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RESEARCH ARTICLE

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Effect of Utilization RPET on the Physical Properties of Asphalt Binder

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Abstract. Through the utilization of waste materials in asphalt pavement, such as plastic water bottles made of Polyethylene Terephthalate (RPET), it is possible to explore alternative solutions that can enhance the service life of asphalt pavement while simultaneously reducing environmental pollution. This research specifically investigates the viability of incorporating waste plastic bottles, made of RPET, as polymer additives in asphalt binder to address common pavement issues. three different proportions of RPET (3%, 5%, and 7%) were added by weight of optimum binder to prepare the specimens. Various tests were conducted, including the physical properties and viscosity. The findings revealed that the optimal modifier content was 5% for the RPET-modified asphalt binder. This composition demonstrated maximum stability. It is observed that the addition of RPET to the asphalt binder resulted in a reduction in penetration values and an increase in softening points. Furthermore, it exhibited improved resistance against permanent deformations and superior engineering properties. This research contributes to the field of modified binder, and waste plastic, specifically Polyethylene Terephthalate (RPET), by providing valuable insights and highlighting the potential benefits of utilizing such materials in pavement construction.

Keywords: Asphalt binder, Physical Properties, Viscosity .

1. Introduction

Asphalt binder stands as an eminent construction material, ubiquitously employed in the realm of infrastructure development. A considerable majority of road networks spanning the globe are meticulously fashioned using the versatile and resilient nature of asphalt binders, resulting in the creation of flexible pavements. In addition to its primary constituents, bitumen also encompasses trace amounts of metallic elements, notably including Vanadium, nickel, iron, magnesium, and calcium [1]. Indeed, asphalt is a viscoelastic material that exhibits time and temperature-dependent behavior. Its performance is influenced by both the temperature and the duration of loading. The composition of asphalt is notably intricate, consisting of carbon, hydrogen, nitrogen, sulfur, and oxygen. These elements contribute to the complex nature of asphalt and its distinctive properties [2]. To enhance the performance of straight asphalt binders, modifications have been made through the addition of two types of polymers: high-density polyethylene (HDPE) and a blend of HDPE and ethylene-propylene-diene-monomer (EPDM). These modifications aim to improve the overall properties and characteristics of the binders, enhancing their durability and resistance to various environmental factors [3]. In the realm of engineering materials, the utilization of recycled polyethylene terephthalate (PET) has been the subject of extensive research and analysis. This review delves into the academic aspects of this topic, examining the various dimensions and implications associated with incorporating recycled PET in engineering materials. The comprehensive evaluation encompasses a range of factors, including mechanical properties, durability, environmental impact, and processability. By adopting an academic lens, this review aims to contribute to the existing body of knowledge and provide valuable insights for researchers, engineers, and practitioners in the field.

Certainly! During the modification process, a polymer is carefully blended with the asphalt binder to achieve desirable outcomes. This blending of polymer with asphalt binder aims to enhance the resistance to pavement distress, particularly at medium to high temperatures. Importantly, this modification should strike a balance, ensuring that the modified binder remains workable at mixing temperatures without becoming excessively viscous. Simultaneously, it should also prevent the modified binder from becoming overly brittle at low temperatures. This delicate balance ensures both the workability during construction and the durability of the pavement in diverse weather conditions [4].

Undoubtedly, the highway system has experienced a surge in challenges due to various factors. The recent escalation in traffic levels, coupled with the presence of larger and heavier trucks featuring new axle designs and higher tire pressures, has exacerbated the severity of the conditions. As a consequence, distresses such as rutting, stripping, fatigue cracking, and reflective cracking have become more prevalent [5].In highway pavement applications, bituminous materials have demonstrated their ability to provide a smooth and comfortable driving surface for motorists. They offer excellent skid resistance, allowing vehicles to maintain traction even in wet or slippery conditions. Additionally, bituminous pavements have proven to be cost-effective, providing a durable and long-lasting surface that requires minimal maintenance. Currently, the most widely employed polymer for modifying asphalt binders is the thermoplastic elastomer known as styrene-butadiene-styrene (SBS). This particular polymer is prized for its ability to enhance the performance characteristics of asphalt mixtures. By incorporating SBS into the binder, several desirable properties can be achieved, including improved elasticity, durability, and resistance to deformation under heavy loads [6].

