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PENGARUH BENTUK PLASTIK UNTUK MENINGKATKAN KINERJA CAMPURAN BERASPAL

THE EFFECT OF PLASTIC SHAPE IN IMPROVING ASPHALT MIXTURE PERFORMANCE

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Abstrak— Indonesia salah satu dari delapan negara penghasil limbah plastik terbesar di dunia mencapai 3,4 juta ton per tahun. Sebagian besar limbah ini belum dimanfaatkan secara optimal dan berakhir di tempat pembuangan akhir. Salah satu solusi potensial adalah memanfaatkan limbah plastik dalam campuran aspal untuk meningkatkan kinerja jalan. Metode ini tidak hanya mengurangi akumulasi limbah plastik, tetapi juga meningkatkan daya tahan dan ketahanan jalan terhadap retak. Penelitian ini mengkaji pengaruh berbagai bentuk plastik LDPE—pelet, cacahan, dan serbuk terhadap kinerja aspal pada kadar plastik optimal. Metode pencampuran kering dipilih karena mudah diterapkan di lapangan, yakni dengan menambahkan plastik ke agregat panas sebelum dicampur dengan aspal panas. Aspal dengan 5% bahan pengikat dimodifikasi menggunakan pelet LDPE dengan kadar 3%, 5%, 7%, dan 9%. Setelah kadar plastik optimum didapatkan 9%, selanjutnya melakukan modifikasi campuran aspal dengan LDPE cacahan dan serbuk. Hasil uji Marshall menunjukkan bahwa meskipun tidak ada perbedaan signifikan dalam stabilitas antar bentuk plastik, pelet LDPE memberikan stabilitas tertinggi, meningkatkan stabilitas aspal konvensional hingga 20% pada kadar 5% bahan pengikat. Campuran pelet LDPE menunjukkan nilai flow tertinggi, meningkat 0,18 mm. Hasil ini menunjukkan bahwa penggunaan pelet LDPE membuat aspal lebih tahan retak.

Kata kunci— Bentuk Plastik, Modifikasi Aspal, Metode Pencampuran Kering.

Abstract— Indonesia is one of the eight largest plastic waste-producing countries, generating 3.4 million tons annually. Most of this waste remains underutilized and ends up in landfills. A potential solution is incorporating plastic waste into asphalt mixtures to enhance road performance. This method not only reduces plastic waste accumulation but also improves road durability and crack resistance. This study examines the effects of different LDPE plastic forms pellets, shredded, and powder on asphalt performance under optimal plastic content. The dry mixing method was chosen for its ease of field application, where plastic is added to hot aggregates before mixing with hot asphalt. Asphalt with 5% binder was modified using LDPE pellets at 3%, 5%, 7%, and 9%. After determining the optimal plastic content at 9%, further modifications were conducted using shredded and powdered LDPE. Marshall test results showed no significant stability differences among the plastic forms, but LDPE pellets achieved the highest stability, increasing conventional asphalt stability by up to 20% at 5% binder content. The highest flow was also observed in the LDPE pellet mixture, increasing by 0.18 mm. These findings suggest that using LDPE pellets enhances asphalt crack resistance.

Keywords— Asphalt Modification, Dry Mixing Method, Plastic Shape.

I. INTRODUCTION

One of the most pressing environmental challenges today is the increasing volume of waste generated daily, particularly plastic waste, which has become a global concern. According to data from the World Population Review in 2024 [1], the five countries contributing the most to ocean plastic pollution in 2021 were all in Asia. The Philippines ranked first with 356,371 tons of plastic waste, followed by India, Malaysia, China, and Indonesia, which placed fifth with 56,333 tons. Despite growing awareness of the plastic waste problem, recycling rates remain low due to the complexity of plastic compositions and the inefficiencies of mechanical recycling processes. Given the long decomposition time of plastic waste, efforts to mitigate its impact are essential, including strategies that enhance its value through reuse. One promising approach is the incorporation of plastic waste as an additive in asphalt mixtures.

