Research Article

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Optimizing asphalt binder performance with various PET types

https://doi.org/10.1515/eng-2022-0595
received November 17, 2023; accepted February 02, 2024

Abstract: The efficacy of a pavement system is significantly influenced by the condition of the road pavement. Improving pavement quality is essentially the key to reducing problems with fatigue cracks and rutting on roads. One of its tenets is changing and enhancing asphalt's performance by use of various additives. One of the plastics having the highest recycling rates across various nations is polyethylene terephthalate, or PET. Since virgin PET (V-PET) and recycled PET (R-PET) cannot currently be analytically separated from one another, numerous indirect approaches have been developed to achieve this. According to one idea, recycling PET causes polymer chains to break, which alters the material's structural, mechanical, and thermal characteristics. R-PET and V-PET can therefore be distinguished from one another. Temperature and load stress cause asphalt pavement damage, especially rutting. In order to reduce the issue of road rutting, several measures have been implemented, such as enhancing the quality of pavement and improving the procedures used for structural design. In recent years, engineers have shown a growing interest in enhancing the performance of asphalt by incorporating various additives and substituting raw materials with virgin and recycled materials. This approach aims to improve environmental sustainability and reduce the cost of modified pavement mixtures. The purpose of the study is to assess the effect of modifying bitumen of grade 40–50 with V-PET. This study examined the use of V-PET as an asphalt modifier, at varying concentrations of 1, 2, and 4% by weight of asphalt. The study aimed to assess the influence of these concentrations on the performance of asphalt under high temperature conditions. The results demonstrated that the addition of 2% V-PET to the asphalt binder significantly improved the characteristics of the asphalt, resulting in increased resistance to rutting in the pavement.

Keywords: PET polymer, penetration, asphalt cement, ductility, SEM

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1 Introduction

The development and maintenance of highways are expensive, yet they are necessary for the country's economic growth. The highway system is designed to meet the required safety standards while offering the best possible serviceability and structural integrity to handle changing traffic demands. The deterioration of pavement materials has coincided with an increase in traffic-related stress in recent years, causing the pavement to distort more frequently. Furthermore, it is possible that the rheological characteristics of the asphalt binder utilized in Iraqi pavements did not meet the performance grade requirements, particularly in relation to traffic loads and climate. There is a reference to back this up [1].

As a result of the need to improve the performance of the currently available pavement materials, there has been a rise in demand for pavement material layers. Furthermore, the search for new modifiers to enhance asphalt binder ingredients and mixes has been made easier by technical developments and the discovery of innovative materials. As a result, our knowledge of the characteristics and actions of asphalt binders has expanded. A variety of elements might be considered modifiers, such as natural materials, waste materials, industrial byproducts, and carefully designed engineering items [2]. Fillers, recovered rubber products, fibers, and polymer types are some examples of commonly used modifiers [3]. It is possible to modify a large range of thermosetting and thermoplastic polymers [4–7]. The engineering characteristics of a modified bitumen mixture are mostly influenced by the specific components employed for the modification [8].

Polyethylene terephthalate (PET) is a very popular plastic that is widely used in the world for both food-grade applications like manufacturing of water, soft drink, and juice bottles as well as non-food products like packaging for cleaners or cosmetics and fibers for different textile products. Since the manufacturing and shipping costs are high, high-quality recycled plastics are usually more expensive than virgin plastics of the same kind. Furthermore, they are often hard to come by because of long-term agreements, lack of providers, or trouble obtaining an input stream of consistent quality [1]. In the industry, there is a prevalent idea that one can determine the difference between recycled PET (R-PET) and virgin PET (V-PET) by testing R-PET's material qualities and contrasting them with V-PET's [9,10].

PET is one of the polymers that can improve the mechanical characteristics of asphalt binders. Many laboratory techniques were used to investigate the physical properties of the original and modified binders.

