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# Performance Evaluation of Low-Density Polyethylene Food Packaging Waste as a Modifier in Performance Grade 70 Porous Asphalt Mixtures

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**ABSTRACT:** Plastic waste, especially Low-Density Polyethylene (LDPE) from food packaging, poses significant environmental challenges due to its non-biodegradable nature and increasing accumulation. In road engineering, porous asphalt is known for its good drainage properties but has lower stability compared to conventional asphalt. This study evaluates the characteristics of porous asphalt mixtures modified with LDPE food packaging waste as a partial substitute for Performance Grade (PG) 70 asphalt. LDPE waste was sourced from the Pasar Pahing Rungkut Temporary Waste Disposal Site in Surabaya, processed, and incorporated into asphalt mixtures at 3%, 4%, and 5% of total weight. The Australian Asphalt Pavement Association was used as a guideline, and the optimum asphalt content (OAC) was determined to be 4.72%. Laboratory tests included Marshall stability, flow, Marshall Quotient (MQ), permeability, and volumetric properties (Voids in Mixture, Voids in Mineral Aggregate, and Voids Filled with Asphalt). The 5% LDPE mixture showed the best performance, with stability reaching 1101.1 kg, MQ of 930.5 kg/mm, and Voids in Mineral Aggregate (VMA) of 54.9%. All mixtures met Australian Asphalt Pavement Association (AAPA) permeability requirements, and the use of LDPE improved mechanical strength without compromising drainage properties. LDPE food packaging waste has potential as an eco-friendly modifier in porous asphalt, enhancing its stability and technical performance while contributing to sustainable waste management.

**KEYWORDS:** Porous asphalt; LDPE waste; PG 70 asphalt; marshall stability; AAPA 2004

## 1. Introduction

Plastic waste pollution has become a pressing environmental issue worldwide, especially in rapidly developing countries like Indonesia. Among the various types of plastic waste, LDPE, commonly used in food packaging, poses a severe threat due to its high production volume and resistance to natural degradation [1]. LDPE contributes significantly to land and water pollution, leading to long-term environmental and public health consequences if left untreated

[2]. Despite the growing awareness of plastic waste hazards, efficient and sustainable recycling or reuse strategies remain inadequate [3].

In the construction sector, particularly in pavement engineering, the need for sustainable practices has prompted researchers to explore the incorporation of recycled waste materials into road infrastructure [4]. Porous asphalt, designed with an open-graded aggregate structure to enhance surface drainage, is increasingly used in modern roadways to mitigate surface runoff and improve driving safety [5−11]. However, this material is challenged by lower mechanical stability compared to dense-graded asphalt mixtures [12], and the inherent porosity of its structure renders it vulnerable to distresses such as raveling and deformation under load, limiting its long-term performance [13, 14].

Given the challenges of LDPE plastic waste accumulation and the need to improve porous asphalt stability, the incorporation of LDPE waste as a binder modifier presents a promising alternative [6]. Previous studies have demonstrated the potential of various types of plastic waste, including PET and HDPE, to improve the mechanical properties of asphalt mixtures [5, 7]. However, the use of LDPE food packaging waste specifically in porous asphalt using a PG 70 binder remains limited in the literature [8, 9]. This highlights a gap in current research, particularly regarding the performance evaluation of LDPE-modified porous asphalt under tropical conditions [10].

The urgency of this research lies in the dual benefit it offers: providing an environmentally responsible solution for LDPE waste recycling while enhancing the performance characteristics of porous asphalt [2]. From a sustainability perspective, repurposing LDPE waste into asphalt mixtures supports circular economy practices and aligns with global efforts to reduce plastic pollution [15]. Technically, the use of LDPE as a polymer modifier could potentially increase the stiffness and stability of porous asphalt, thereby extending its service life without compromising drainage capacity [16–18].