II. LITERATURE REVIEW

The incorporation of plastic in asphalt mixtures has received increasing attention in recent years, driven by the dual need to reduce plastic waste and improve road infrastructure quality. Low-Density Polyethylene (LDPE), commonly found in plastic bag waste, is a thermoplastic material suitable for use in asphalt mixtures [2]. The long, flexible, and linear chains of polyethylene in LDPE enable it to withstand external pressure, potentially enhancing the stability and durability of asphalt mixtures [3]. However, the physical form of LDPE—such as pellets, shredded pieces, or powder—is believed to influence the performance of asphalt mixtures differently, which is the focus of this study.

Several studies have examined the impact of plastic on asphalt mixture performance. In Indonesia, research involving LDPE plastic bag waste has been implemented on various road segments, showing an increase in asphalt mixture stability by up to 40% with the use of 6% asphalt content and LDPE [4]. Bagampadde’s study found that LDPE plastic bags cut into small pieces (approximately 5 mm × 5 mm) can be effectively incorporated into asphalt mixtures [5]. The addition of oil as an additive further enhances the mixture's resistance to fatigue cracking [6]. Other studies have also demonstrated that plastic additives can increase stability and resistance to plastic deformation [7]. Furthermore, the inclusion of LDPE has been shown to raise the penetration grade of asphalt binders at high service temperatures due to increased stiffness, making LDPE-modified mixtures suitable for thick pavement layers in high-temperature climates to mitigate rutting [8].

Nonetheless, the effect of the size and shape of plastic on mixture homogeneity and stability remains a subject of debate. Most studies suggest that smaller plastic particles lead to more homogeneous and stable mixtures [9]. However, this study finds that LDPE in pellet form provides greater stability compared to shredded and powdered forms, suggesting that smaller particle size does not always yield better performance. For other types of plastic, such as High-Density Polyethylene (HDPE), Favian Gian’s research investigated the effect of plastic size on the Marshall characteristics of asphalt mixtures using the dry mixing method and found that 1 cm HDPE pieces yielded the highest stability. However, for LDPE, there is a lack of research specifically addressing how its physical form influences asphalt performance [10].

The gap in the existing literature lies in the absence of a comprehensive study comparing the performance of different physical forms of LDPE—pellets, shredded pieces, and powder—in asphalt mixtures, particularly in terms of stability and flow. Moreover, although several studies have addressed the use of plastics in asphalt, none have focused on how variations in LDPE physical form affect asphalt mixture performance in Indonesia at different concentrations.

This research seeks to explore the influence of LDPE's physical form on the stability and flow of asphalt mixtures by comparing the performance of pellets, shredded pieces, and powder at the optimum LDPE content. It is anticipated that this study will contribute meaningfully to the existing body of knowledge by offering new insights into the role of LDPE’s physical characteristics in asphalt applications. The findings may support the advancement of more environmentally sustainable road construction technologies through the effective utilization of plastic waste.

III. METHODS

A. *Material*

1) Asphalt

The asphalt used in this study is penetration grade 60/70. All asphalt testing procedures were conducted in accordance with the Technical Specifications of the Directorate General of Highways (Bina Marga), 2018 [11]. The results of the asphalt testing are presented in Table 1.

Table 1. Asphalt Testing Results

Testing	Method	Asphalt 60/70 Spec	Testing Result
Penetration, 25°C (0,1 mm)	SNI 06-2456-1991	60-70	63.70
Viscosity 135°C (cSt)	SNI 06-6441-2000	≥ 300	420
	Mixing Temperature		158
	Compaction Temperature		145

Testing	Method	Asphalt 60/70 Spec	Testing Result
Softening Point °C	SNI 06-2434-2011	≥ 48	51
Ductility, 25°C, (cm)	SNI-06-2432-2011	≥ 100	≥ 100
Fire point(°C)	SNI-06-2433-2011	≥ 232	334
Specific gravity	SNI-06-2441-2011	≥ 1,0	1.01
Weight Loss (with TFOT); % weight	SNI 06-2441-1991	≤ 0.8	0.25
Penetration After Heating; % of Original	SNI 06-2456-1991	≥ 54	62.1
Ductility After Heating; % of Original	SNI 06-2432-2011	≥ 100	≥ 100

2) Aggregat

The results of the aggregate testing are presented in Table 2. This study employed a continuous gradation, commonly referred to as Asphalt Concrete Wearing Course (AC-WC). Figure 1 displays the gradation curve, which confirms that the gradation is continuous and includes a full range of coarse, medium, and fine aggregates. This gradation results in strong particle interlocking, thereby producing stiffer and more stable pavement.