The incorporation of polymers, consisting of interconnected chains of recurrent small molecules, into asphalt has demonstrated a substantial enhancement in performance [7]. "The successful implementation of polymer-modified binders has been observed in high-stress areas, specifically at critical junctions such as busy street intersections, airports, vehicle weigh stations, and race tracks. Numerous research teams across the globe have been diligently investigating the advantages of polymer modification in enhancing pavement performance. These endeavors have led to the ongoing development of tests and specifications for binders, as a means of continually improving and assessing their efficacy [8]. The utilization of polymer-modified binders in asphalt mixtures has experienced a remarkable surge in popularity, primarily owing to their inherent qualities of diminished thermal susceptibility, as well as enhanced resistance against rutting and fatigue [9]. In the past few decades, the surge in traffic volume and intensity, coupled with the pronounced thermal variations encountered in certain regions, has led to the premature degradation of pavements [10].

The polymers frequently employed for binder modification can be categorized into three primary groups: thermoplastic elastomers, plastomers, and reactive polymers [11]. Despite the acknowledged ability of these modifiers to enhance the thermal susceptibility of asphalt binders, it is noteworthy that each category exerts distinctive effects on their properties. Thermoplastic elastomers primarily bolster the elastic characteristics of binders, thereby augmenting fatigue resistance. On the other hand, plastomers and reactive polymers predominantly enhance stiffness and fortify resistance against deformation in the face of loading [12]. The utilization of polymer modification in asphalt binders has gained widespread acceptance as an effective approach to alleviate pavement distresses. The rise in vehicle loads, traffic volumes, and tire pressures has compelled user agencies to embrace polymer modification for asphalt pavement applications. It is important to note that the compatibility between the asphalt and polymer is contingent upon various factors [13].

The incorporation of modified asphalt binders has presented transportation agencies with a valuable tool for designing well-balanced mixtures capable of withstanding diverse distresses while upholding long-term durability. While conventional polymer-modified asphalt mixtures have demonstrated enhanced long-term performance, it is also believed that asphalt mixtures with high polymer (HP) content may provide additional benefits for flexible pavements subjected to heavy and/or slow-moving traffic loads [14]. Indeed, polymer modified asphalt binders have proven to be highly effective in addressing various causes of asphalt pavement failures. The incorporation of polymers into asphalt binders brings about several beneficial properties that help mitigate common issues faced by pavements. Here are some of the key causes of asphalt pavement failures that can be addressed by using polymer modified asphalt binders**:** rutting: Polymer modified binders offer increased stiffness and improved resistance to deformation under heavy traffic loads. This helps reduce rutting, which is a major cause of pavement failure characterized by permanent depressions or wheel path indentations**.** Cracking: Polymer modification enhances the binder's ability to resist cracking, which can occur due to thermal stresses, traffic loads, or age-related factors. The improved flexibility and elasticity provided by polymers help prevent the propagation of cracks and maintain the structural integrity of the pavement**.** By addressing these major causes of asphalt pavement failures, polymer modified asphalt binders contribute to the development of more resilient and long-lasting pavements. Their successful implementation has been witnessed in various road infrastructure projects, leading to improved performance, reduced maintenance needs, and increased pavement life expectancy [15].

2. Sample Preparation and Testing Methods

2.1.Materials

Rynite® FR530 NC010 is an approved UL94V-0 @ 0.35mm flame retardant, modified polyethylene terephthalate resin with a 30% glass reinforcement. It has been recognized by UL for its flame retardancy properties. The resin is known for its excellent performance in various applications**.** According to the findings reported in reference [16], it was observed that the desired outcomes were achieved using single size RPET (Recycled Polyethylene Terephthalate) particles within the range of 0.425–1.18 mm. As a result, powdered RPET particles were utilized as an additive to enhance the quality of the asphalt mixture**.** To obtain the Rynite PET material, PET was initially crushed using a crushing machine and then sieved to achieve the desired particle size distribution of 0.075µm. This sieving process ensured the selection of appropriate particle sizes for the desired application**.** Table 1 provides information on the mechanical properties of Rynite PET 530-NC10, including details about its strength, durability, and other relevant characteristics.

