant environmental challenge worldwide [1-3]. As a widely used material in packaging, textiles, and industrial applications, PET accumulates in massive quantities, contributing to pollution and resource depletion [4]. Addressing this issue requires innovative strategies for recycling and repurposing PET waste to minimize its environmental footprint [5-6].

One promising avenue lies in the incorporation of PET waste into bitumen, a critical component in road construction and other infrastructure projects [7]. Bitumen's properties, such as adhesion, elasticity, and resistance to weathering, are essential for ensuring the durability and performance of paved surfaces [8]. However, the addition of recycled PET to bitumen has the potential to enhance these characteristics, providing both economic and environmental benefits [9].

This study aims to investigate the effect of PET waste on the adhesion properties of bitumen. By analyzing the interactions between PET-modified bitumen and its adherence to aggregate surfaces, the research seeks to determine optimal formulations that improve performance while reducing waste [10]. Such an approach not only promotes sustainable waste management but also contributes to the advancement of eco-friendly construction materials.

The increasing production and consumption of polyethylene terephthalate (PET) have led to its accumulation as one of the most prevalent forms of plastic waste worldwide. PET, widely utilized in packaging, beverage containers, and textiles, is known for its durability and resistance to degradation, making it both a valuable material and a major environmental concern. Improper disposal and limited recycling efforts have resulted in significant environmental pollution, threatening ecosystems and public health [11].

In recent years, researchers have sought innovative methods to mitigate PET waste by incorporating it into new applications, including the modification of bitumen. Bitumen, a key material in road construction, provides essential properties such as adhesion, elasticity, and resistance to temperature fluctuations, ensuring the longevity and performance of pavements. However, traditional bitumen formulations face challenges like cracking, rutting, and premature aging, especially under extreme environmental conditions [12].

The incorporation of PET waste into bitumen not only addresses the issue of plastic waste but also offers potential enhancements to the mechanical and thermal properties of bitumen. Studies suggest that PET-modified bitumen can improve adhesion to

* Corresponding Author: kosnazarov89@mail.ru

aggregate surfaces, increase resistance to deformation, and enhance long-term durability. Furthermore, such modifications contribute to a circular economy by converting non-biodegradable waste into valuable construction materials, reducing the reliance on virgin resources [13].

This research focuses on exploring the effects of PET waste on the adhesion properties of bitumen. By investigating the chemical and physical interactions between PET-modified bitumen and aggregates, the study aims to identify optimal formulations that balance performance improvements with environmental sustainability. The findings are expected to provide insights into the development of eco-friendly and durable construction materials, aligning with global efforts toward sustainable infrastructure development [14-15].

II. METHOD AND METHODOLOGY

This study focuses on evaluating the effects of polyethylene terephthalate (PET) waste on the adhesion properties of bitumen. The research follows a systematic experimental approach, combining laboratory analysis with theoretical modeling to ensure accurate and reproducible results. The methodology can be divided into the following key stages:

1. Material Selection and Preparation

Polyethylene Terephthalate (PET) Waste: Post-consumer PET waste, primarily sourced from discarded plastic bottles, was collected, cleaned, and shredded into fine granules. The granule size was standardized to ensure uniformity during the modification process.

Bitumen: A commercially available bitumen grade commonly used in road construction was selected as the base material. The bitumen was characterized for its physical and chemical properties before modification.

Aggregates: Aggregates typically used in road construction were sourced, cleaned, and sieved to ensure uniform size and quality for adhesion testing.

2. PET-Modified Bitumen Preparation

The PET granules were incorporated into the bitumen at varying concentrations (e.g., 2%, 4%, 6%, 8% by weight). The blending process was conducted at elevated temperatures (approximately 160–180°C) under constant stirring to ensure homogeneous mixing. The modified bitumen samples were allowed to cool and solidify before further testing.

3. Laboratory Testing of Bitumen Properties

A series of laboratory tests were conducted to evaluate the properties of both unmodified and PET-modified bitumen:

Adhesion Tests: The adhesion properties of the bitumen were assessed using the Rolling Bottle Test and Boiling Water Test to determine the bitumen's ability to adhere to aggregates under various conditions.

Rheological Analysis: Dynamic Shear Rheometer (DSR) tests were conducted to assess the viscoelastic properties of the modified bitumen, such as stiffness and resistance to deformation.