Prior studies established that using nanomaterials improved the chemical and physical properties of asphalt binder, resulting in enhanced asphalt performance [11,12]. Nur *et al.* investigated the use of waste polyethylene powder in enhancing rutting resistance performance in concrete mixtures. The findings indicated that incorporating 0.75% of PET by weight of the whole aggregate resulted in improved rutting resistance compared to the typical mixture [13].

Taher and Ismael observed an improvement in stiffness and consistency of nano silica-modified asphalt under various aging conditions compared to unmodified asphalt, thus enhancing the hot mix asphalts resistance to rutting [14].

Notably, these studies found that rutting resistance could be significantly enhanced by the addition of plastic polymers. Additionally, research has validated that the incorporation of plastic improved the mixture's workability and stability. Further research has demonstrated that the incorporation of waste plastic into asphalt formulations also enhances their resistance to rutting [15–20].

Xu *et al.* observed that bitumen samples, when treated with 8% waste PET, exhibit enhanced performance in terms of increasing the complex shear modulus and reducing sensitivity to deformation at high temperatures. This modification also improves fatigue cracking resistance, as seen by a low fatigue factor [21].

This research aims to determine the effect of adding virgin PET to basic asphalt on the mechanical properties of asphalt. Therefore, it focuses on finding the changes that occur in the asphalt mixture when using a PET additive.

2 Materials and methods

The current experiment has made use of the asphalt binder (40/50). The attributes of this binder are given in Table 1.

Virgin PET was utilized in the form of powder [2]. Carbon and hydrogen atoms are combined to form PET, a thermoplastic polymer material used to make high molecular weight products. It has outstanding impact resistance, low moisture absorption, and high tensile strength [22] (Figures 1–3).

2.1 Preparation of specimens

Particle sizes of PET and asphalt have been combined in a mixer. PET can be blended at a constant 2,000 rpm rotational speed using a manual mixer. The mixing time, which is fixed at 30 min, is the variable in the creation of a homogenous composite material. Most researchers suggest 160°C heating for the asphalt binder. After that, the heated

Table 1: Characteristics of asphalt binder

Test	Conditions of test	Specifications	Results	Limitations[(1)]
Penetration	25°C, 0.1 mm	ASTM D5	46	40–50
Ductility	5 cm/min	ASTM D113	140	>100
Flash point	—	ASTM D92	Flash 323°C	>232°C
Rotational viscosity	@ 135°C	ASTM D4402	600 Pa s	Min. 400
	@ 165°C		155 Pa s	—
TFOT	163°C, 50 g, 5 h	Mass loss 0.222 ≥ 1 ASTM D1754	Penetration	>52
			Ductility	>50
Softening point	—	ASTM D36	52	—
Specific gravity	25°C	ASTM D70	1.03	
PI	—	ASTM D36	−0.7	—

[(1)]Iraqi Specification's Standard Limits (SCRB/R9, 2003) [147].

Figure 1: (1-5) Collection, Cutting, Crushing, Milling, Sieving of the PET respectively.

asphalt binder is progressively combined with weighted 1, 2, and 4% PET particles inside a closed steel enclosure and heated for 30 min in an electric oven. Additionally, an evaluation was conducted to determine the rheological and physical properties of the modified asphalt binder [23–27].

Figure 2: Preparation of asphalt binder modified with PET.

3 Results and discussion

3.1 Penetration and softening point

The penetration grade, softening point temperature, and flow temperature of asphalt all affect its consistency. There is a difference in the penetration levels and softening point