This study aims to evaluate the performance of PG 70 porous asphalt mixtures modified with LDPE food packaging waste at different addition levels (3%, 4%, and 5%). The novelty of this research lies in the combination of LDPE food waste with performance-grade asphalt and its application in porous mixture design under Indonesian climatic conditions. The investigation was conducted based on the guidelines of the Australian Asphalt Pavement Association (AAPA, 2004), assessing key parameters such as Marshall stability, flow, MQ, permeability, and volumetric properties (Voids in Mixture, VMA, VFWA). The results of this study are expected to contribute scientific evidence to support the integration of LDPE waste management with sustainable pavement design and policy in Indonesia.

## 2. Materials and Methods

This study employed an experimental approach to evaluate the performance of porous asphalt mixtures modified with LDPE food packaging waste. The materials and testing procedures adopted in this investigation are summarized in Figure 1, which presents a flowchart of the porous asphalt testing process.

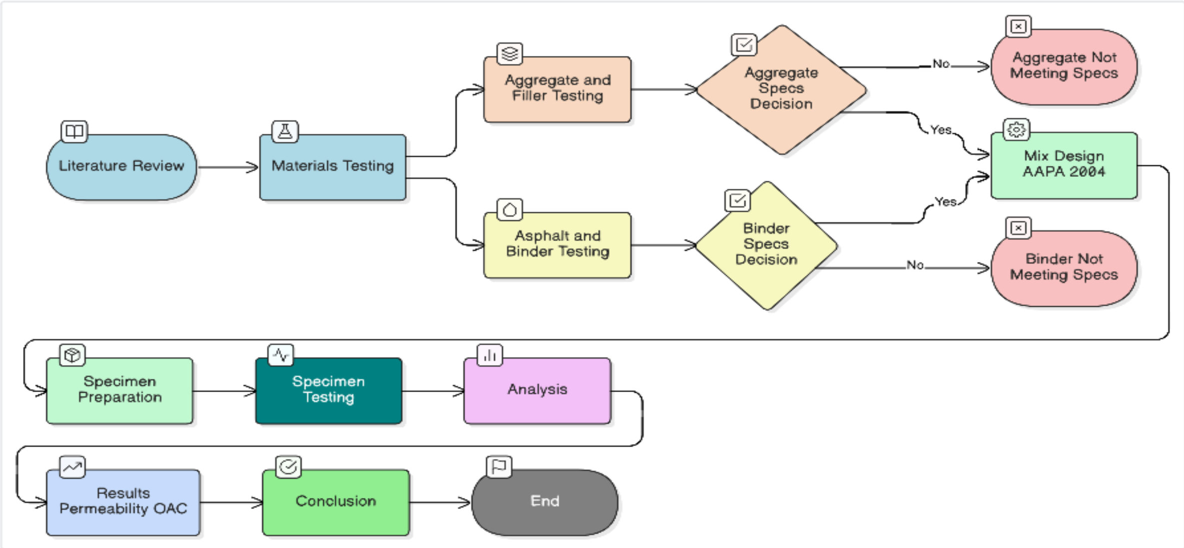


**Figure 1.** flowchart of the porous asphalt testing process.

*2.1.Materials.*

The primary materials used in this study included PG 70 asphalt binder, LDPE waste, and aggregates conforming to the open-graded requirements of porous asphalt as specified by the Australian Asphalt Pavement Association (AAPA, 2004) guidelines. PG 70 asphalt was selected due to its superior resistance to deformation under high temperatures, making it suitable for application in tropical climates [16]. LDPE waste was sourced from the temporary waste disposal site at Pasar Pahing Rungkut in Surabaya, Indonesia. The plastic packaging waste was carefully sorted, cleaned, and shredded into small, manageable pieces prior to incorporation into the asphalt mixture [8]. Coarse and fine aggregates, as well as mineral filler, were prepared and blended to achieve the target gradation following porous asphalt specifications [18].

