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Utilizing Air Plastic Bottle Waste for Eco-Friendly Asphalt Mix to Support SDG 12 in State University of Malang

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ABSTRACT

This study aims to analyze the effect of adding AirUM plastic bottle waste as a partial asphalt substitute on the Marshall characteristics and volumetric properties of asphalt concrete (Asphalt Concrete–Wearing Course/AC-WC). The use of AirUM plastic bottles, consisting of 75% Polyethylene Terephthalate (PET) and 25% High-Density Polyethylene (HDPE), represents an innovative approach to promoting sustainable development and reducing plastic waste within the campus environment. The research employed a laboratory experimental method referring to SNI 06-2489-1991 and the 2018 Indonesian Highway Specification (Revised 2). Variations of plastic waste content were 6%, 8%, and 10% by asphalt weight. The Marshall test was conducted to evaluate stability, flow, Marshall Quotient (MQ), Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB) parameters. The results show that adding AirUM plastic waste significantly affects the mechanical performance of asphalt mixtures. Plastic content of 6–8% provides the most optimal performance with stability values of 2378–2430.5 kg, flow values of 3.36–3.97 mm, and Marshall Quotient of 707.73–612.21 kg/mm, all meeting the Indonesian highway standards. At 10%, the mixture exhibits higher stability but becomes overly plastic, resulting in excessive flow values. Overall, incorporating AirUM plastic bottle waste as a modifier in asphalt mixtures enhances structural strength and deformation resistance, while supporting the development of environmentally sustainable materials for future road infrastructure.

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1. INTRODUCTION

State University of Malang (UM), through its Green Campus program, is committed to creating an environmentally friendly and sustainable educational environment in line with the principles of the Sustainable Development Goals (SDGs) (Rachmadian et al., 2024) one of the major issues faced on campus is the accumulation of single-use plastic bottle waste, particularly from AirUM, a campus-produced drinking water product widely consumed by students and staff. The plastic waste, mainly PET (Polyethylene Terephthalate) from the bottles and HDPE (High-Density Polyethylene) from the caps, is difficult to decompose naturally and therefore poses a serious environmental (Maricar et al., 2024). This condition aligns with national data showing that Indonesia generates more than 64 million tons of waste annually, with approximately 9% consisting of plastic bottles, most of which remain improperly managed (Utami & Saleh, 2022).

UM's commitment to sustainability is reflected in its Green Campus movement, which aims to create a clean, healthy, and resource-efficient environment. The utilization of AirUM plastic bottle waste as an environmentally friendly asphalt mixture not only helps reduce the plastic waste problem on campus but also contributes to SDG 12: Responsible Consumption and Production (Novianti et al., 2019) this innovation is expected to provide both technical benefits by improving pavement quality and strategic benefits by supporting sustainable waste utilization as part of UM's Green Campus branding (Muzaki & Yustiarini, 2021).

The use of PET and HDPE plastic waste as a partial substitute in asphalt mixtures offers a sustainable solution aligned with SDG 12 by improving pavement performance and reducing environmental impact. Previous studies show that recycled plastics enhance mechanical properties, with HDPE increasing the Marshall Quotient (MQ) by up to 14.1% and significantly affecting stability and durability (Calderón-Ramírez et al., 2025; Mukhlis et al., 2022) in practice, this modification is more suitable for low to medium traffic roads due to its balanced stability and flexibility, while excessive plastic content may increase the risk of rutting under high traffic loads (Hao et al., 2024; Shah et al., 2025) considering that traffic at State University of Malang is dominated by light to moderate vehicles, the application of plastic-modified asphalt at an optimum range of 68% is considered appropriate. Supported by pilot implementations in Indonesia, this approach is both technically feasible and relevant, forming the basis for evaluating AirUM plastic waste in AC-WC mixtures (Telehala, 2023).