Table1: Mechanical properties of Rynite PET

Property	Test Method	Units	Value
Stress at Break	ISO 527	MPa (kpsi)	135 (19.6)
Tensile Strength	ASTM D 638	MPa (kpsi)	-40°C (-40°F)
Strain at Break	ISO 527	%	2
Tensile Modulus	ISO 527	MPa (kpsi)	11500 (1670)
Flexural Modulus	ASTM D 790	MPa (kpsi)	11000 (1600)

2.2 Preparation of Samples

The experiment involved heating asphalt to a specific temperature (180 ± 5 °C) until it reached a fully flowing state in a small container. Different percentages of SBS (3%, 4%, 5%, and 6% of the weight of the base asphalt) were gradually added to the melted asphalt using a high shear mixer operating at 4500 rpm for 2 hours. This process ensured that the blends became thoroughly mixed and homogeneous**.**

3.Binder Physical Tests

Asphalt binder physical tests are essential for evaluating the properties and performance of asphalt binders. These tests provide valuable insights into the characteristics of the binder, aiding in the design and construction of high-quality pavements. Some commonly conducted binder physical tests include**:** penetration Test: This test measures the hardness of the binder by assessing the depth to which a standard needle penetrates the binder sample under specified conditions**.** Softening

Point Test: This test determines the temperature at which the binder softens and flows under the weight of a steel ball. Ductility Test: The ductility test measures the ability of the binder to stretch without breaking by evaluating the length of a binder sample that can be extended before it breaks. Elastic Recovery Test: This test measures the ability of the binder to recover its original shape after being stretched, indicating its elasticity. These physical tests help in characterizing the binder's consistency, stiffness, temperature susceptibility, and other important properties. They play a crucial role in ensuring the quality and performance of asphalt binders in pavement applications. In this study, the researchers conducted several conventional binder tests, which are empirical rheological tests commonly used to evaluate the properties of asphalt binders. The tests performed included: Penetration Test at 25 °C (ASTM D5): This test measures the hardness of the binder by determining the depth to which a standardized needle penetrates the binder sample under specific conditions. Softening Point Test (ASTM D36): The softening point test determines the temperature at which the binder softens and starts to flow when subjected to increasing temperatures and the weight of a steel ball. Ductility Test at 25 °C (ASTM D113): The ductility test measures the ability of the binder to elongate without breaking by determining the length of a binder sample that can be stretched under specified conditions. Additionally, the viscosity of the modified binder was measured at 135 °C using a Brookfield viscometer, following the ASTM D4402 standard. Viscosity measurement provides information about the flow characteristics and resistance to deformation of the binder at elevated temperatures.

4.Viscosity

Viscosity test was performed to measure the flow characteristics of asphalt binder and to establish the asphalt binder at hot mix asphalt facilities. Viscosity at two temperatures was determined by using rotational viscometer at 135°C for compacting temperature, while 165°C is used for mixing temperature. The test procedure was outlined in accordance to ASTM D4402. Approximately 30 g of asphalt were heated in an oven, which was sufficiently fluidized to pour into the sample chamber, and the amount of asphalt was changed with different sizes of the spindles. The sample chamber was then placed in the thermo container. After the desired temperature was stabilized for about 30 minutes, the spindle was lowered into the chamber to test the viscosity.

5.Result Discussion

5.1. Physical properties of the modified binders

The needle penetration test is a well-established and widely-used empirical method for assessing the consistency of asphalt binders. In Figure 1, the results of the needle penetration tests for various asphalt binders, both modified with RPET (presumably a specific type of modifier) and unmodified, are presented. It was observed that all the RPET modified asphalt binders exhibited lower penetration values compared to the unmodified samples. This decrease in penetration can be attributed to the increased stiffness of the modified asphalt binder, which was found to be approximately 5.68% higher than that of the unmodified binder. The reduced penetration values indicate that the incorporation of RPET particles into the asphalt binder has led to an increase in its stiffness. This can have several implications for pavement performance, such as enhanced resistance to deformation and improved durability**.** By understanding the impact of RPET modification on the penetration values, engineers and researchers can make informed decisions regarding the selection and application of asphalt binders in different pavement scenarios. It is important to consider the specific requirements of the project and the desired performance characteristics when choosing the appropriate asphalt binder formulation. The decrease in penetration values indicates that the modified binder has a higher resistance to penetration, suggesting improved hardness and durability. On the other hand, the increase in softening points suggests that the modified binder is less susceptible to softening at elevated temperatures**.**