*2.2. Mix design procedure.*

The mix design process began with determining the gradation of aggregates through trial blending, ensuring that the resulting blend fell within the specified limits for porous asphalt mixtures [11]. The OAC was determined through a series of preliminary tests, including Cantabro Loss (CL), Voids in Mixture (VIM), and Asphalt Flow Down (AFD) tests [19, 20]. Based on these results, the OAC was established at 4.72%. LDPE was then incorporated into the asphalt mixture at three different proportions, namely 3%, 4%, and 5% by total weight of the mix.

*2.3. Specimen preparation.*

The mixing procedure involved heating the aggregates to the required mixing temperature, followed by combining them with hot asphalt binder and LDPE to ensure homogeneous distribution. Each mixture was then compacted into cylindrical specimens using a Marshall compactor in accordance with ASTM D1559 standards [21–25]. For each LDPE content variation (0%, 3%, 4%, and 5%), twelve Marshall specimens were prepared and tested (n = 12).

*2.4. Testing methods.*

The compacted samples underwent several laboratory tests, including Marshall stability and flow tests to determine load resistance and deformation characteristics [17]. The MQ, calculated as the ratio of stability to flow, was used as an indicator of mixture stiffness [19]. Additional evaluations included permeability testing to assess drainage capability and volumetric calculations such as VIM, VMA, and VFWA [21].

*2.5. Data analysis.*

The experimental data obtained from laboratory testing were analyzed using both descriptive and inferential statistical methods to evaluate the effect of LDPE content on the performance of porous asphalt mixtures. For each mixture variation, twelve replicate specimens ($n = 12$) were tested, and the results are reported as mean values with standard deviations. Descriptive statistics were used to summarize key performance indicators, including Marshall stability, flow, MQ, permeability, and volumetric properties (VIM, VMA, and VFWA). To assess whether the differences in performance among mixtures with different LDPE contents were statistically significant, a one-way analysis of variance (ANOVA) was conducted at a 95% confidence level ($\alpha = 0.05$). The ANOVA test was applied to critical mechanical parameters such as Marshall stability, flow, and Marshall Quotient, as these properties are commonly used to evaluate the structural performance of porous asphalt mixtures. All statistical analyses were performed to justify performance comparisons among the control mixture and LDPE-modified mixtures and to support the interpretation of experimental trends. The analytical results were subsequently compared with the specification limits provided by the AAPA (2004), allowing the identification of the optimal LDPE content for porous asphalt mixture performance. This methodological approach is commonly adopted in laboratory-scale asphalt mixture evaluation studies [22–24].

## 3. Results and Discussion

*3.1. Material characterization results.*

The laboratory investigation began with a series of basic material property tests to ensure that the aggregates and asphalt binder used in the porous asphalt mixture met the required technical specifications. Coarse aggregate tests focused on abrasion resistance, specific gravity, and water absorption. The results presented in Table 1 indicate that the coarse aggregates exhibited adequate mechanical strength and low water absorption values, conforming to AAPA (2004) requirements, and were therefore suitable for porous asphalt applications. Fine aggregates were evaluated in terms of gradation, sand equivalent, and cleanliness.

**Table 1**. Coarse aggregate test results.

| No. | Test Item | Test Method | Unit | Specification | Result | Remarks |
|---|---|---|---|---|---|---|
| 1 | Sieve Analysis (5–10 mm) | SNI ASTM C136-2012 | % | < 1 | 0.93 | Yes |
| 2 | Sieve Analysis (10–15 mm) | SNI ASTM C136-2012 | % | < 1 | 0.94 | Yes |
| 3 | Bulk Specific Gravity | SNI 1969-2016 | gr/cm³ | > 2.5 | 4.28 | Yes |
| 4 | SSD Specific Gravity | SNI 1969-2016 | gr/cm³ | > 2.5 | 4.34 | Yes |
| 5 | Apparent Specific Gravity | SNI 1969-2016 | gr/cm³ | > 2.5 | 4.59 | Yes |
| 6 | Water Absorption | SNI 1969-2016 | % | < 3.0 | 1.43 | Yes |
| 7 | Los Angeles Abrasion | SNI 2417-2008 | % | < 40 | 35.45 | Yes |
| 8 | Aggregate Adhesion | SNI 2439-2011 | % | > 95 | 96.01 | Yes |

As shown in Table 2, all measured parameters satisfied the relevant specifications. The mineral filler test results, summarized in Table 3, showed acceptable fineness and specific gravity, confirming its effectiveness in filling voids and enhancing aggregate–binder adhesion.

