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FORMULATING AN ECO-FRIENDLY ASPHALT MIX USING RECYCLED PLASTIC WASTE: A SUSTAINABLE APPROACH

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Abstract: *This study evaluated the effectiveness of recycled plastic as an additive in asphalt to improve road durability and reduce plastic pollution. The test samples contained a mixture of PET and LDPE plastics at 4%, 5%, and 6%, which were tested using the Marshall Stability Test and Water Absorption Test. The results showed that 6% plastic provided the highest stability (16.3 kN) and the lowest water absorption rate (1.0%), making it more resistant to traffic loads and moisture. This study supports the use of recycled plastic in more sustainable and environmentally friendly road construction, with the potential to reduce reliance on conventional bitumen. The study methodology involves experimental sampling by producing four types of asphalt samples, namely control samples (0% plastic), 4%, 5%, and 6% plastic, which are then tested using water permeation tests and Marshall Stability tests to evaluate their mechanical performance. The population of this study includes construction materials used in road construction, while sample selection is done based on the controlled random sampling method to ensure more valid results. The expected findings show that the use of recycled plastic can increase the resistance of asphalt to mechanical loads and reduce the air permeation rate, thus improving the lifespan of roads. Significantly, this study contributes to increasing the durability of road infrastructure while reducing plastic pollution, changing the green approach that can be applied in the construction industry. In addition, new knowledge highlighted in this study is the optimization of the plastic mixture rate in asphalt to achieve a balance between flexibility, strength, and air resistance, which has not been widely explored in the context of road maintenance in Malaysia.*

Keywords: *Recycled plastic, asphalt mixture, road durability, water permeation rate, sustainable engineering.*

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Introduction

The deterioration of road infrastructure and the increase in plastic pollution have created an urgent need for more sustainable solutions in the construction industry. Conventional asphalt has limitations in terms of mechanical durability, resulting in frequent maintenance and high operating costs. At the same time, the accumulation of non-biodegradable plastics continues to increase, threatening the environment. Therefore, the integration of recycled plastics in asphalt has gained attention as a potential alternative that can not only reduce plastic pollution, but also improve the resilience of roads to traffic loads and weather factors. The accumulation of non-biodegradable plastics in landfills and oceans has raised long-term ecological concerns, prompting researchers to explore sustainable solutions for waste management and infrastructure development (Javadi et al., 2024; Chukwuka et al., 2021). One innovative approach that has received attention is the integration of recycled plastics as additives in asphalt mixtures, which not only helps reduce plastic waste but also improves the mechanical properties of asphalt.

Studies have shown that the addition of Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE) in asphalt can increase resistance to water absorption, increase stiffness, and improve overall mechanical performance (Ogundana, 2023; Nizamuddin et al., 2021). The use of recycled plastic as a bitumen modifier has been identified as an effective alternative to traditional asphalt materials, reducing cracking, rutting, and premature degradation of roads (Mushtaq et al., 2022; Almahdi et al., 2021). By optimizing the percentage of plastic in the asphalt mix, this method can contribute to the construction of more durable and cost-effective roads. To evaluate the effectiveness of plastic in asphalt, this study involved stiffness, flexibility, and water absorption tests. Initial results show that roads built using plastic-enhanced asphalt exhibit higher durability and require less frequent maintenance, making it a suitable choice for areas with extreme weather conditions and high traffic loads (Mohammed et al., 2018; Biswas & Potnis, 2022).

In addition to the engineering benefits, this approach also has a positive impact on the environment as it supports the concept of a circular economy by reducing reliance on petroleum-based bitumen (Asteray & Elsaigh, 2024). However, further studies are needed to assess long-term field performance, environmental impacts, and large-scale implementation strategies of this technology (Enfrin & Giustozzi, 2022; Deepa et al., 2019). Therefore, this study examines the potential of recycled plastics in road construction as a step towards sustainable development solutions.

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Literature Review

The accelerated deterioration of road infrastructure due to the limited durability of conventional asphalt, faced with the growing issue of plastic pollution, has led to increasing environmental and engineering challenges. The use of traditional bitumen-based asphalt contributes to high maintenance costs and depletion of natural resources, making it an unsustainable construction practice. At the same time, the accumulation of non-biodegradable plastic waste continues to increase, creating an urgent need for solutions that can reduce pollution impacts and improve road durability. Therefore, the use of recycled plastic as an additive in asphalt has gained attention as an alternative that not only addresses the issue of plastic disposal but also improves the mechanical durability of road pavements. Recent studies have shown that the integration of recycled plastic in asphalt can provide significant benefits in terms of strength and durability. Beghetto et al. (2022) emphasized the importance of optimizing air voids in asphalt, where uncontrolled air voids can cause defects, such as pitting and cracking, resulting in premature pavement deterioration. Other studies have shown that the addition of polyethylene (PE) and

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polypropylene (PP) in asphalt mixtures improves structural integrity and extends the lifespan of roads (Nizamuddin et al., 2021). Meanwhile, Mushtaq et al. (2022) confirmed that incorporating waste plastics into asphalt increases mechanical strength, making it more resistant to heavy loads and extreme weather, thus reducing the need for frequent maintenance.