Previous studies support the potential of PET and HDPE waste as asphalt modifiers. (Hafidz et al., 2025) reported a 40.85% increase in Marshall Stability using PET waste, while (Hasrullah et al., 2023) found that 4% plastic content provides optimal performance in tropical climates. Similar results were obtained by (Mukhlis et al., 2022) regarding the influence of HDPE on volumetric properties and asphalt stability. International studies also reinforce these.

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Findings by (Hao et al., 2024) demonstrated that recycled polyethylene improves resistance to rutting and extends pavement service life, while (Ameur et al., 2025) found that PET, HDPE, and PP in dry-mix asphalt enhance water resistance and fatigue strength by 30–40%. (Fahmy et al., 2024) observed increases in Marshall values and reduced flow when PET was added, indicating increased asphalt stiffness. (Shah et al., 2025) showed that HDPE content between 8–10% yields optimal stability and flexibility balance. (Pangestika et al., 2023) reported a 29% reduction in rutting depth, and (Fonseca et al., 2022) highlighted improved asphalt temperature resistance of up to 15°C.

Previous research on plastic-modified asphalt largely focuses on single-type plastics or non-uniform mixed waste, resulting in a limited understanding of the interaction between PET and HDPE within a controlled composition. This study addresses this limitation by employing AirUM plastic bottle waste consisting of PET and HDPE from a consistent and well-defined source to ensure material uniformity and reliable analysis. The key novelty lies in systematically examining the interaction of PET–HDPE at substitution levels of 6%, 8%, and 10%, which are adopted from (Hafidz et al., 2025) as the optimum range for balancing stability and flexibility. By combining technical performance evaluation with a campus-based waste management approach, this research offers both a more accurate determination of optimum plastic content and a practical framework for sustainable pavement development in line with Green Campus initiatives and SDG 12.

2. METHOD

This research is a laboratory experimental study aimed at analyzing the effect of asphalt content variation on the Marshall characteristics and volumetric parameters of Asphalt Concrete–Wearing Course (AC-WC) mixtures modified with AirUM plastic bottle waste. The research approach is empirical and quantitative, referring to SNI 06-2489-1991 concerning the Marshall Test Method for Asphalt Mixtures, as well as the 2018 Bina Marga General Specifications (Revision 2). This method aligns with the approach used by (Mukhlis et al., 2022) which emphasizes the importance of maintaining consistent Marshall test parameters in determining the optimum asphalt content for AC-WC mixtures modified with plastic waste.

The primary materials used in this study include penetration grade 60/70 asphalt as the binder, coarse and fine aggregates meeting AC-WC gradation requirements according to Bina Marga standards, stone dust filler passing the No. 200 sieve (0.075 mm), and AirUM plastic bottle waste composed of 75% Polyethylene Terephthalate (PET) and 25% High-Density Polyethylene (HDPE). The plastic waste was shredded into particles sized 1–2 mm to enhance compatibility with hot asphalt. The mixing process was conducted using the wet process, in which the plastic was melted into the asphalt at 160–170°C until a homogeneous mixture was achieved before being blended with the aggregates. This method refers to (Gaus et al., 2022) who demonstrated that the wet process produces more uniform blending and improved mixture stiffness compared to the dry process.

Asphalt content variations of 6%, 8%, and 10% of the total mixture weight were selected, based on recommendations by (Hafidz et al., 2025) who found that the optimum asphalt content in PET-modified mixtures generally falls within this range to achieve maximum stability. For each asphalt content variation, three test specimens were prepared to ensure representative test results. Specimen fabrication involved heating the aggregates and asphalt to the mixing temperature, followed by molding with a Marshall mold measuring 10.16 cm in diameter and 6.35 cm in height. Compaction was performed with 75 blows per side in accordance with SNI 06-2489-1991, after which specimens were cooled for 24 hours prior to testing.

The Marshall test was conducted to obtain Stability and Flow values. Stability represents the maximum load the mixture can withstand, while Flow indicates the level of plastic deformation at maximum load. These parameters were then used to calculate the Marshall Quotient (MQ), indicating the relative stiffness of the mixture (Farida et al., 2025). Furthermore, volumetric properties were analyzed, including Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB). These parameters were calculated based on the specific gravity of the mixture and aggregates according to formulas in SNI 06-2489-1991, as also applied by (Nawir & Mansur, 2021) in their evaluation of HDPE-modified asphalt mixtures.