**Table 2**. Fine aggregate test results.

| No. | Test Item | Test Method | Unit | Specification | Result | Remarks |
|---|---|---|---|---|---|---|
| 1 | Sieve Analysis | SNI ASTM C136-2012 | % | < 10 | 5.5 | Yes |
| 2 | Bulk Specific Gravity | SNI 1970-2016 | gr/cm³ | > 2.5 | 2.6 | Yes |
| 3 | SSD Specific Gravity | SNI 1970-2016 | gr/cm³ | > 2.5 | 2.63 | Yes |
| 4 | Apparent Specific Gravity | SNI 1970-2016 | gr/cm³ | > 2.5 | 2.67 | Yes |
| 5 | Water Absorption | SNI 1970-2016 | % | < 3.0 | 0.97 | Yes |

**Table 3**. Filler material test results.

| No. | Test Item | Test Method | Unit | Specification | Result | Remarks |
|---|---|---|---|---|---|---|
| 1 | Sieve Analysis | SNI ASTM C136-2012 | % | > 75 | 9.56 | Yes |
| 2 | Specific Gravity | SNI 1970-2016 | gr/cm³ | > 2.5 | 3.08 | Yes |

*3.2. Asphalt binder properties and aggregate gradation.*

The asphalt binder used in this study was PG 70. Its physical properties, including penetration, softening point, ductility, and flash point, were evaluated and are presented in Table 4. The results demonstrate that the binder met national and international specifications for porous asphalt applications, ensuring its suitability for use in the mixture. Aggregate blending was subsequently conducted to achieve a gradation within the recommended limits for porous asphalt as specified by AAPA (2004). The final combined gradation curve is illustrated in Figure 2, showing that the aggregate blend fell within both the lower and upper boundary limits, thereby ensuring an appropriate balance between permeability and mechanical strength.

**Table 4**. PG 70 asphalt binder test results.

| No. | Test Item | Test Method | Unit | Specification | Result | Remarks |
|---|---|---|---|---|---|---|
| 1 | Penetration | SNI 2456-2011 | 0.1 mm | ≥ 54 | 79 | Yes |
| 2 | Specific Gravity | SNI 2441-2011 | gr/cm³ | - | 1.09 | Yes |
| 3 | Flash Point | SNI 2433-2011 | °C | ≥ 230 | 348 | Yes |
| 4 | Softening Point | SNI 2432-2011 | °C | ≥ 54 | 57 | Yes |