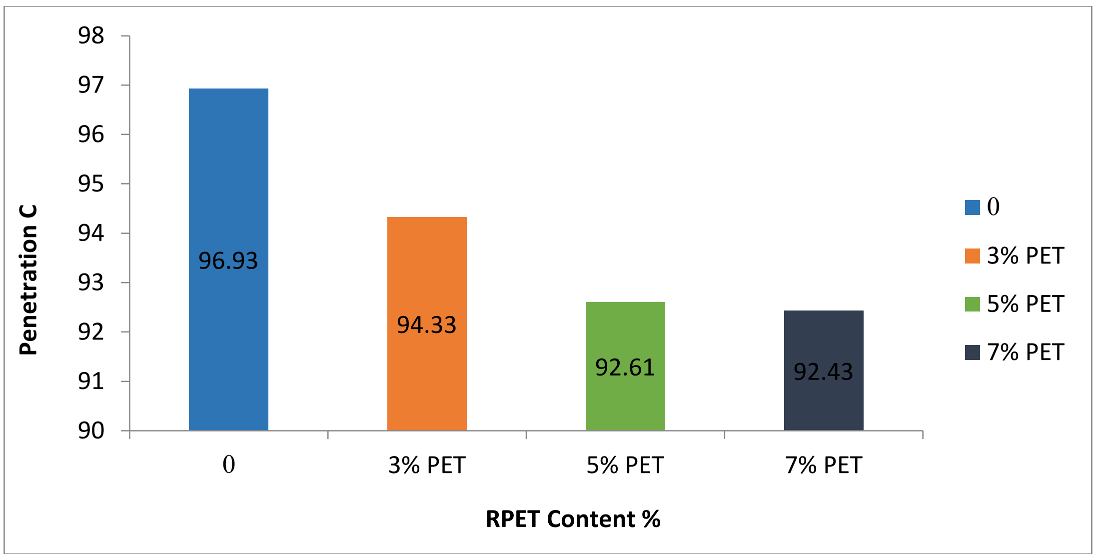

Figure 1: Penetration Against RPET Contents at 25°C

The softening point test was used to measure and specify the temperature at which binder begin to show liquidity. Figure 2 shows the experimental results of softening point versus RPET contents. As shown in figure, it can be noted that there was an increase in softening point up 3% of RPET. Hence, RPET particles had a higher value than unmodified samples, this in turn boost the stiffness of asphalt binder by (6.1**0**%).