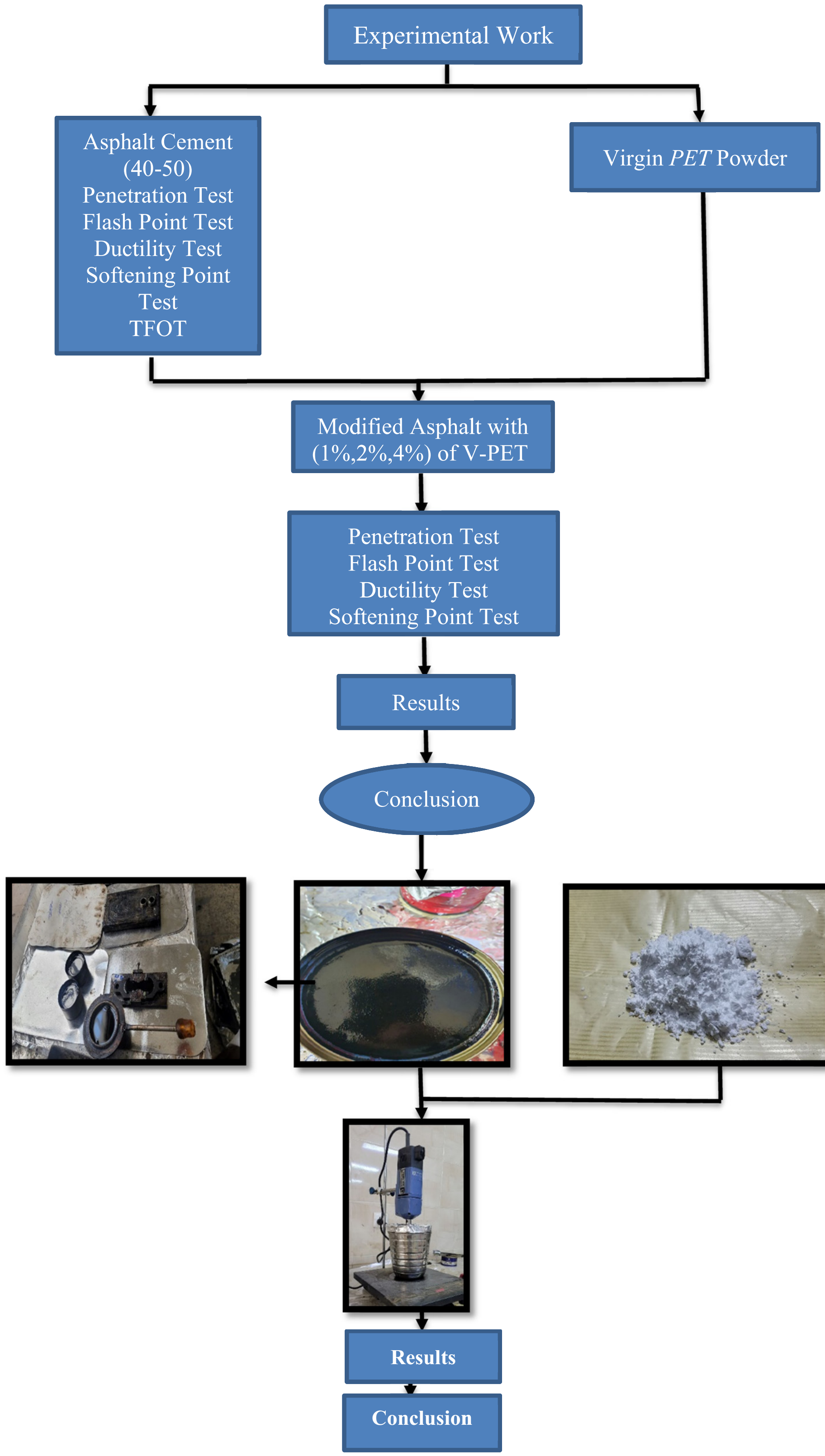

Figure 3: Work methodology.