Table 2. Aggregate Testing Results.

No	Testing	Method	Standard Specification (%)	Testing Result (%)
1	Abrasion	SNI 2417:2008	Max 40	17.7
2	Elongation	BS 812 Part1: 1975	Max 25	13.55
3	Soundness	SNI 3407:2008	Max 12	0.18
4	Adhesion	SNI 2439:2011	Min 95	98
5	Aggregate Impact Value	BS 812-110:1990	Max 30	8.95

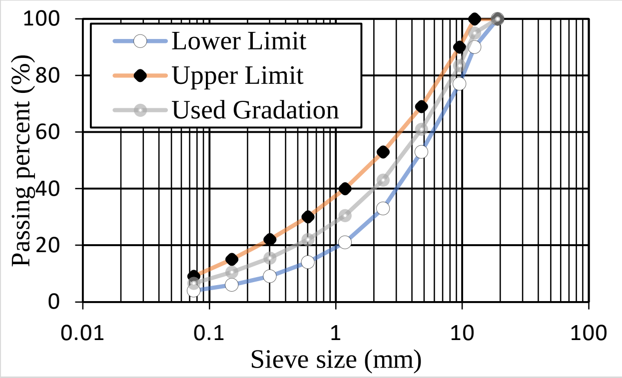

Figure 1. Aggregate Gradation with Gradation Limits

3) Plastic

The plastic used for asphalt substitution comprises three forms of Low-Density Polyethylene (LDPE): pellets, shredded plastic, and powder. These various forms were incorporated into the asphalt mixture to enhance its performance, particularly in terms of durability, flexibility, and resistance to deformation. The variation in shape and size enables the evaluation of each form's influence on the mechanical properties and overall performance of the asphalt pavement.

B. Mixing Method

In preparing the Marshall specimens, the composition of the mixture was determined based on asphalt content. Multiple asphalt contents were tested using the Marshall Method in accordance with SNI 2489:2018 to identify the optimum asphalt content (OAC). The Marshall Test was conducted with six variations of asphalt content, increasing by 0.5% per increment, including at least two values below and above the estimated optimum. Asphalt contents tested included 4%, 4.5%, 5%, 5.5%, and 6%. The optimum asphalt content was determined through the analysis of Marshall characteristic curves, which included parameters such as Voids in Mineral Aggregate (VMA), Voids in Mixture (VIM), Voids Filled with Asphalt (VFA), Marshall Stability, and Marshall Flow [12]. These curves were analyzed using the Narrow Range method to determine the asphalt content that meets all specification criteria. Generally, a higher asphalt content improves stability by strengthening the bond between aggregates [13]. However, excessive asphalt may lead to saturation, which weakens aggregate interlocking and reduces stability [14]. Based on the narrow range analysis of the Marshall test results, the optimum asphalt content was determined to be 5%. This 5% asphalt content was then substituted with LDPE plastic.

The substitution of asphalt with plastic was based on the determined optimum asphalt content. LDPE was used at substitution rates of 0%, 3%, 5%, 7%, and 9% by weight of the asphalt. Initially, LDPE in pellet form was used across all percentages. Following the identification of the optimum LDPE content, further testing was conducted using shredded and powdered LDPE, following the same methodology.

There are two primary methods for incorporating plastic waste into asphalt mixtures: the wet mixing method and the dry mixing method [15]. In the wet mixing method, plastic waste is added directly to the asphalt binder as a modifier prior to blending with aggregates. In the dry mixing method, plastic waste is added to the heated aggregates before mixing with asphalt. The mixing temperature for each type of plastic varies, depending on its softening point, viscosity, and density [16]. Figure 2 illustrates the variation in temperature, mixing duration, and speed during the blending process of various types of polymers with asphalt using the wet mixing method. For example, polyethylene (PE) plastic is typically mixed at temperatures ranging from 150°C to 180°C, for durations between 3 minutes and 4 hours, and at speeds ranging from 120 to 7200 rpm. In this study, the dry mixing method was selected for its practicality and ease of field implementation, based on findings from previous research [17].