Results of the analysis of SNI and Bina Marga specification requirements to determine the suitability of mixture performance. The Optimum Bitumen Content (OBC) was determined based on the combination of the best parameters, including high stability and MQ, VIM between 3–5%, VFB between 65–82%, and VMA ≥ 15%. The research procedures included material preparation, asphalt-plastic blending, specimen molding and compaction, Marshall testing, volumetric analysis, and determination of the optimum asphalt content. This approach is expected to produce a technically feasible asphalt–plastic mixture that supports the Green Campus initiative and sustainable waste management efforts at State University of Malang.

The secondary data utilized in this study were obtained from literature reviews of various journals that had been analyzed in accordance with SNI 06-2489-1991 and the Marshall testing method for asphalt mixtures based on the 2018 Bina Marga General Specifications. To validate the findings derived from these literature sources, experimental testing was conducted at the Road Laboratory of the GKB Building A20 through several systematic stages. The initial stage involved the preparation and weighing of materials, including coarse aggregate, fine filler, and asphalt. The aggregates were weighed according to the predetermined gradation in compliance with SNI 06-2489-1991. Subsequently, the materials underwent a heating process, where the aggregates were heated to approximately ±165°C, the asphalt to ±150°C, and the plastic material until it melted at approximately ±220°C.

Following heating, the mixing process was carried out by combining the aggregates, asphalt, and plastic in a mixing container until the entire surface of the aggregates was uniformly coated with asphalt and the plastic was evenly distributed. The mixture was then placed into a cylindrical mold that had been pre-coated with oil. To facilitate compaction, the mixture was penetrated 15 times along the edges and 10 times at the center, and subsequently covered with filter paper. The compaction process was performed using a hammer with 75 blows applied to each side of the specimen. After compaction, the test specimen was removed from the mold using an extruder once it had sufficiently cooled. The specimen was then left to rest at room temperature for 24 hours before being weighed and measured.

Next, the specimen was immersed in a water bath at a temperature of 60°C for 30–40 minutes prior to stability testing. Finally, the Marshall Quotient test was conducted by placing the specimen in the Marshall testing apparatus and applying a load to determine its stability and related parameters. To clarify the research process, a framework has been developed that systematically and structurally outlines the research stages. This framework illustrates the sequence of activities, from problem identification and mixture design to the testing process and analysis of results based on applicable standards. With this flowchart, the research process can be understood more clearly and systematically, as shown in **Figure 1**.

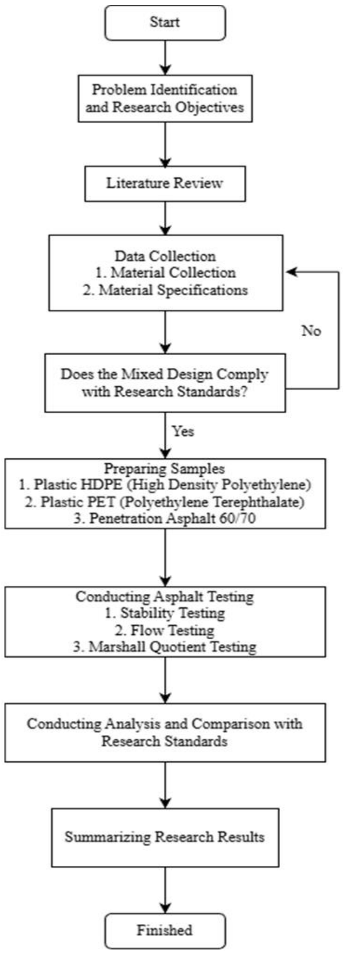

Figure 1. Research sequence flowchart

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In **Figure 1,** This study began with problem identification and a literature review, followed by the collection and verification of material specifications in accordance with SNI and Bina Marga standards. AC-WC mixtures modified with AirUM plastic waste (PET and HDPE) were then formulated using asphalt content variations of 6%, 8%, and 10%. After meeting the design criteria, test specimens were prepared through a wet mixing process, followed by compaction and conditioning. Subsequently, Marshall testing was performed to obtain stability, flow, and Marshall Quotient (MQ) values, as well as volumetric parameter analysis (VIM, VMA, and VFB). The test results were then analyzed and compared with applicable specifications to determine the Optimum Asphalt Content (OAC). The final stage of the research involved drawing conclusions based on the mixture's performance against established standards.