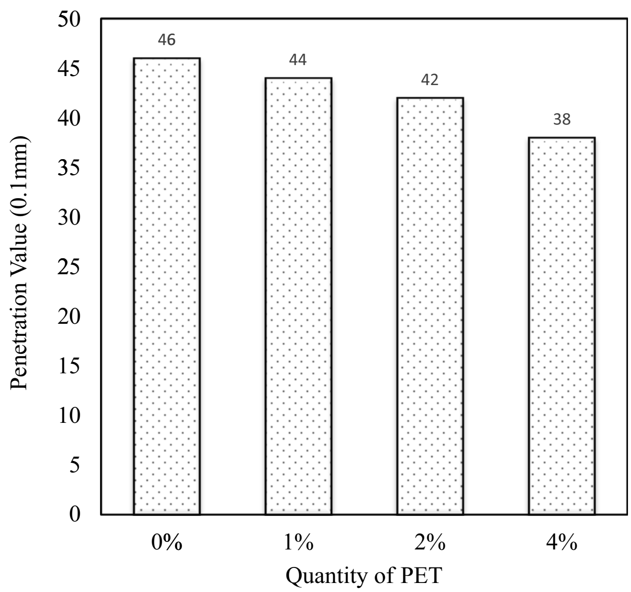

Figure 4: Penetration value at different quantities of PET.

temperatures when the modified asphalt binder is mixed with the basic asphalt binder, as shown in Figures 4 and 5. Regardless of how the powder was integrated, it was clear that adding PET particles decreased the penetration values and increased the softening point. The addition of 2% PET results in a 15.4% increase in the softening point temperature and an 8.7% decrease in penetration.

The asphalt binder may become stiffer as a result of PET particles diffusing and adhering to it. PET particles have a higher hardness than asphalt binder because of the absorption of PET and the resin's conversion during the asphalt modification process, which reduces the amount of oily substances in the liquid form. An increased softening point temperature accurately indicates the enhanced stability and durability of the asphalt mixture. It also helps reduce the issue of bleeding, which is frequently faced by flexible pavement projects, particularly in hot regions.

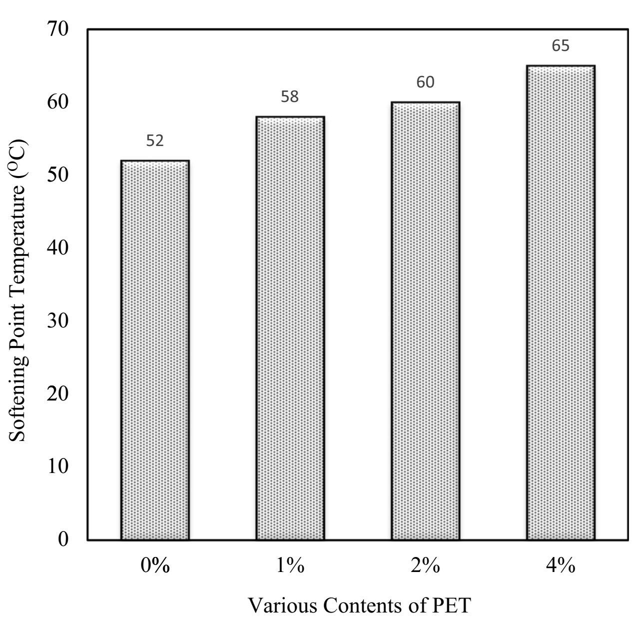

Figure 5: Softening point temperature at various percentages of PET content.

3.2 Penetration index (PI)

The PI is used to determine how sensitive asphalt is to temperature (PI). The temperature susceptibility decreases as the PI value increases. A greater degree of resistance to low-temperature cracking and rutting deformation is indicated by lower temperature susceptibility throughout the summer [28,29]. Figure 6 shows how PI levels and PET content are related. A representative scan that demonstrates the increase in PI values brought about by the inclusion of PET particles is shown. Furthermore, the asphalt treated with PET exhibited a notable decrease in its sensitivity to temperature changes. The addition of PET increases the thermal resistance of the modified asphalt. When building roadway pavements, it is beneficial that the PI stays within the usual range of +2.0 to −2.0 [30].

The ductility of asphalt demonstrates its cohesion. The test is also believed to demonstrate the improved consistency, flexibility, and durability of the upgraded asphalt binder, particularly in its ability to withstand low-temperature cracking.

