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Properties of Modified Asphalt Concrete with Polyethene Terephthalate (Pet) as Additional Material

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Abstract

Plastic waste, particularly polyethylene terephthalate (PET), has become a significant environmental issue due to its extensive use and persistence in nature. The accumulation of PET waste in landfills and oceans poses a serious threat to the environment. To address this issue, the potential application of PET in asphalt mixtures for road construction was explored in this study. The research aimed to evaluate the effects of incorporating PET plastic waste into asphalt mixtures, focusing on the improvement of physical and mechanical properties. This study involved modifying asphalt concrete by adding plastic waste (PET) with different PET proportions (0%, 4%, 6%, 8%, and 10%) into the asphalt mix. The properties of the modified asphalt binders were evaluated through testing, including penetration test and softening test, while the performance of the asphalt mixtures was assessed through Marshall stability and flow tests. The inclusion of PET in asphalt mixtures resulted in increased stiffness and stability, with higher softening points, indicating improved resistance to high-temperature deformation. However, the addition of PET reduced flexibility, as shown by lower penetration values. Marshall test results demonstrated enhanced performance, including higher stability and optimized bitumen content. The findings suggest that PET-modified asphalt could be a viable solution for sustainable road construction, offering a dual benefit of reducing plastic waste and enhancing the performance of road materials. In conclusion, the study demonstrated that PET plastic waste can be effectively utilized in asphalt mixtures, contributing to more sustainable road construction practices. The use of PET in asphalt has the potential to improve the durability of road surfaces while addressing the global plastic waste crisis.

1. Introduction

Plastic waste constitutes a significant global environmental crisis, with millions of tons of plastic entering oceans and landfills annually. The need to address the growing issue of plastic pollution is urgent, as plastics, particularly polyethylene terephthalate (PET), have persisted in the environment for hundreds of years. The extensive use of PET in consumer products like beverage bottles has led to an overwhelming accumulation of plastic waste, most of which is not properly recycled. With increasing urbanization and industrialization, the disposal and recycling of PET waste remain significant challenges globally [1]. The potential for using PET waste in construction materials has gained attention as a promising solution, especially in the context of sustainable development and resource management. To date, significant research has focused on the reuse of waste plastics in construction, with particular emphasis on their role in modifying asphalt mixtures [2,3]. Asphalt, as one of the most commonly used materials in road construction, requires constant innovation to meet the demands of modern infrastructure. The integration of recycled materials, particularly plastic, in asphalt has been proposed as a way to improve performance and reduce environmental impact.

Decades of research have focused on the modification of asphalt with various materials, including polymers and waste products, to improve its properties, such as resistance to high temperatures, durability, and cracking [4]. The integration of plastic (PET) into asphalt mixtures has shown promise, improving the viscosity and thermal stability of asphalt binders, and enhancing the overall durability of pavement [5]. While some studies have reported positive effects of PET-modified asphalt, other studies have raised concerns about the long-term performance and stability of such mixtures [6]. It remains uncertain whether the integration of PET waste into asphalt binders can consistently lead to improved performance under varying environmental and mechanical conditions. Despite advancements, the question of whether PET-modified asphalt can achieve the same or superior performance compared to conventional asphalt remains an open issue [7].

Several methods have been explored to incorporate PET waste into asphalt mixtures, including dry and wet processes. In the dry process, PET is typically shredded and mixed directly with the asphalt binder, while in the wet process, PET is dissolved in solvents and then mixed with the asphalt [8,9]. Each method has its advantages and challenges, with the dry process being simpler but potentially leading to inconsistent dispersion of the plastic particles in the binder. Meanwhile, the wet process may improve the uniformity of the plastic distribution but involves additional steps and costs. Moreover, the impact of different plastic concentrations and the influence of the plastic's physical properties on the overall performance of the asphalt are still not fully understood [10]. In addition to the method of incorporation, the type of PET waste used also plays a crucial role in determining the properties of the final asphalt product [11].

The goal of the past article was to evaluate the potential of using PET plastic waste in asphalt mixtures, focusing on its impact on the physical and mechanical properties of the resulting asphalt concrete. Specifically, it aims to explore the effect of different PET sizes and incorporation methods on the temperature susceptibility of the asphalt. It is hypothesized that PET can significantly improve the high-temperature performance and resistance to deformation of asphalt mixtures, making them more suitable for extreme climatic conditions [12]. To test this hypothesis, a series of laboratory experiments were conducted involving the preparation of PET-modified asphalt using dry methods with a different percentage of plastic waste (4%, 6%, 8%, 10%). First, the physical properties of the modified binders and the mechanical properties, including Marshall stability and flow tests, were analyzed. Second, the performance of standard asphalt and the modified asphalt with plastic waste were compared. Finally, an evaluation was conducted to determine whether the data and results can be applied to real-life situations.