3. RESULT AND DISCUSSION

The discussion in this study focuses on explaining the results of the Marshall Quotient (MQ) parameters of mixtures modified with AirUM plastic bottle waste produced by State University of Malang. The research aims to analyze the influence of adding Polyethylene Terephthalate (PET) from the bottle body and High-Density Polyethylene (HDPE) from the bottle cap on the mechanical and volumetric characteristics of the mixture (Pinem et al., 2022). The plastic composition used consists of 75% PET and 25% HDPE, with substitution levels of 6%, 8%, and 10% of the total asphalt weight. This discussion includes analysis of Marshall parameters, namely stability, flow, and Marshall Quotient (MQ), as well as the volumetric characteristics of the mixture, including Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB). The results are compared with the requirements stated in the 2018 Bina Marga General Specifications (Revision 2) and SNI 06-2489-1991, as well as with findings from previous studies to strengthen the validity of the experimental outcomes.

Furthermore, the discussion emphasizes how the addition of AirUM plastic waste affects the mixture's resistance to deformation due to traffic loads. Increases in stability and MQ indicate an enhancement in structural strength and the mixture's ability to withstand bending stresses, while variations in flow values reflect the mixture's flexibility and its capacity to absorb deformation. To reinforce the analysis, the research findings are compared with the results of earlier studies, such as (Mukhlis et al., 2022) it was reported that HDPE significantly increases the stability and volumetric density of AC-WC mixtures (Hafidz et al., 2025) who documented a stability increase of up to 40.85% in mixtures containing PET waste and (Hasrullah et al., 2023) who identified that plastic content of 4–6% provides optimal performance in tropical climates. These findings are consistent with the results of the present study, which indicate that the optimum plastic substitution level lies in the range of 6–8%, where a balance between stability, flexibility, and deformation resistance is achieved, as shwo in following **Table 1.**

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Table 1. Table of Marshall Quotient Parameter Analysis Results

Plastic Contentc	Combinations Variations		Flow	Stability	VIM	VMA	VFB	MQ	Standrads Binamarga
	HDPE	PET	(mm)	(Kg)	(%)	(%)	(%)	(Kg/ mm)	
0%	-	-	3,02	2016,4	4,64	15,29	80,31	332,58	**Fullfiled**
6%	25%	75%	3,36	2378	4.28	16,57	75.86	707,73	**Fullfiled**
8%	25%	75%	3,97	2430,5	3.72	17,92	80.47	612,21	**Fullfiled**
10%	25%	75%	4,68	2803,3	3.24	19,29	84.45	598,99	**NO**
Binamarga Standarts			**2-4**	**Min 800**	**3-5**	**Min 15**	**Min 65-82**	**Min 250**	

Based on the **Table 1**, the addition of plastic waste affects the increase in stability values and changes in other Marshall parameters. A plastic content of 6–8% yields the most optimal performance, as all parameters still meet the Bina Marga specifications. At a 10% content, although stability increases, the flow and VFB values exceed the permitted limits, causing the mixture to become less stable. This indicates that an excessively high plastic content can reduce the performance quality of the asphalt mixture.

3.1 Discussion

3.1.1 Stability

The stability value increased along with the rise in plastic content, from 2378 kg at 6% to 2803.3 kg at 10%. This indicates that the plastic acts as a reinforcing modifier (filler modifier), filling the voids between aggregates, enhancing particle cohesion, and improving the bonding between asphalt and aggregates. However, although the 10% plastic content results in the highest stability, the mixture becomes more rigid (brittle), reducing its resistance to bending stress and dynamic loading. Therefore, the optimum plastic content is identified within the range of 6–8%, where high stability is achieved while maintaining adequate elasticity.