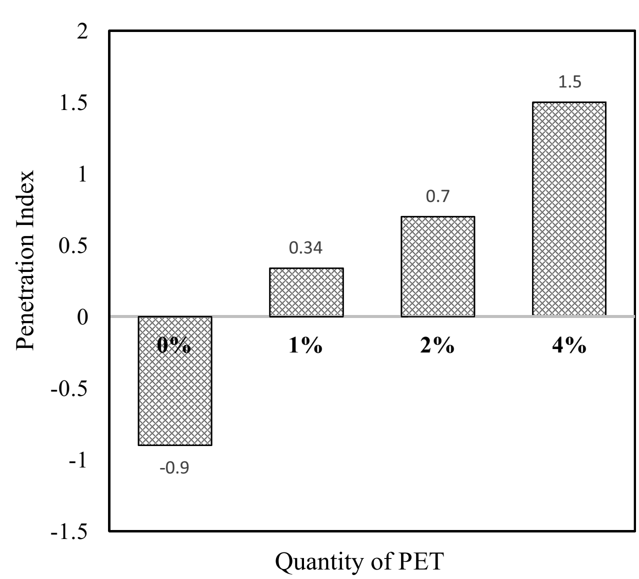

Figure 6: PI at different quantities of PET.

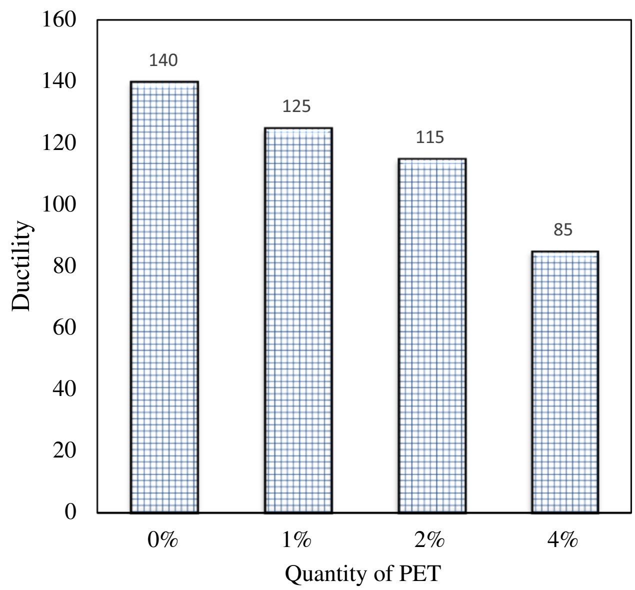

Figure 7: Ductility at different quantities of PET.

The ductility values with respect to PET content are shown in Figure 7. As the percentage of PET particles increased, the ductility value declined. Furthermore, the use of 2% PET results in a significant reduction in ductility, specifically by 18%. This could be because light volatiles are less prevalent in molten materials.

3.3 Flash point

The flash point of the asphalt establishes its safety criteria. Figure 8 illustrates the relationship between the percentage of PET addition and the flash point values. The flash point value climbed in tandem with the PET concentration. This could be as a result of the molten phase having fewer light volatile flammable chemicals. Particles made of PET have a significant melting point and is inherently non-combustible, the inclusion of PET enhanced the safety of handling bitumen throughout the mixing phase. In addition, the utilization of 2% PET leads to a notable increase in flash point by 4.3%.

3.4 Rheological properties and the rotational viscosity

We examined and contrasted the modified and control asphalt binder's rheological characteristics – including viscosity – with the required standards. The rotating viscosity