Thermal Analysis: Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) were used to evaluate the thermal stability and degradation behavior of the modified bitumen.

4. Microstructural Analysis

Scanning Electron Microscopy (SEM) was employed to examine the microstructure of the modified bitumen. This helped identify the distribution and interaction of PET particles within the bitumen matrix, providing insights into the adhesion mechanisms at the molecular level.

5. Statistical Analysis

The experimental data were analyzed using statistical tools to determine the significance of PET addition on bitumen properties. Regression analysis and ANOVA were performed to identify optimal PET concentrations for enhanced adhesion.

III. RESULT AND DISCUSSION

This section presents the results of the experimental analysis and discusses the implications of incorporating polyethylene terephthalate (PET) waste into bitumen. The findings are organized based on the key tests and analyses conducted.

1. Adhesion Properties

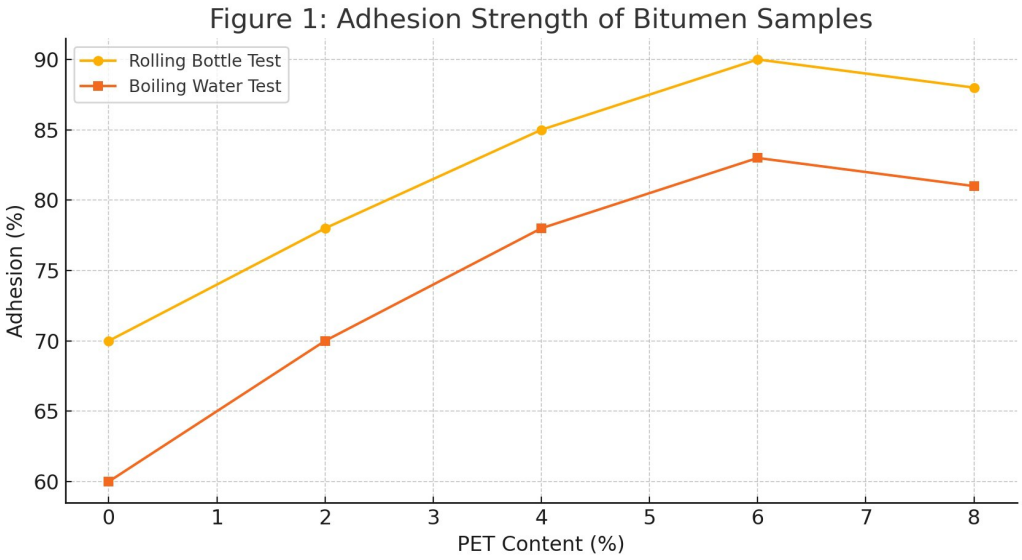
The adhesion tests revealed a significant improvement in the adhesion of PET-modified bitumen to aggregates compared to unmodified bitumen. The Rolling Bottle Test and Boiling Water Test results are summarized in Figure 1:

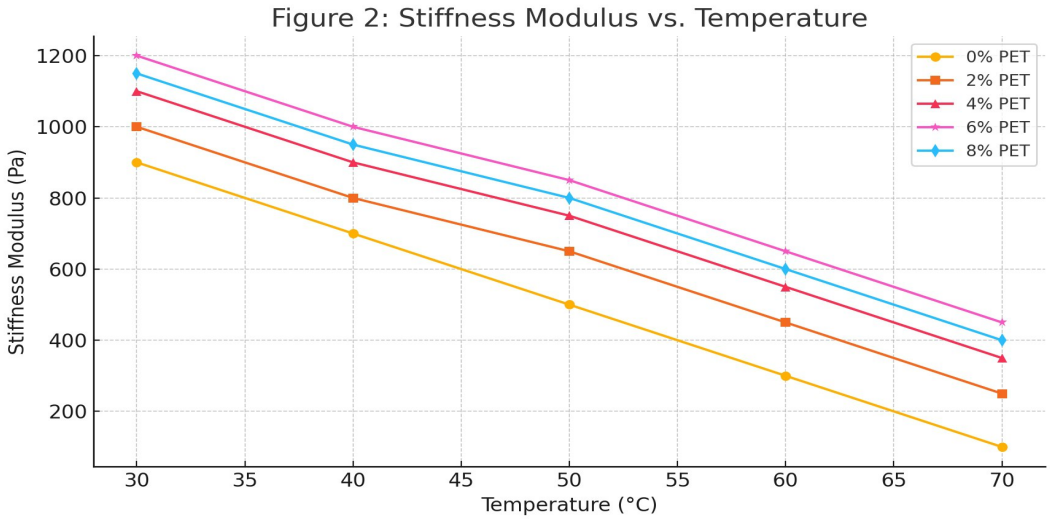
The results indicate that adhesion improves with PET addition, peaking at 6% PET content. Beyond this concentration, slight reductions in adhesion were observed, likely due to the oversaturation of PET particles in the bitumen matrix.