3.1.2 Flow

The flow value increases from 3.36 mm to 4.68 mm as the plastic content increases. The values at 6% and 8% are still within the Bina Marga specification range (2–4 mm), indicating that the mixture retains a balance between rigidity and flexibility. However, at the 10% plastic content, the flow value exceeds the allowable limit, indicating increased plasticity and a greater tendency toward permanent deformation (rutting). This suggests that excessive plastic creates an overly thick film layer, reducing the adhesion between asphalt and aggregates and lowering the structural stiffness of the asphalt concrete mixture.

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3.1.3 Marshall Quotient (MQ)

The MQ value decreases from 707.73 kg/mm at 6% plastic content to 598.99 kg/mm at 10%. Better resistance to load-induced deformation is indicated by a higher MQ value. The 6% plastic content produces the highest MQ value, demonstrating a well-balanced structural performance between stability and flexibility. At 8–10% plastic content, MQ decreases due to the mixture becoming too soft, thereby reducing its ability to withstand shear stress and bending loads from traffic. Accordingly, the optimum plastic content is determined to be 6% AirUM plastic.

3.1.4 Volumetric Parameters (VIM, VMA, and VFB)

The results indicate that the Void in Mix (VIM) values range from 3.24% to 4.28%, which fall within the standard requirement of 3–5%, suggesting that the air void content is sufficient to accommodate thermal expansion within the asphalt mixture. Furthermore, the Void in Mineral Aggregate (VMA) values increase from 16.57% to 19.29% and consistently exceed the minimum standard of 15%, indicating that the effective aggregate volume is well maintained. In addition, the Void Filled with Bitumen (VFB) values range from 75.86% to 84.45%, demonstrating that the asphalt binder adequately fills the voids and effectively coats the aggregate surfaces.

However, at the 10% plastic content, the relatively high VFB value (84.45%) indicates that the mixture becomes oversaturated with asphalt, increasing the risk of permanent deformation, the result of the graph can be see in **Figure 2.**