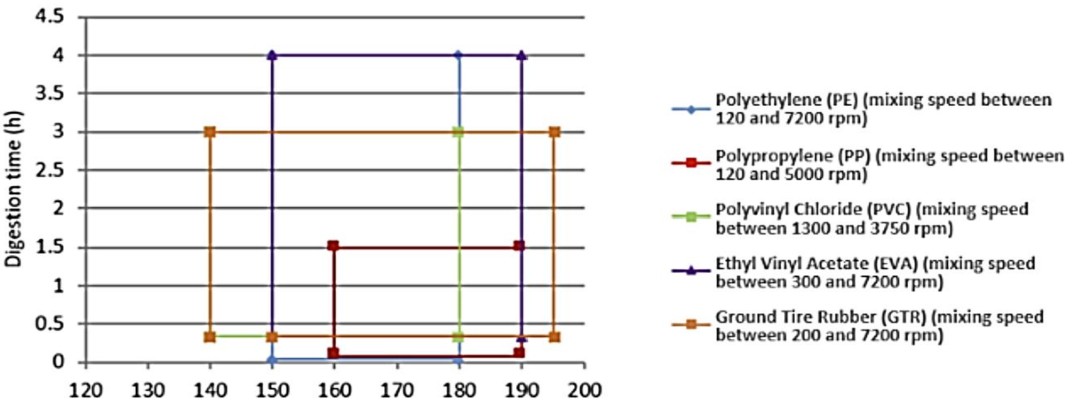

Figure-2. Variation of Temperature, Digestion Time, and Mixing Speed in the Polymer Blending Process [18]

1) Mixing Method for LDPE Pellets

In this experiment, only the dry mixing method was employed. The plastic pellets were initially heated together with the aggregates in an oven at 100°C for 30 minutes. Subsequently, the mixture was further heated until the temperature reached 170°C, at which point hot asphalt was added and the mixture was compacted. The detailed procedure for mixing LDPE pellets is illustrated in Figure 3.

 The aggregate and LDPE pellets are heated at 100°C for 30 minutes.	 The heated aggregate and LDPE pellet mixture is then transferred into a mixing pot and heated until the temperature reaches 170°C.	 Hot asphalt is added to the heated aggregate and LDPE pellet mixture and thoroughly mixed.	 Final Mixing

Figure 3. The process of mixing LDPE pellet plastic with aggregates and asphalt

2) Mixing Method for LDPE Powder

After determining the optimum LDPE content, further experimentation was conducted by grinding the LDPE pellets into powder using a grinder. The resulting LDPE powder had a particle size of less than 100 microns, as measured under a microscope (Figure 4).

Figure 4. Measurement of LDPE powder particle size.

The use of LDPE powder in asphalt mixtures is expected to enhance homogeneity. For practical application in the field, the dry mixing method was used, wherein the LDPE powder was first blended with hot aggregates before being combined with hot asphalt. The process of mixing LDPE powder with aggregates and asphalt at the optimum LDPE content of 9% is shown in Figure 5.

The aggregate and LDPE powder are heated at 100°C for 30 minutes.	The heated aggregate and LDPE powder mixture is then placed into a mixing pot and heated until the temperature reaches 170°C.	Hot asphalt is added to the heated aggregate and LDPE powder mixture and thoroughly mixed.	Final mixing.

Figure 5. The process of mixing LDPE powder with aggregates and asphalt at the optimum LDPE content of 9%

4) Mixing Method for LDPE Shredded from Plastic Bags

In Indonesia, research on asphalt modification using plastic bags was initiated by the Ministry of Public Works and Housing (PUPR), which demonstrated that such modification can enhance the stability of conventional asphalt and reduce rutting [4]. In this study, shredded LDPE plastic derived from plastic bags was also incorporated into the asphalt mixture. The plastic bags were shredded into smaller pieces using a blender to facilitate the mixing process (Figure 6).