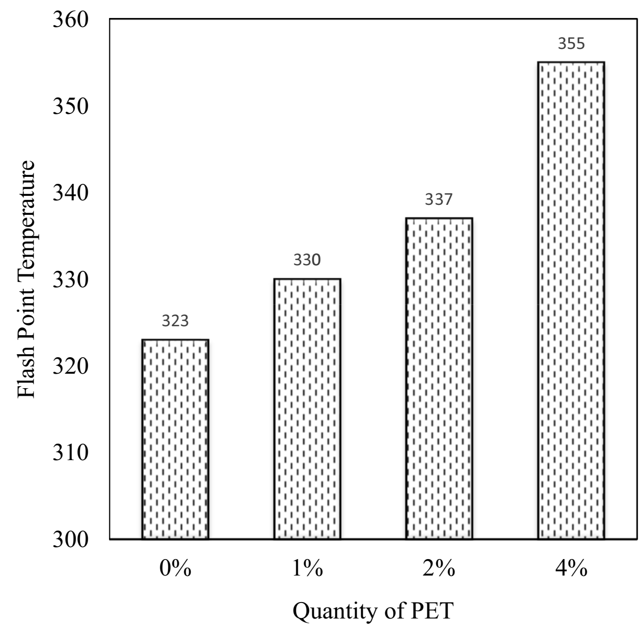

Figure 8: Flash point with different quantities of PET.

test is used to verify whether asphalt is suitable for use at high temperatures, particularly while mixing and compacting. As the concentration of PET was adjusted, the temperature-dependent viscosities of the original and modified asphalt binders were measured. Figures 9 and 10 show the relationship between PET content and rotational viscosity in the original and modified asphalt binder. It is obvious that the viscosity of asphalt binder rose as the amount of PET used increased. Additionally, 2% of PET with a penetration

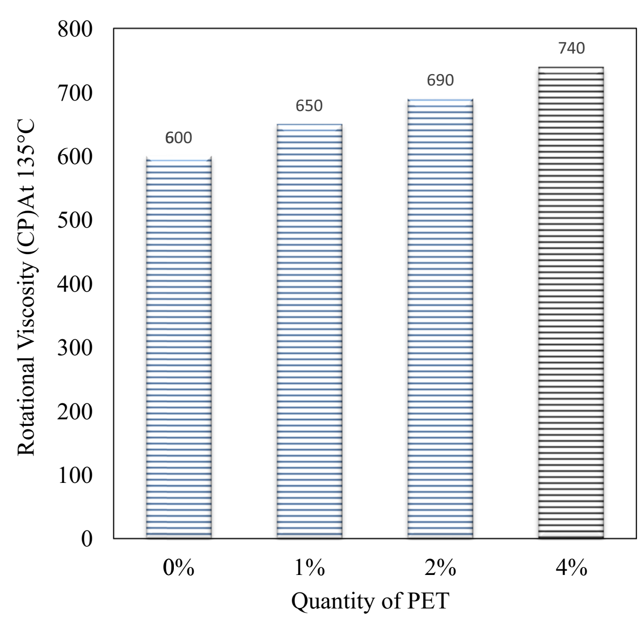

Figure 9: Viscosity values with different percentages of PET.

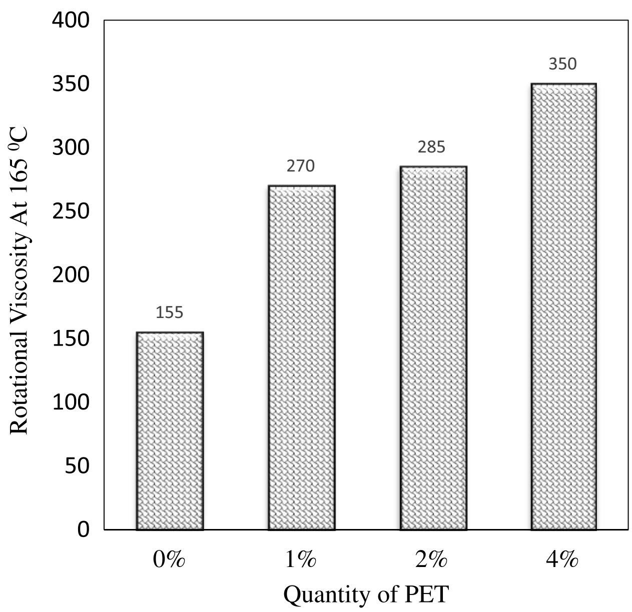

Figure 10: Viscosity and different quantities of PET.

grade of 40/50 exhibits greater viscosity compared to standard 40/50 asphalt. The rise in viscosity amounted to a 15% increase.