While laboratory studies have shown positive results, research on the long-term performance of plastic-enriched asphalt in real-world conditions is still limited. Hall and White (2021) asserted that recycled plastics such as PET can improve the resistance of asphalt to deformation and fatigue, but most of this research is still in the laboratory testing stage. More data from field tests are needed to confirm the effectiveness of plastics in asphalt under real-world conditions. Enfrin and Giustozzi (2022) also identified challenges in the chemical compatibility of plastics with bitumen and long-term durability, while Abd-Karim et al. (2023) highlighted that the lack of a standardized methodology for incorporating plastics into asphalt hinders its widespread use in the industry. With increasing awareness of sustainability, studies have shown that plastic-modified asphalt can be a viable alternative to traditional road materials. Dong et al. (2023) highlighted the environmental advantages and potential cost savings of using plastics as additives in asphalt, making them a more sustainable option for road construction. Birega et al. (2024) also found that the use of recycled plastics in asphalt increases resistance to temperature and humidity fluctuations, thus reducing the rate of pavement degradation in the long term.

However, a large amount of plastic waste is still not optimally utilized, leaving the potential of this innovation untapped (Xu et al., 2021). Although early studies show the great potential of plastic-enhanced asphalt, there is a gap in assessing its long-term effectiveness and large-scale implementation. Further research is needed to develop more systematic plastic incorporation techniques, assess their long-term durability, and optimize asphalt formulations to improve the sustainability of road infrastructure. By addressing these challenges, plastic-modified asphalt has the potential to become a major innovation in modern road engineering, offering multiple benefits in terms of road durability and environmental conservation.

Research Methodology

This study was conducted to evaluate the potential use of recycled plastic as an additive in asphalt mixtures to improve road durability. The methodology of this study involved several main phases, namely material selection, sample preparation, laboratory testing, and data analysis to determine the effect of plastic on the mechanical properties of asphalt.

Material Selection and Sample Preparation

This study used Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE) as additives in asphalt to evaluate the effects of plastics on mechanical stability and water resistance. The test samples contained four types of asphalt mixtures: 0% (control), 4%, 5%, and 6% plastic. Laboratory tests included the Marshall Stability Test to measure resistance to traffic loads and the Water Absorption Test to evaluate water absorption rates. The data obtained were statistically compared to identify the optimal plastic ratio that provides the best performance in pavement durability.

Preparation and Testing of Asphalt Mix

The mixing process is carried out using the Hot Mix Asphalt (HMA) method, where the bitumen is heated between 163°C – 177°C, while the aggregate is heated at 170°C – 180°C before being mixed with plastic. The finished mixture is compacted using a Marshall Compactor with 75 impacts per side, to simulate actual road compaction.

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Laboratory Test

To evaluate the stability and durability of the modified asphalt, the following tests are carried out:

- Water Permeation Test: To determine the water absorption rate in the pavement.
- Marshall Stability Test: To measure the strength and resistance of the asphalt to load.
- Bulk Density Measurement: To analyze the density and structural integrity of each sample.

Data Analysis

Test results were analyzed using statistical comparison methods to identify the optimal percentage of plastic that provides the best resistance to water and mechanical stress.

This methodology allows for a comprehensive assessment of the ability of recycled plastic to improve asphalt durability, thus supporting efforts towards more sustainable and environmentally friendly road development.

Result Analysis

Figure 1: Results of plastic research in bitumen

Figure 1 above shows a compacted asphalt test sample, used in a study of the use of recycled plastic as an additive in asphalt mixtures. The sample was compacted using a Marshall Compactor to simulate the conditions of real pavement on the road. These samples were made from different plastic content (4%, 5%, and 6%). The sample was subjected to several mechanical tests, including the Marshall Stability Test and the Water Absorption Test, to determine the durability and stability of the asphalt mixture modified with recycled plastic.

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Table 1 : Results of Asphalt Study with Recycled Plastic

Sample	Marshall Stability (kN)	Flow (mm)	Bulk Density (g/cmÂ³)	Water Absorption (%)
Control (0%)			2.338	
4% Plastic	15.2	3.1	2.344	1
5% Plastic	14.8	3.5	2.327	1.4
6% Plastic	16.3	2.9	2.343	1

Table 1 presents the results of asphalt samples incorporating 4%, 5%, and 6% recycled plastic, compared to the control sample without plastic. The parameters evaluated included Marshall Stability, Flow, Bulk Density, and Water Absorption. This is a benchmark against Road Engineering Directive (ATJ) 5/85, the Malaysian standard guideline for road construction materials. According to ATJ 5/85, the minimum Marshall Stability requirement for wearing courses in flexible pavement is 8.0 kN. All samples exceeded this standard. Notably, the 6% plastic blend achieved the highest value at 16.3 kN, indicating superior structural strength, followed by 4% (15.2 kN) and 5% (14.8 kN). This confirms that recycled plastic contributes positively to the load-bearing performance.