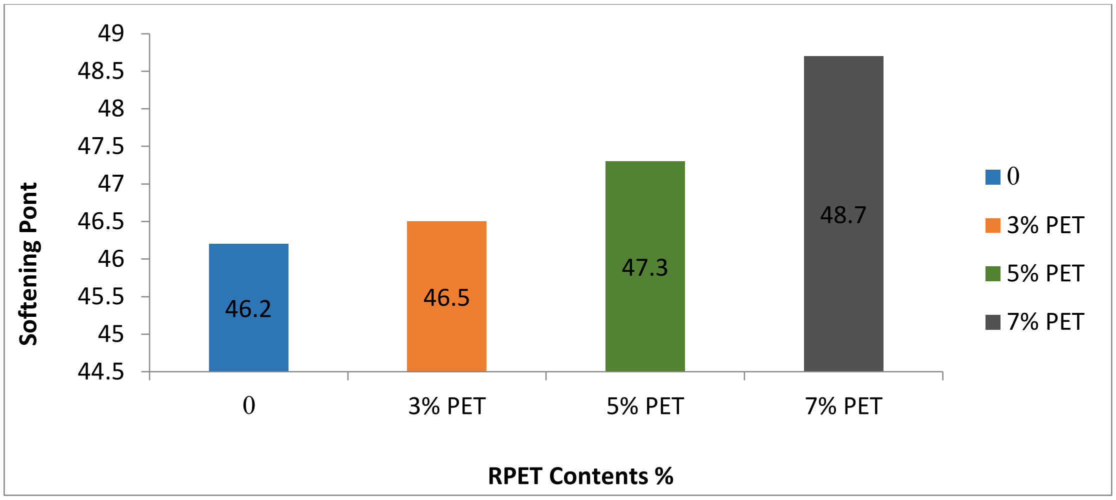

Figure 2: Softening point versus RPET Contents

Ductility is an important physical property that plays a significant role in improving pavement performance. Higher ductility values are generally desired as they contribute to the overall flexibility and resilience of the pavement. In Figure 3, the relationship between ductility and different ratios of BPSC (presumably a specific type of modifier) is depicted **.**The ductility of the modified binders gradually decreases. This decrease in ductility can be attributed to the corresponding increase in binder stiffness. The incorporation of RPET particles leads to a rise in the stiffness of the binders, resulting in reduced ductility **.**Interestingly, at an 7% concentration of RPET, a different behavior is observed, as the ductility value increases. This may be attributed to the presence of a high specific surface area in RPET particles, which enhances the absorption of asphalt. This behavior might be the result of chemical reactions and changes in the chemical structure of the binder, caused by the interaction between the RPET particles and the asphalt binder **.**Understanding the impact of RPET concentration on ductility is crucial for optimizing the performance of modified binders in pavement applications.

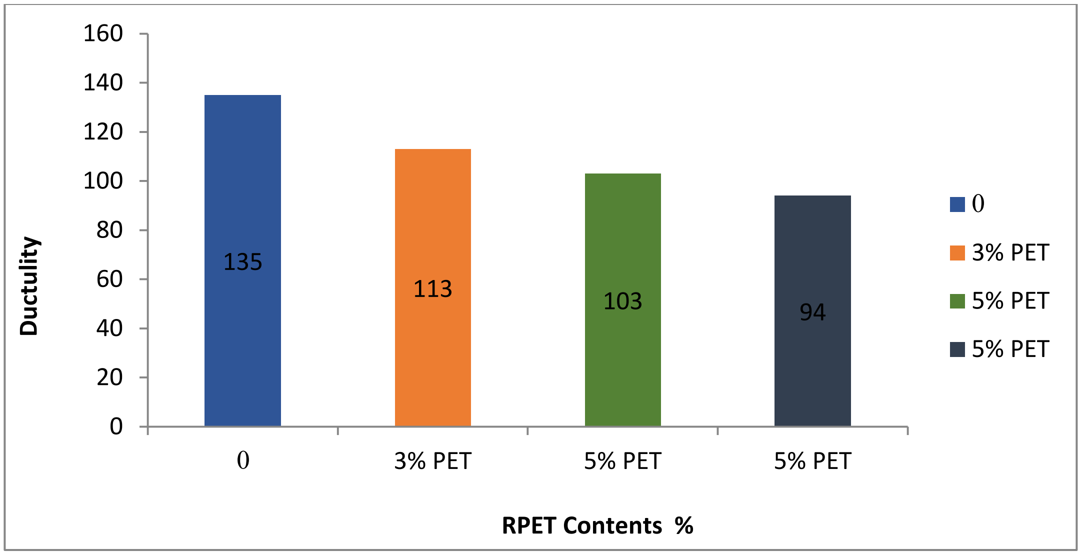

Figure 3: Ductility versus different ratios of RPET Contents

The viscosity of asphalt binder plays a crucial role in determining its flow properties. It is essential to ensure that the asphalt binder has a suitable viscosity for efficient pumping and handling during the hot mixing process. Additionally, viscosity is used to estimate the optimal mixing and compaction temperatures for asphalt mixtures. Reference viscosity values of 0.37–0.42 Pa/s and 0.46–0.51 Pa/s are commonly used for this purpose**.** In Figure 4.8, the experimental viscosities of asphalt binder with different percentages of RPET modifier under unaged conditions are presented. The results clearly demonstrate that as the temperature increases, the viscosity values decrease. This reduction in viscosity enhances the flow characteristics within the asphalt mixture and reduces stress. Consequently, higher viscosity values correspond to higher mixing and compaction temperatures, which in turn require more heating work during asphalt pavement construction**.** By understanding the relationship between temperature and viscosity, it is possible to optimize the flow properties of asphalt mixtures and minimize the associated costs of heating during construction.Dlurekovic and Mladenovic [17] found that the addition of fly ash to asphalt binder would increases the viscosity.