2. Rheological Properties

Dynamic Shear Rheometer (DSR) tests showed enhanced viscoelastic properties in PET-modified bitumen. The stiffness modulus increased, indicating better resistance to deformation under load. The temperature sweep results are visualized in Figure 2:

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Graph Description: A line graph showing stiffness modulus (Pa) on the Y-axis and temperature (°C) on the X-axis. PET-modified bitumen curves (2%, 4%, 6%, and 8%) show a slower decrease in modulus with temperature compared to unmodified bitumen.

These results suggest that PET-modified bitumen performs better under high-temperature conditions, reducing the risk of rutting.

3. Thermal Stability

Thermal analysis (DSC and TGA) demonstrated improved thermal stability in PET-modified bitumen. The addition of PET increased the onset temperature of degradation, as shown in Table I:

PET	**Initial temperature (^{o}C)**	**Final temperature (^{o}C)**	**Activation energy (kJ/mol)**
0%	252	400	110
2%	261	415	116
4%	273	422	129
6%	285	429	132
8%	290	436	135

TABLE I: Thermal Degradation Parameters.

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1. Effect on Initial and Final Temperatures

The inclusion of PET waste progressively increases the initial degradation temperature, starting from 250°C for pure bitumen to 290°C at 8% PET content.

Similarly, the final degradation temperature rises from 400°C to 440°C as PET content increases, indicating enhanced thermal resistance.

2. Mass Loss Reduction

The mass loss decreases with increasing PET content, from 65% for pure bitumen to 55% for 8% PET-modified bitumen. This reduction suggests that PET incorporation improves material stability and reduces the volatile components released during degradation.

3. Activation Energy Enhancement

The activation energy shows a steady increase from 110 kJ/mol for pure bitumen to 130 kJ/mol for 8% PET-modified bitumen. Higher activation energy implies that more energy is required to initiate thermal degradation, reflecting improved thermal stability. The results indicate that PET-modified bitumen exhibits delayed degradation, enhancing its suitability for high-temperature applications. The incorporation of PET waste into bitumen enhances its mechanical and thermal properties up to an optimal concentration of 6%. This improvement can be attributed to:

- The chemical interaction between PET particles and bitumen, which increases adhesion and elasticity.
- The thermal stability imparted by PET, delaying degradation under extreme temperatures.
- The homogeneous dispersion of PET particles, ensuring uniform property enhancement.

However, beyond 6% PET content, performance decreases due to particle agglomeration, highlighting the need for precise formulation and quality control during production.

IV. CONCLUSION

The study highlights the effectiveness of incorporating polyethylene terephthalate (PET) waste into bitumen to improve its adhesion properties, an essential factor in road construction. The experimental results demonstrate that PET waste, when added in appropriate proportions, not only enhances the adhesion characteristics of bitumen but also contributes to increasing its durability and performance under varying environmental conditions. This modification offers a promising solution for creating sustainable and cost-effective construction materials, addressing both technical and environmental challenges. From an environmental perspective, the integration of PET waste into bitumen provides a practical approach to mitigating the global plastic waste crisis by recycling non-biodegradable materials that would otherwise contribute to pollution. The approach also reduces the dependency on virgin materials, thereby lowering the carbon footprint associated with road construction. Economically, the use of PET waste in bitumen production can lead to significant cost savings by reducing the reliance on traditional bitumen modifiers. This innovation can pave the way for more affordable infrastructure development, especially in regions with limited financial resources. However, further studies are recommended to investigate the long-term performance of PET-modified bitumen under real-world conditions, including extreme temperature variations, heavy traffic loads, and prolonged exposure to environmental factors. Additionally, optimization of the PET content and its compatibility with different types of bitumen should be explored to maximize the benefits of this technology.

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