In terms of Flow, ATJ recommends a range of 2.0–4.0 mm, to ensure sufficient flexibility without compromising stiffness. All tested mixtures were within this range, with the 6% plastic mixture recording the lowest flow at 2.9 mm, suggesting better resistance to deformation under load. For Bulk Density, although ATJ does not specify an exact value, higher density is often associated with better compaction and durability. The 4% plastic sample showed the highest density at 2.344 g/cm³, closely followed by the 6% plastic (2.343 g/cm³), compared to the control (2.338 g/cm³), indicating a slight increase in the compactness of the mixture.

Water Absorption is a key indicator of durability. Although ATJ does not set a specific limit, values below 2% are generally accepted. The 4% and 6% plastic samples both recorded 1.0%, indicating excellent moisture resistance. In conclusion, the use of 6% recycled plastic offers the most balanced performance and complies well with ATJ requirements, showing promise for improving pavement sustainability without compromising structural integrity.

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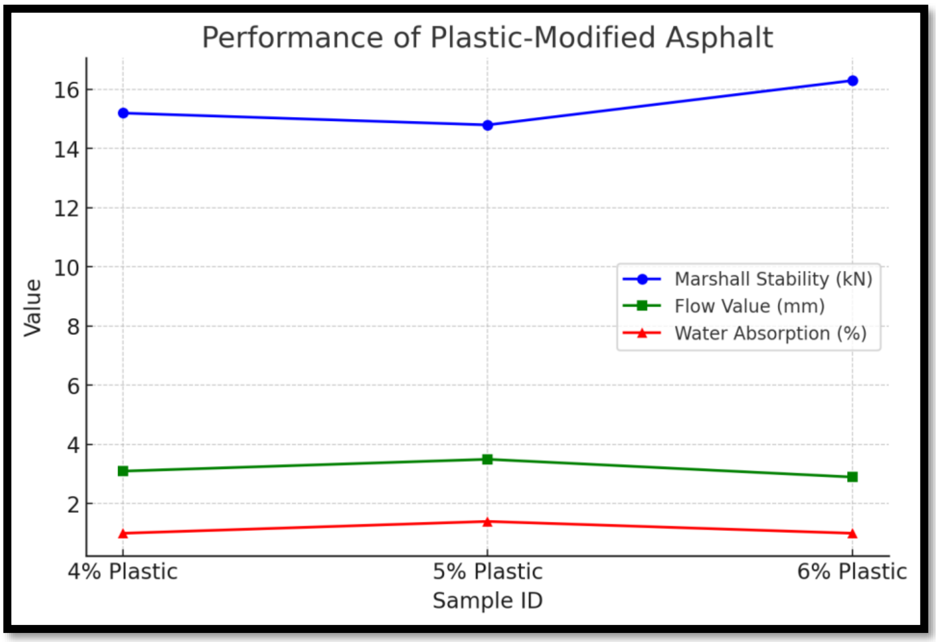

Figure 2: Performance of Plastic-Modified Asphalt

Figure 2 showed that the addition of plastic to asphalt increased mechanical stability and reduced water absorption, making it more suitable for high-intensity road conditions. The sample with 6% plastic recorded the highest Marshall Stability (16.3 kN), indicating greater resistance to traffic loads. However, the 5% plastic sample had the highest Flow Value (3.5 mm), indicating better flexibility but may be less stable in the long term. In terms of water absorption, the 6% plastic sample recorded the lowest rate (1.0%), making it more resistant to moisture and erosion. These results prove that 6% plastic provides the best balance of stability and water resistance, making it a more resilient choice for road pavement applications.

Conclusion

This study proves that the use of recycled plastic in asphalt mixtures has the potential to improve road durability and reduce the impact of plastic pollution. The sample with 6% plastic showed the best stability (16.3 kN) and the lowest water absorption rate (1.0%), making it more resistant to traffic pressure and environmental factors such as moisture and erosion. Therefore, the use of plastic in asphalt can be a sustainable alternative to conventional bitumen, with the ability to reduce road maintenance costs in the long term and support more sustainable infrastructure development.

In addition, the test results showed that 5% plastic recorded the highest Flow Value (3.5 mm), indicating a higher level of flexibility but may be less stable in the long term. The sample with 4% plastic recorded the highest bulk density (2.344 g/cm^3), indicating more dense space filling and higher resistance to pressure. Meanwhile, the lowest water absorption rate (1.0%) in the 6% plastic sample indicates that it is more resistant to moisture, thus reducing the risk of pavement erosion. These results prove that the addition of plastic to asphalt has a positive effect on road durability and can contribute to efforts to reduce plastic pollution more effectively.
Overall, this study supports the use of recycled plastic as a sustainable additive in road construction, which has the potential to reduce dependence on conventional bitumen and increase pavement durability. Although the test results show encouraging performance, further research is needed to assess the effectiveness of plastic-modified asphalt in the long term and under real traffic conditions. Additional studies are also needed to optimize the method of

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incorporating plastic into asphalt and assess the safety and environmental impact before large-scale implementation in the road construction industry. With continued research in this area, recycled plastic has the potential to become an innovative alternative to conventional asphalt, helping reduce the impact of plastic pollution and strengthen the durability of roads in the future.

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