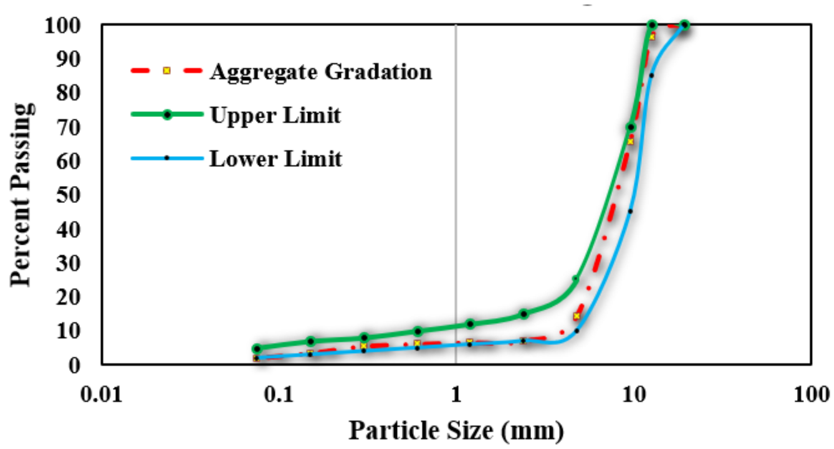


**Figure 2.** Aggregate gradation for porous asphalt.

*3.3.OAC Determination.*

Following the establishment of a suitable aggregate gradation, the design asphalt content was selected. Initial estimates were calculated based on AAPA recommendations, and five asphalt content variations were trialed. The mid-values of these variations are presented in Table 5. The average binder content was calculated as 4.92% and subsequently rounded to 5% for further evaluation. The OAC was determined using key performance criteria, namely VIM, CL, and AFD. As shown in Table 6, the upper limit of the OAC was governed by the CL requirement at 4.16%, while the lower limit was controlled by the VIM requirement at 4.87%. By averaging these values and applying AFD considerations, the final OAC was established at 4.72%.

**Table 5**. Mid values of asphalt content variations.

| Component | Percentage (%) |
|---|---|
| Coarse Aggregate (CA) | 0.72 |
| Medium Aggregate (MA) | 0.22 |
| Fine Aggregate (FA) | 0.05 |
| Filler (FF) | 0.01 |
| Calculated Binder Content (Pb) | 4.92% (rounded to 5%) |

**Table 6**. OAC determination test results.

| No. | Parameter | Value/Limit |
|---|---|---|
| 1 | CL (%) | ≤ 35 |
| 2 | AFD (%) | ≤ 0.3 |
| 3 | Marshall Stiffness (kg/mm) | ≤ 400 |
| 4 | Marshall Stability (kg) | ≥ 500 |
| 5 | VIM (%) | 18 – 25 |
| 6 | Number of Blows | 50 |
| | Calculated OAC (Average) | 4.72% |

*3.4. Marshall properties of ldpe-modified porous asphalt.*

Marshall tests were conducted on porous asphalt mixtures containing LDPE waste at three different contents: 3%, 4%, and 5% by weight of asphalt binder. For each LDPE content variation, twelve Marshall specimens were tested, and the results are reported as mean values. The test results are summarized in Table 7. The mixture with 3% LDPE exhibited a Marshall stability of 864.0 kg, a flow value of 1.3 mm, and a MQ of 716.7 kg/mm. Increasing the LDPE content to 4% resulted in a slight decrease in stability to 831.9 kg and an increase in flow to 1.5 mm, leading to a reduced MQ of 561.5 kg/mm. A one-way analysis of variance (ANOVA) indicates that LDPE content has a statistically significant effect on Marshall stability and MQ values ($p < 0.05$), confirming that the observed performance differences among mixtures are not caused by random variation. In contrast, the mixture containing 5% LDPE demonstrated a significant improvement in mechanical performance, with Marshall stability reaching 1101.1 kg and the MQ increasing to 930.5 kg/mm. This behavior indicates enhanced load-bearing capacity and resistance to deformation at higher LDPE content, which is consistent with previous findings reported for LDPE-modified porous asphalt mixtures [6, 8, 17].

**Table 7**. Marshall test results at oac with ldpe waste additions.

| Parameter | 0% LDPE | 3% LDPE | 4% LDPE | 5% LDPE |
|---|---|---|---|---|
| MQ (kg/mm) | 400.7 | 716.7 | 561.5 | 930.5 |
| VMA (%) | 51.5 | 51.9 | 51.4 | 54.9 |
| VIM (%) | 18.3 | 19.4 | 19.9 | 21.4 |
| VFWA (%) | 64.4 | 62.5 | 61.2 | 60.8 |
| Stability (kg) | 771.6 | 864 | 831.9 | 1101.1 |
| Flow (mm) | 1.9 | 1.3 | 1.5 | 1.3 |

Values represent the mean of twelve Marshall specimens (n = 12)

*3.5. Volumetric properties.*

The volumetric characteristics of the LDPE-modified porous asphalt mixtures were evaluated using Voids in Mineral Aggregate (VMA), VIM, and Voids Filled with Asphalt (VFWA), as presented in Table 7. The mixture containing 5% LDPE exhibited the highest VMA value of 54.9%, indicating improved aggregate structure and enhanced binder retention. The VIM value of 21.4% obtained for the 5% LDPE mixture falls within the acceptable range for porous asphalt, ensuring sufficient interconnected voids to maintain permeability. Additionally, the VFWA value of 60.8% suggests adequate asphalt coating without excessive binder content. These results indicate that the incorporation of LDPE does not adversely affect the porous structure of the mixture, which is consistent with findings reported in previous studies on plastic-modified porous asphalt mixtures [11, 16].