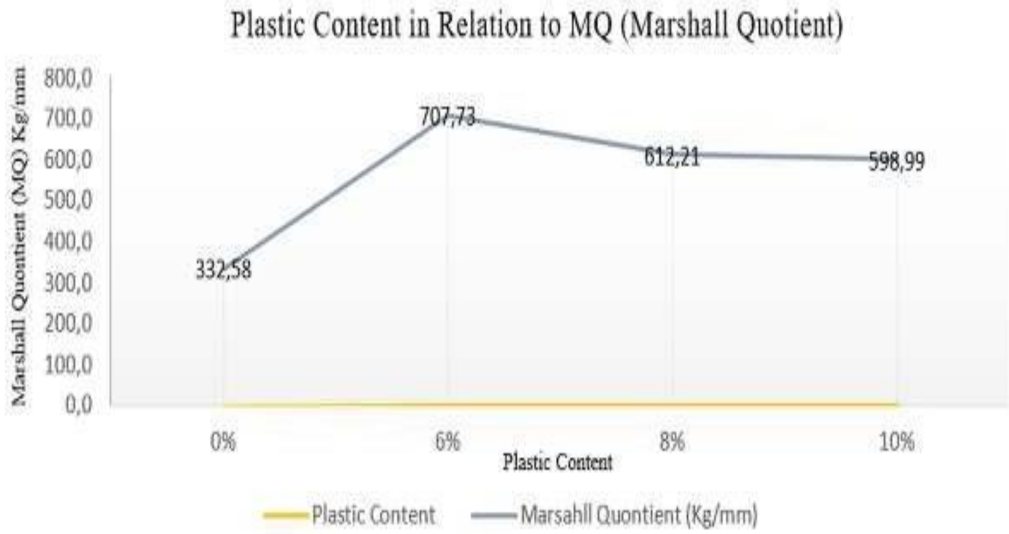

Figure 2. Marshall Charts 0%, 6%, 8% and 10%

In **Figure 2,** the graph shows that the Marshall Quotient (MQ) value decreases as the plastic content in the asphalt mixture increases. At a plastic content of 6%, the MQ value is the highest, at 707.73 kg/mm, indicating optimal stiffness and stability of the mixture. When the plastic content increases to 8%, the MQ value decreases to 612.21 kg/mm, suggesting that the mixture begins to exhibit greater plasticity and a slight reduction in stiffness. At 10% plastic content, the MQ value further decreases to 598.99 kg/mm, indicating that the mixture becomes softer and more vulnerable to deformation under traffic loads. Overall, the increase in plastic content leads to a reduction in MQ values because excessive plastic reduces the bonding quality between asphalt and aggregates. Thus, the optimum MQ value is obtained at 6% plastic content, where the balance between strength and flexibility is still well maintained.

The asphalt concrete mixture modified with AirUM plastic at concentrations of 6–8% demonstrates the best performance in resisting traffic loads and flexural stress. The high stability and Marshall Quotient (MQ) values indicate the mixture's ability to withstand compressive stress, shear forces, and plastic deformation. At these levels, the combination of PET and HDPE strengthens the link between aggregate and asphalt, raises the rigidity modulus, and improves resistance to deformation. The pavement can withstand rutting and cracking brought on by repeated pressure on road surfaces because the 6% plastic content provides the best balance between rigidity and flexibility. These findings are consistent with the study by (Jexembayeva et al., 2024) which reported that modifying asphalt with a combination of PET and HDPE increases the stiffness modulus by up to 35% and extends the fatigue life of asphalt mixtures by 28%.

Similarly, found that the incorporation of plastic waste into AC-WC mixtures enhances resistance to permanent deformation by up to 25% compared to conventional mixtures. Therefore, it can be concluded that the AirUM plastic-modified asphalt concrete mixture at 6–8% plastic content exhibits high structural durability and flexural strength, making it suitable for application as a surface layer (wearing course) under heavy traffic conditions and tropical climate environments. The findings of this study are consistent with results reported in several previous studies, including the study by (Mukhlis et al., 2022) that found that the use of HDPE and PET plastic waste at levels of 6–8% increased the stability of the asphalt mixture by up to 30%, while levels above 10% resulted in excessive flow values and reduced mixture stiffness. Next, (Hafidz et al., 2025) reported that the addition of PET plastic in AC-WC mixtures improved the compressive strength and aggregate adhesion by 40.85%, with an optimum plastic content of 6% to maintain balanced mechanical performance. Last the study by (Hasrullah et al., 2023) states that plastic-modified asphalt mixes show the best performance at a plastic content of 6%, with an increase in Marshall Quotient (MQ) and producing a more stable pavement with asphalt savings of 3.47% and cost savings of 5% per m3 from the budget.

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Based on these studies, it can be concluded that the results of the present research reinforce the existing findings, indicating that the optimum plastic content lies within the range of 6–8%. At this level, all Marshall parameters still comply with Bina Marga 2018 specifications, and the mechanical performance of the asphalt concrete mixture is enhanced effectively.

4. CONCLUSION

The findings indicate that incorporating AirUM plastic bottle waste, composed of PET and HDPE, enhances the performance of AC-WC mixtures. The optimal content is within 6–8%, where the mixture exhibits a balanced level of stability, flexibility, and resistance to deformation, meeting Bina Marga standards. A key contribution of this study is the systematic assessment of combined PET–HDPE derived from a single, consistent waste source, offering deeper insight into their interaction within asphalt mixtures—an area that remains underexplored in existing research. The results confirm that this material combination can act as an effective modifier without compromising volumetric properties. From a practical perspective, the study proposes an applicable substitution range for pavements with low to moderate traffic and presents a replicable model for utilizing plastic waste in road construction. This approach supports sustainable infrastructure development, circular economy implementation, and Green Campus initiatives aligned with SDG 12.

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