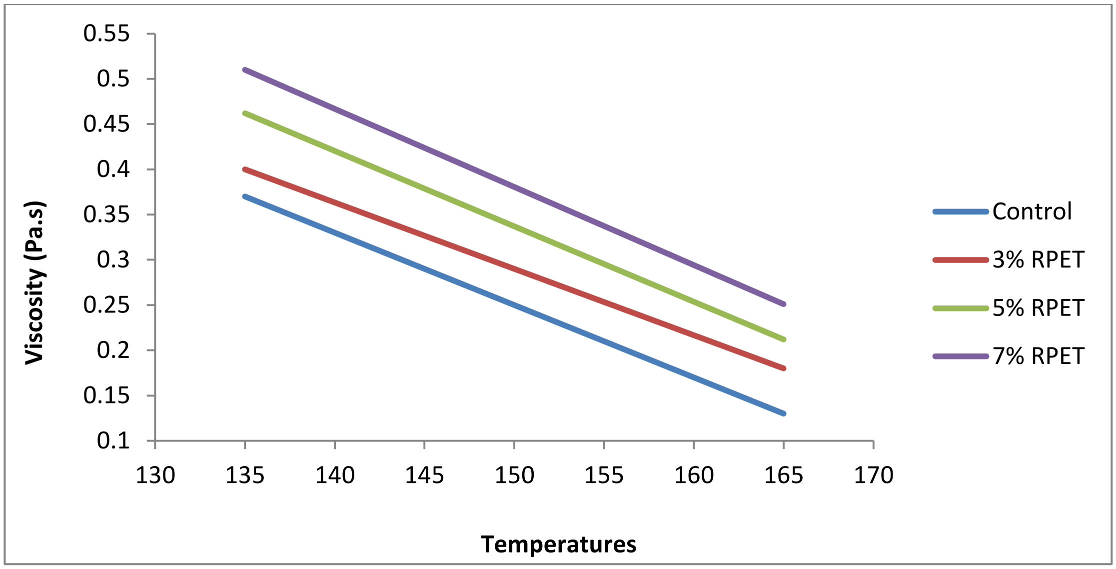

Figure 4: Viscosity of different percentages of RPET modifier asphalt binder

In Figure 4, the viscosity of asphalt binder with different percentages of RPET. The alteration in the molecular structure of RPET due to aging might contribute to this phenomenon**.** This finding is consistent with previous research, which also indicated that longer aging times at low temperatures are not as detrimental compared to higher temperatures, specifically at 135ºC. It implies that the aging process at lower temperatures has a less significant effect on the flow properties of the asphalt binder**.** Understanding the influence of temperature and aging on the viscosity of asphalt binders is crucial for designing asphalt mixtures with desired flow characteristics and ensuring the long-term performance of asphalt pavements.[18].

6.Conclusion

The utilization of asphalt binder additives in highway construction projects depends on various factors, including cost, construction feasibility, availability, and anticipated performance. These additives are employed to enhance the performance of asphalt pavements and mitigate issues such as moisture damage, permanent deformation, and thermal fatigue cracking. Consequently, modified asphalt pavements are expected to exhibit improved stability in warmer temperatures and increased flexibility in colder temperatures. The conventional testing conducted to evaluate the physical properties of the modified asphalt binder revealed some interesting findings. One notable result was that the addition of RPET (presumably a specific type of modifier) led to an increase in the hardness of the asphalt binder. This suggests that the incorporation of RPET particles can contribute to enhancing the stiffness and durability of the modified binder**.**

Based on these findings, it is recommended to use RPET particles in hot climate regions. This is because the presence of RPET particles was found to reduce the penetration of the asphalt binder, thereby making it less susceptible to deformation under high temperatures. Additionally, the softening point and viscosity of the asphalt binder were observed to increase with the addition of RPET particles. These changes in the physical properties of the binder can further contribute to improved performance and stability in hot climate conditions**.** Considering these results, the utilization of RPET particles in asphalt binder modification could be an effective strategy for enhancing the performance and longevity of asphalt pavements in hot climate regions.

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