The absorption and dispersion of PET particles within the asphalt binder is responsible for the modified asphalt's improved stiffness. During the asphalting process, oily materials can be reduced to a molten phase and transformed into resin materials by PET particles because of their absorbent nature. Furthermore, PET particles have a higher hardness than asphalt binder [31–33]. Additionally, regardless of the mixing technique, the viscosity of modified asphalt reduces as the test temperature rises. The rise in viscosity can be attributed to the stiffening impact of plastics, as evidenced by the decline in penetration values. It is also crucial to note that asphalt binders must meet a minimum viscosity requirement of 400 c.p. at 135°C according to the Iraqi standard (SCRB/R9, 2003) [34]. It is important to note that all viscosity readings for asphalt binder treated with PET are higher than the value given in the Iraqi standard.

3.5 Retained penetration after thin film oven test (TFOT)

To determine the asphalt binder's sensitivity to short-term aging, a TFOT is performed and the penetration retention is measured. The relationship between the concentrations of PET and the percentage of sustained penetration is shown in Figure 11. The maintained penetration percentage decreased when the amount of PET content was increased at a revolution rate of 2,000 rpm. A decrease in the more readily evaporating chemicals in the liquid state can be used to explain this occurrence. The SCRB guidelines forbade any penetration greater than 50%.

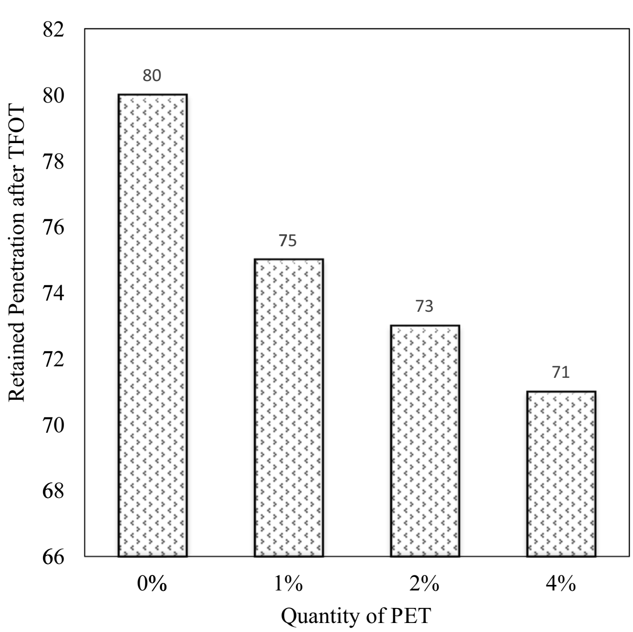

Figure 11: Retained penetration with different quantities of PET.

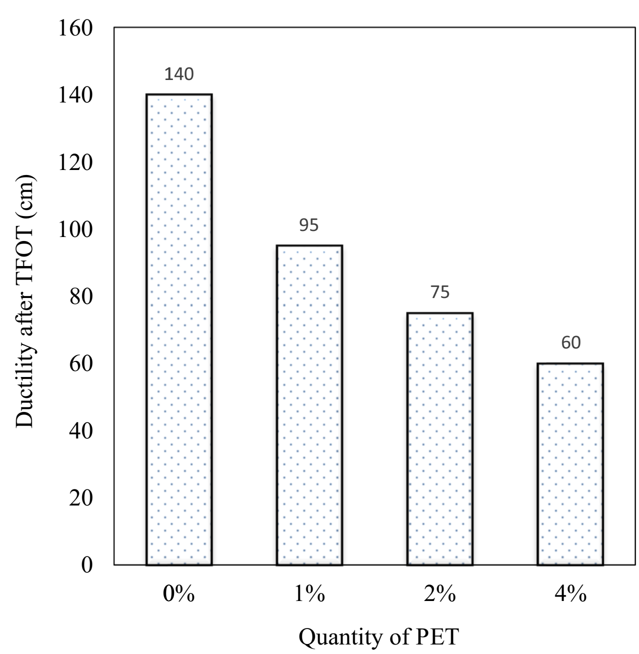

Figure 12: Retained ductility and different quantities of percentage of PET.