2. Methodology

The methodology serves as a guide through a network of questions during the complex process of studying. By utilizing this methodological part, the validity and accuracy of the findings are guaranteed, in addition to gaining new perspectives.

2.1 Reference Code

Table 1: Reference code (JKR, 2008)

Standard	Standard Code
Penetration	ASTM D-5
Softening point	ASTM D36-95
Marshall Mix design	JKR/SPJ/2008-S4
Flow and stiffness	ASTM D 1559-76

2.2 Materials

2.2.1 Plastic Waste (PET)

In this study, plastic waste (PET) will be used entirely as an additional material of aggregate. Plastic waste used was from plastic bottles that were collected from various places in the UTHM Residential College. After a sufficient amount of plastic bottles was collected, it was then shredded using a manual plastic bottle cutter with 10mm respectively. Figure 1 shows the shredded plastic waste.

Fig. 1: Shredded plastic waste

2.2.2 Asphalt Binder

Asphalt binder, more commonly known as bitumen, was the main component used in this study. The physical appearance of the asphalt binder is dark. The asphalt binder is an important component in asphalt concrete pavement construction and plays a key role in the performance characteristic. For this study, 60/70 grade bitumen was utilized. The asphalt binder was obtained from the Laboratory of Road Engineering Technology at UTHM.

Fig. 2: Asphalt binder

2.2.3 Aggregate

Aggregates, typically consisting of crushed stone, sand, and gravel, are bound together with bitumen (a viscous and waterproof substance) at high temperatures to form asphalt. The aggregates used were obtained from the Laboratory of Road Engineering Technology at UTHM. The test performed for aggregate preparation was the sieve analysis test. The condition of the aggregate surface plays a critical role in determining its ability to bond with the asphalt binder.

Fig. 3: Aggregate

2.3 Laboratory Work

2.3.1 Marshall Mix Design

The control and modified samples were prepared following the Marshall Mix Design according to ASTM D 1559-76. The apparatus used included a 110 mm x 110 mm x 60 mm mould, specimen extractor, compaction hammer, oven, covered containers for heating asphalt binder, mixing tools, sieve, and balance. This method must be carried out because asphalt concrete must be designed based on traffic volume, weather, and surrounding conditions. Hence, the properties of asphalt concrete must adhere to the guidelines from JKR/SPJ/2008-S4.

After the mould has been opened, it will then be compacted using automatic Marshall compaction and ready for testing (stability and flow). The optimal bitumen content is selected based on meeting criteria for maximum stability, appropriate flow values, and adequate air voids.

2.3.2 Marshall Stability Test

The goal of this testing is to determine the ideal bitumen content for the modified asphalt concrete. In this study, several characteristics are employed, including stiffness, flow, and stability. Thus, the testing was used to determine the mixture's maximum load that can be carried, predict the deformation of the specimen, and discover the mixture's performance. Once the test was performed, the data was then analyzed by comparing it with JKR specifications, as shown in Table 2.

Table 2: Marshall Test Specifications (JKR, 2008)

Parameter	Wearing Course
Stability, S	> 8000 N
Flow, F	2.0 – 4.0 mm
Stiffness, S/F	> 2000 N/mm
Air voids in mix (VIM)	3.0 – 5.0%
Voids in aggregate filled with bitumen (VFB)	70 – 80%

2.3.3 Penetration test

Penetration test was used in order to establish the softness of bituminous material in terms of consistency in millimeters by the penetration of a loaded needle vertically in five seconds at the temperature of 25°C for the tested sample of bitumen. This test was carried out according to the process described by the ASTM D-5.

2.3.4 Softening test

The softening point test was conducted to evaluate the consistency of the bitumen used it this study, the test provided the temperature at which the bitumen softens. When the temperature is high the viscosity of the bitumen decreases and so the bitumen starts to soften, and as a result, the softening point was as defined above. The ESR was tested based on ASTM D36-95.

3. Results and Discussion

This study discusses the results of using Polyethylene Terephthalate (PET) as an additive in asphalt concrete, based on physical and mechanical tests. Specimens were made with 0%, 4%, 6%, 8%, and 10% PET from waste bottles, and results are shown in tables and graphs. The binder used was penetration grade 60/70, following the Marshall Mix Design specification.