*3.6. Overall performance evaluation.*

Overall, the results demonstrate that LDPE food packaging waste is a viable eco-friendly modifier for PG 70 porous asphalt mixtures. The incorporation of LDPE, particularly at a content of 5%, significantly enhanced mechanical properties such as Marshall stability and stiffness while maintaining the porous structure required for effective surface drainage. These findings align with recent studies highlighting the potential of recycled plastic waste to improve asphalt mixture performance while supporting sustainable infrastructure development and plastic waste reduction strategies [1, 5, 10].

*3.7. Comparison with previous studies.*

The performance trends observed in this study are consistent with findings reported in previous research on plastic-modified porous asphalt mixtures. Several studies have shown that the incorporation of LDPE or other thermoplastic wastes can improve Marshall stability and mixture stiffness due to enhanced binder rigidity and improved aggregate–binder interaction [8, 17]. Research involving other plastic modifiers, such as HDPE and PET, has also demonstrated comparable improvements in MQ and stability values, although excessive plastic content may negatively affect workability and permeability [6, 9, 25]. In the present study, the mixture containing 5% LDPE achieved higher Marshall stability and MQ values while maintaining volumetric properties within the acceptable porous asphalt range. This indicates that the selected LDPE content provides a balanced performance in terms of mechanical strength and drainage capability when compared with previously published results.

## 4. Conclusions

This study evaluated the performance of porous asphalt mixtures modified with LDPE food packaging waste using a PG 70 asphalt binder, based on laboratory testing in accordance with AAPA (2004) guidelines. The conclusions presented in this section are strictly derived from the experimental results obtained in this study.The OAC for the porous asphalt mixture was determined to be 4.72%, based on Cantabro Loss, Voids in Mix, and Asphalt Flow Down criteria. This OAC provided a suitable balance between mechanical stability and volumetric characteristics required for porous asphalt applications. The incorporation of LDPE waste significantly influenced the mechanical performance of the porous asphalt mixtures. Among the evaluated LDPE contents (3%, 4%, and 5% by weight of asphalt binder), the mixture containing 5% LDPE exhibited the highest Marshall stability (1101.1 kg) and MQ (930.5 kg/mm), indicating improved load-bearing capacity and stiffness compared to mixtures with lower LDPE contents and the control mixture. The volumetric properties of the LDPE-modified mixtures remained within the acceptable range for porous asphalt. The mixture with 5% LDPE demonstrated the highest VMA (54.9%) while maintaining Voids in Mix at 21.4%, confirming that the enhancement in mechanical performance did not compromise the porous structure required for drainage functionality. Based on the laboratory results obtained, LDPE food packaging waste shows potential for use as a modifier in PG 70 porous asphalt mixtures, particularly at a content of 5%. However, the findings of this study are limited to laboratory-scale evaluation. Further research is recommended to investigate long-term field performance, durability, and environmental impacts under actual traffic loading and climatic conditions.

## Competing Interest

All authors should disclose any financial, personal, or professional relationships that might influence or appear to influence their research.

## Author Contributions

Mochamad Indra Ramadhan: Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Writing—Original Draft. Aditya Rizkiardi: Validation, Software, Visualization, Writing—Review & Editing. Nurani Hartatik: Supervision, Project Administration, Funding Acquisition, Writing—Review & Editing, Correspondence. Siti Sekar Gondoarum: Resources, Data Collection, Technical Support, Validation.

## Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Raw data, including laboratory test results and material properties, have been securely archived and can be provided for verification or further research purposes.

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