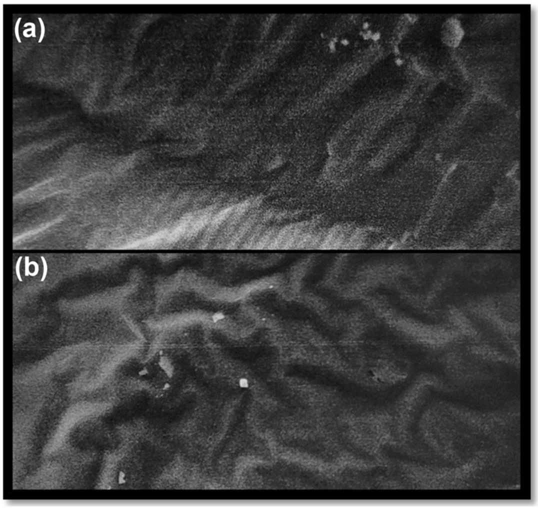

Figure 13: SEM images for asphalt: (a) base asphalt and (b) modified asphalt with PET additives.

3.6 Degree of ductility retained during TFOT

After the TFOT, the asphalt's preserved ductility is used to evaluate its short-term aging [35–38]. The percentage of preserved ductility is directly impacted by the concentration of PET, as shown in Figure 12. It is clear that the percentage of preserved ductility at a 2,000 rpm rotation rate was decreased by the addition of PET. The decrease in the concentration of fatty compounds in the liquid phase may be the cause of this. The remaining ductility was reduced by 25 cm as a result of SCRB's restrictions [34].

3.7 Scanning electron microscope (SEM)

The microstructure and dispersion quality of the additive in the bitumen were examined using SEM. Figure 13 presents the SEM images for the asphalt modified with PET at 4%. It is clear from the figure that the modifier was uniformly distributed throughout the asphalt binder.

4 Conclusion

The PET polymer material behaves elastically when molded. Within the limitations of the investigation, the following conclusions were drawn:

- Regardless of the mixing method used, PET polymer enhances asphalt's viscosity by increasing its softening point temperature by 15.4% and decreasing the penetration by 8.7% with the addition of 2% PET.
- The addition of PET polymer to modified asphalt results in an increase in temperature susceptibility (PI). In comparison to the other varieties of asphalt binder, the one containing 2% PET had a higher PI.
- When PET is added, modified asphalt becomes less ductile. After being mechanically mixed, asphalt treated with 4% PET polymer loses a substantial amount of its ductility, by about 40% of its initial amount.
- Adding 2% PET polymer by weight improved the modified asphalt binder's physical properties compared to regular asphalt. This caused an acceptable ductility value, a higher softening point temperature, a lower penetration value, and a higher PI value.
- PET additions increase asphalt's high temperature resistance, binder flash point, and bitumen mixing safety in hotter places. Furthermore, the SEM test findings indicated that the base asphalt with a certain percentage of PET additive exhibited a uniform and equally spread composition.

Acknowledgements: The authors would like to thank the Asphalt Laboratory personnel in the Department of Civil Engineering at the University of Technology-Iraq for their general assistance in the preparation, production, and testing of the specimens, and also for their support.

Funding information: Authors state no funding involved.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and consented to its submission to the journal, reviewed all the results and approved the final version of the manuscript. IKA: data collection, experimental lab, data analysis, interpretation, and writing – original draft; HHJ: conception or design, methodology, writing – review and editing, supervision, and resources; TDS: methodology, writing – review and editing, supervision, resources, and visualization; AD: writing – review and editing, supervision, and resources.

Conflict of interest: Authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are comprised in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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