3.1 Asphalt Binder Test

Penetration and softening point tests were conducted to assess its quality. The penetration test showed that a higher number indicates a softer consistency. Based on ASTM D-5, the bitumen grade was confirmed as 60/70. In the softening point test, the bitumen softened at 54°C, meeting the standard requirements. Results are shown in Table 3.

Table 3: Result for asphalt binder test

Test	Standard	Standard Requirements	Value	Result
Penetration test (25°C) dmm	ASTM D-5	60-70	63	Accepted
Softening point (25°C)	ASTM D36-95	49-56	53	Accepted

3.1.1 Penetration Test

The penetration test evaluated the physical properties and durability of the asphalt binder, with higher values indicating a softer, more flexible binder and lower values indicating a harder, more rigid one. The standard penetration range for grade 60/70 is between 60 and 70 dmm at 25°C.

Figure 4 shows the results for asphalt with 0%, 4%, 6%, 8%, and 10% waste plastic. The 0% waste plastic sample had a penetration value of 63 dmm, within the standard range for grade 60/70. However, with increasing waste plastic content, the penetration values decreased with the value of 49 dmm at 4%, 41 dmm at 6%, 37 dmm at 8%, and 32 dmm at 10%. These lower values indicate increased stiffness, suggesting that while waste plastic increases rigidity, it reduces flexibility, making it unsuitable for applications requiring compliance with the 60/70 standard.

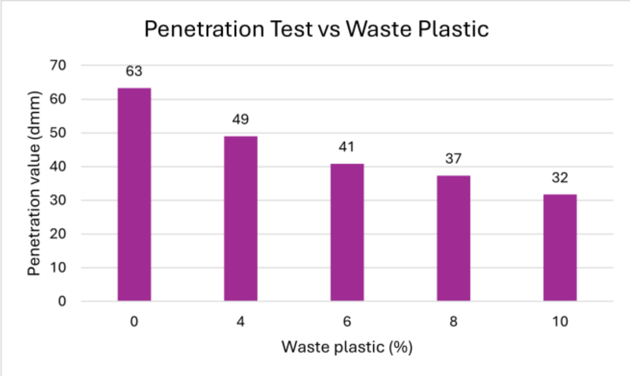


Fig. 4: Graph of Penetration test value (dmm) vs waste plastic (%)

3.1.2 Softening Point Test

Softening point test was used to determine the temperature at which the asphalt binder changes from a semi-solid to a soft state. This test helps assess the binder's suitability for specific applications, as bituminous materials gradually soften with temperature increase.

Figure 5 shows the softening point results for 0%, 4%, 6%, 8%, and 10% of waste plastic. At 0% waste plastic, the softening point is 53°C, within the standard range of 49°C to 56°C for grade 60/70 bitumen. With the addition of waste plastic, the softening points increase with the value of 61°C at 4%, 64°C at 6%, 68°C at 8%, and 69°C at 10%. These values exceed the standard range, indicating the binder becomes more resistant to softening under high temperatures. While this may improve performance in hot climates, the higher softening points suggest the binder no longer meets the 60/70 standard, affecting its further application.

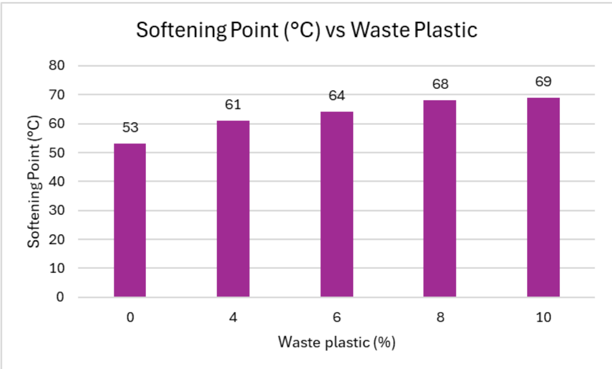


Fig. 5: Graph of Softening point (°C) vs waste plastic (%)

3.2 Optimum Bitumen Content (OBC)

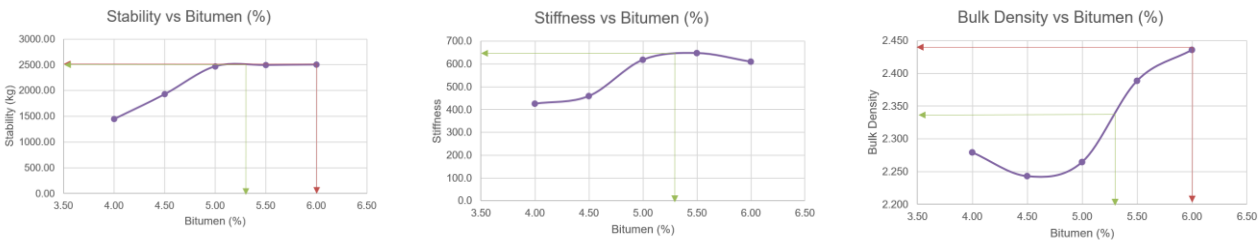
The Marshall Mix Design method was used to determine the optimum bitumen content (OBC) for the asphalt mixture in this research. Table 4 summarizes the results, showing key parameters (stability, bulk density, flowability, VFB, VTM, and stiffness) plotted against binder percentages (4%, 4.5%, 5%, 5.5%, and 6%). These averages highlight the binder content required for the control asphalt mix.