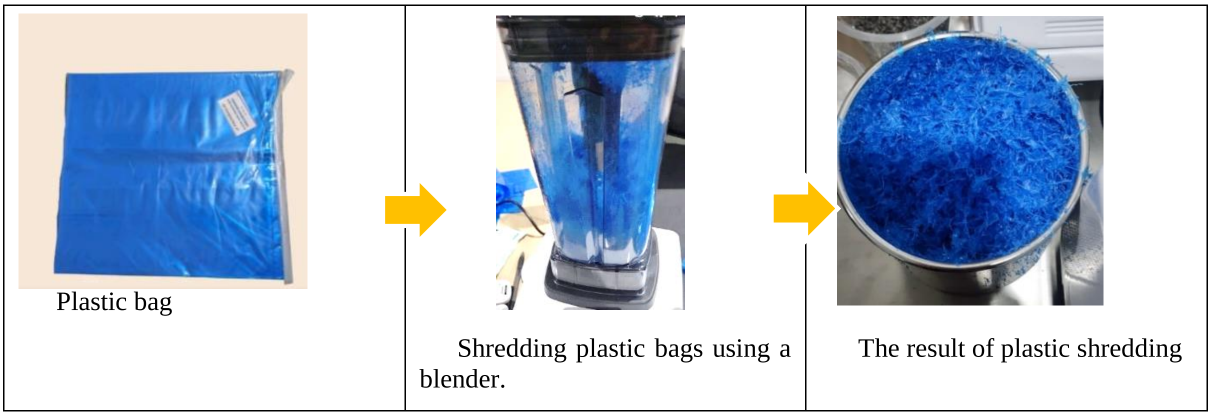

Figure 6. Shredding of plastic bags using a blender.

The dry mixing method was again applied, consistent with the procedures used for LDPE pellets and powder. The process of mixing shredded LDPE plastic with aggregates and asphalt is illustrated in Figure 7.

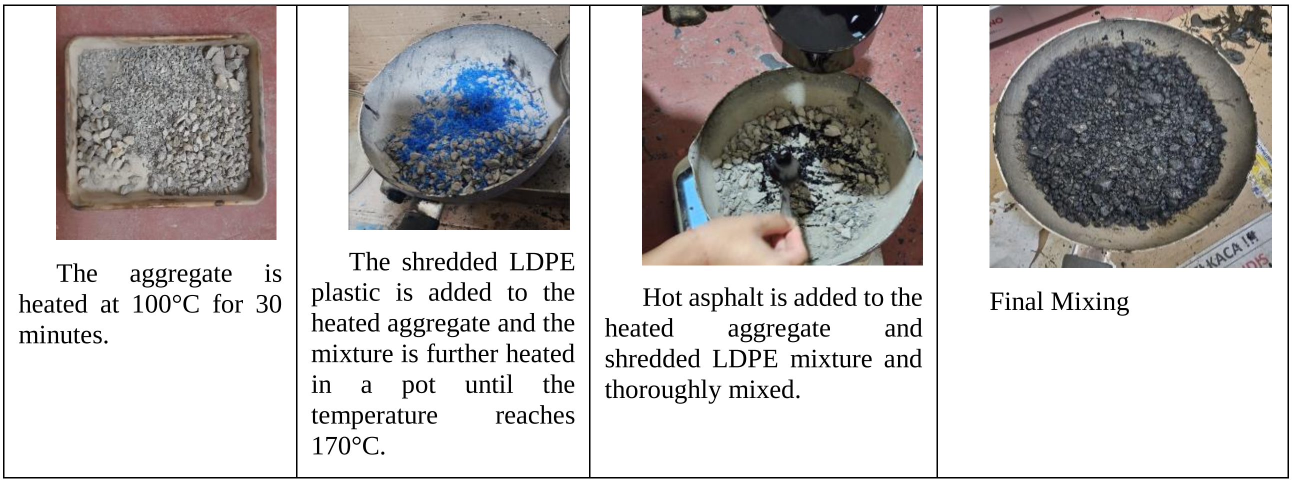

Figure-7. The mixing process of shredded LDPE plastic with aggregates and asphalt.

IV. RESULT AND DISCUSSIONS

Based on the Marshall test, the optimum asphalt content was determined to be 5%. This content was subsequently used for trial mixtures with LDPE pellets at substitution levels of 3%, 5%, 7%, and 9% by weight of the asphalt. The Marshall test results indicated that the highest stability was achieved at 9% LDPE content, with a stability value of 2123.02 kg (Table 3). Furthermore, all Marshall criteria—stability, flow, VIM (Voids in Mixture), MQ (Marshall Quotient), VMA (Voids in Mineral Aggregate), and VFA (Voids Filled with Asphalt)—met the standard requirements outlined in the 2018 Bina Marga Technical Specifications for the AC-WC mixture type.