Table 4: Result of Marshall Mix Design for the control sample

Bitumen (%)	Stability (kg)	Bulk Density (g/cm^3)	Flow (mm)	VFB (%)	VTM (%)	Stiffness
4.0	1449.12	2.280	3.41	50.9	8.4	426.9
4.5	1929.0	2.243	4.49	51.4	9.1	431.9

Figures 6 and 7 provide insights into the effect of bitumen content on various properties of the asphalt mix, aiding in determining the optimum bitumen content (OBC) for ideal performance, strength, and durability. Figure 6 (a) shows that the stability of the asphalt mix increases with bitumen content initially but eventually levels off. This indicates the point where the mix achieves maximum strength and can effectively handle traffic loads.

Similarly, Figure 6 (b) illustrates the relationship between stiffness and bitumen content. Stiffness increases initially as more bitumen is added but decreases beyond a certain point, as the mix becomes too flexible. This balance ensures the asphalt mix remains strong and durable while maintaining the necessary flexibility. In Figure 6 (c), bulk density is plotted against bitumen content. The graph shows a slight decrease in density at lower bitumen levels, indicating insufficient compaction. As bitumen content increases, density rises steadily, highlighting the optimal range where compaction and stiffness are maximized for durability.

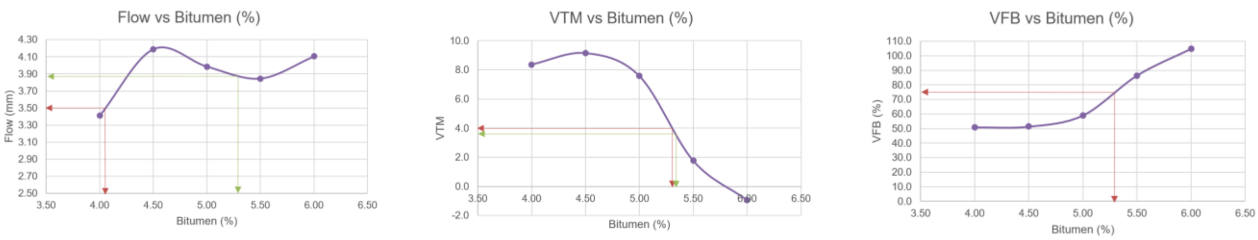


(a) (b) (c)

Fig. 6: Graph of (a) Stability, (b) Stiffness, and (c) Bulk vs Bitumen Content (%)

Figure 7 (a) depicts the flow characteristics of the asphalt mix. Flow values increase with bitumen content as the mix becomes softer and more workable, providing useful data for achieving the desired workability. Figure 7 (b) examines voids in the total mix (VTM) against bitumen content, with the graph's optimal point indicating the best void properties. This balance ensures proper void distribution, essential for durability and performance.

Lastly, Figure 7 (c) presents voids filled with bitumen (VFB) versus bitumen content. The optimal point on this graph suggests the ideal bitumen quantity for adequate void filling, stability, and overall strength of the asphalt mix.



(a) (b) (c)

Fig. 7: Graph of (a) Flow, (b) VTM, and (c) VFB vs Bitumen Content (%)

From the collected data, Table 5 shows that the average optimum bitumen content (OBC) for this control sample is 5.32%. This value must comply with the guidelines of Standard Marshall Parameters (JKR 2008) to ensure the quality and performance of the bituminous mixtures used in construction.

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Table 5: Value of average bitumen content

Properties	Bitumen (%)
Stability Maximum	6.00
Density Maximum	6.00
Flow (3mm)	4.05
VFB (75%)	5.30
VTM (4%)	5.25
Average	5.32

3.3 Optimum Bitumen Content with Waste Plastic

The relationship between the required amount of bitumen for the required performance characteristics and the amount of waste plastic was added to the asphalt concrete mixture. In this study, we examine the impact of adding waste plastic (0%, 4%, 6%, 8%, and 10%) on the required bitumen content and the properties of asphalt concrete. The incorporation of waste plastic alters the stiffness, workability, and performance of the mixture, thereby affecting the optimal bitumen content, which is determined to be 5.2%, 5.55%, 5.95%, 5.4%, and 5.68% for the corresponding percentages, as illustrated in Figure 8.

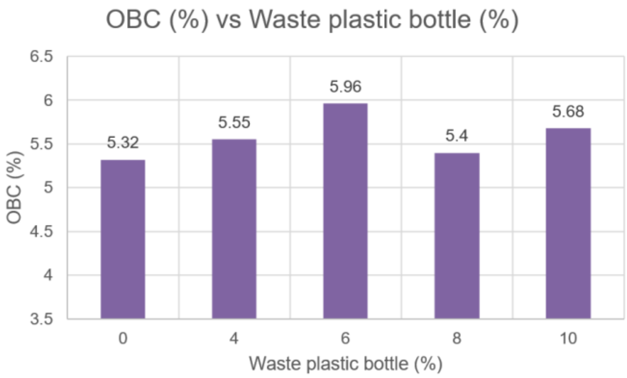

Fig. 8: Graph of OBC vs Waste plastic bottle

It is important to understand the OBC for each percentage of plastic waste is essential to optimize asphalt mix performance in terms of stability, durability, and mechanical properties, ensuring the mixtures meet performance and sustainability criteria.

Table 6 summarizes the Marshall Mix Design results, revealing that only the control sample with 0% plastic and the 6% plastic sample met JKR 2008 standards. These samples achieved the required VTM (3.0–5.0%), VFB (70–80%), stability (>816 kg), and flow (2.0–4.0 mm). Notably, the 6% plastic sample exhibited superior stability (3201 kg) and stiffness (890 kg/mm), enhancing structural performance without compromising durability. In contrast, samples with 4%, 8%, and 10% plastic failed to meet VTM and VFB standards, showing that excessive plastic disrupts the mix's balance, highlighting the need for moderation in plastic content.

Table 6: Overall value of Marshall Mix Design

Plastic (%)	OBC	Stability (kg)	Flow (mm)	Stiffness (kg/mm)	VTM %	VFB %
0	5.32	2495	3.88	630	3.33	75
4	5.55	2350	4.02	585	9.8	52
6	5.96	3201	3.70	890	4.4	73
8	5.4	1400	3.28	480	7.8	59
10	5.68	840	3.10	265	19	36

4. Conclusion

In summary, the first objective of this study was to evaluate the physical and mechanical properties of modified asphalt concrete using PET as an additive material. The results demonstrate that PET can be incorporated into asphalt concrete to enhance its performance under specific conditions. However, the penetration test and softening test with plastic waste failed to meet the standard specifications for grade 60/70 bitumen. The penetration values decreased with increasing plastic content, dropping from 63 dmm at 0% to 32 dmm at 10%, which is below the standard range of 60–70 dmm. For the softening point, the value increased with plastic content, exceeding the standard range of 49–56°C, reaching a maximum of 69°C at 10%. All the results indicate that while plastic waste increases binder stiffness and resistance to high temperatures, it affects compliance with grade 60/70 specifications by JKR, 2008.

The second objective was to compare the performance of standard asphalt concrete with modified asphalt containing plastic waste. From the data, the results revealed that the optimum performance occurred at 6% plastic waste, achieving the highest stability (3201 kg) and stiffness (890 kg/mm) while meeting JKR 2008 standards for VTM (4.4%) and VFB (73%). However, 4%, 8%, and 10% of plastic waste have failed to meet these void parameters, highlighting the negative impact of excessive plastic content on mix durability and balance. The control sample that is 0% and the 6% containing plastic waste mixture were the only ones to meet all standard criteria, demonstrating that moderate plastic incorporation improves structural performance without compromising durability. Overall, this study shows that PET can be a sustainable additive for asphalt concrete, as long as the content is carefully optimized to meet standard requirements.

Based on the findings of this study with additional waste plastic, there are improvements that need to be made. The guidelines are intended for future research, application, and development of using plastic waste as a modifier on the impacts and usage of asphalt mixes. Given the limitations of the current study, a few recommendations that could enhance the findings and be helpful for future research are as follows:

1. Ensure accurate compaction to minimize void variations and improve the consistency of asphalt samples.
2. Investigate the impact of different PET sizes on the performance of modified asphalt concrete.
3. Analyze and resolve issues with failed penetration and softening tests by optimizing plastic proportions and mixing techniques.
4. Collaborate with waste management systems to sustainably source PET plastic and promote a circular economy.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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