Table-3. Marshall Test Results for 5% Asphalt Content with LDPE Addition

LDPE Content (%)	Stability (Kg) Min 800	Flow (mm) 2-4	VIM (%) 3-5	MQ (Kg/mm)	VMA (%) Min 15	VFA (%) 65-78
0%	1766.29	3.43	4.68	526.57	15.92	67.5
3%	1917.31	3.49	4.75	552.09	16.85	68.95
5%	1947.86	3.52	4.89	542.90	16.75	68.32
7%	2000.08	3.56	4.96	557.28	16.83	67.11
9%	2123.02	3.61	4.99	588.44	17.63	65.69

Table 3 presents the results of the Marshall Test at 5% asphalt content using LDPE pellets as a partial asphalt substitute with the dry mixing method. The maximum stability was observed at 9% LDPE content, reaching 2123.02 kg, which represents a 20% increase compared to conventional asphalt mixtures. Additionally, the data showed a consistent increase in flow with higher levels of LDPE substitution. At 9% substitution, the maximum flow was recorded at 3.61 mm, only 0.18 mm higher than that of the conventional mix. These findings align with previous studies indicating that the addition of LDPE enhances the stability of asphalt mixtures—up to 2.5 times higher—while also improving elasticity[19]. However, according to regulations from the Ministry of Public Works and Housing (PUPR), the maximum allowable plastic content in asphalt mixtures is 6%; exceeding this threshold requires additional oversight [20].

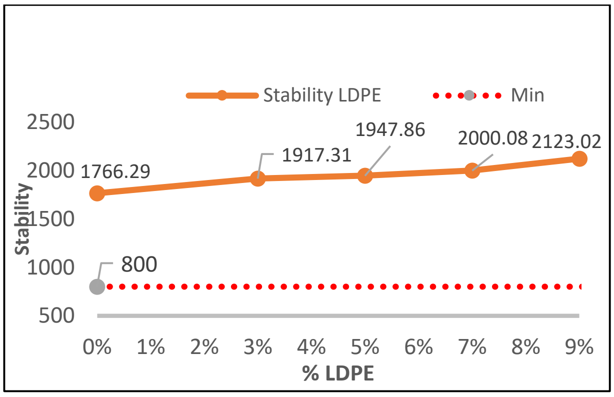

Figure-8. Stability with the addition of LDPE at 5% asphalt content.

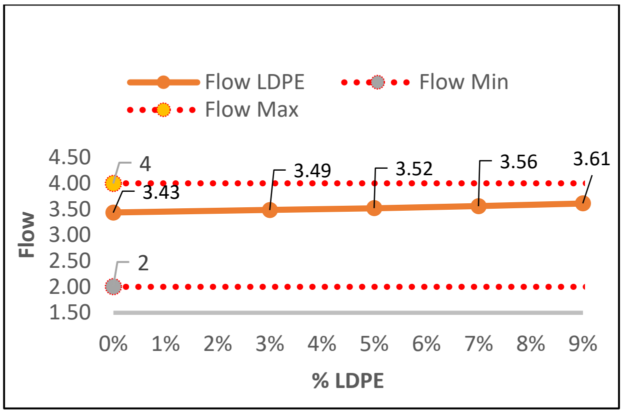

Figure-9. Flow with the addition LDPE at 5% asphalt content.

Following the identification of 9% as the optimum LDPE content, further experiments were conducted using smaller particle forms of LDPE (i.e., powder and shredded). The comparative results for stability and flow are shown in Figures 10 and 11. In general, the form of LDPE—whether pellets, shredded, or powder—did not significantly influence pavement stability. As shown in Figure 10, the highest stability was obtained with 9% LDPE pellets, reaching 2123.0 kg. Several factors contribute to this:

1. LDPE pellets have larger and more consistent particle sizes, allowing for more uniform dispersion within the asphalt mixture. Their form prevents premature clumping, promoting better interaction between LDPE and aggregates.
2. In pellet form, LDPE effectively fills voids between aggregates, resulting in a denser and more structurally robust mixture. Conversely, smaller particles (e.g., powder or shredded LDPE) may create more voids, potentially reducing overall stability.
3. LDPE pellets require longer exposure and higher temperatures to melt compared to finer forms. This delayed melting allows for a more gradual and controlled interaction with the aggregates, enhancing the mixture's structural integrity.
4. The larger particle size of LDPE pellets may also contribute to improved viscoelastic properties, increasing the stiffness of the asphalt mixture. In contrast, smaller particles are more prone to disintegration and displacement within the mixture.
5. For practical implementation, both shredded LDPE and pellets are preferable. LDPE powder, while potentially beneficial in laboratory settings, requires specialized equipment (e.g., grinders), increasing construction costs and complexity.

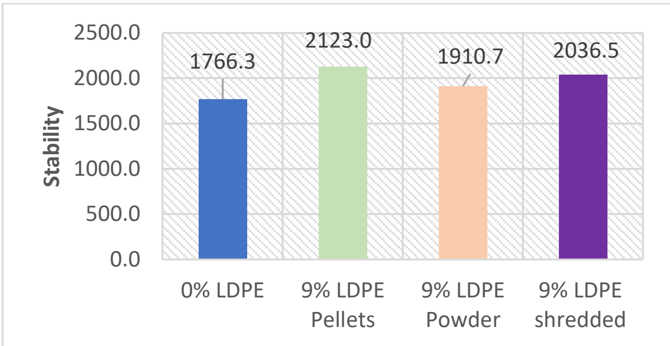

Figure-10. Comparison of Stability Between LDPE Pellets and LDPE Powder at 9% Content

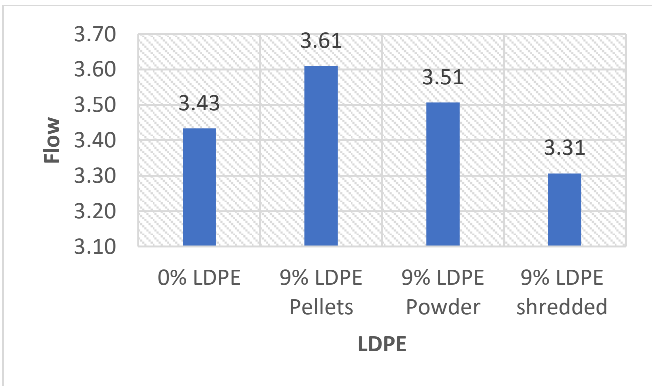

Figure 11. Comparison of Flow Between LDPE Pellets and LDPE Powder at 9% Content

The inclusion of LDPE in asphalt mixtures tends to increase the flow value. This improvement is attributed to enhanced crack resistance, which permits better deformation without compromising stability. Additionally, the reduction in mixture density due to the presence of LDPE creates more space for deformation, thereby increasing flow. Among the different forms of LDPE, pellets produced the highest flow value, due to several factors:

1. The larger size of LDPE pellets compared to powder or shredded forms results in more voids within the mixture, promoting greater deformation due to reduced structural rigidity.
2. Larger particles such as pellets are more difficult to blend uniformly, leading to reduced stiffness in the final mixture. Lower stiffness increases susceptibility to deformation, thereby increasing the flow.
3. LDPE pellets do not react with asphalt as efficiently as smaller particles. Finer particles possess a greater surface area, enabling better bonding with the asphalt matrix and minimizing deformation. Pellets, by contrast, tend to interact less uniformly.
4. LDPE powder has a greater capacity for homogeneous dispersion within the asphalt mixture, which contributes to enhanced structural cohesion. This improved distribution increases stability and reduces flow. In contrast, pellets, due to their size, may not distribute evenly, leading to increased susceptibility to deformation.

V. CONCLUSION

Indonesia is among the largest contributors to plastic waste globally. One innovative approach to mitigating this issue involves incorporating plastic waste into asphalt mixtures to enhance the mechanical properties of pavements, particularly in terms of durability and crack resistance. In this study, LDPE pellets were used as a partial asphalt substitute through the dry mixing method. At the optimum asphalt content of 5%, the optimal LDPE content was determined to be 9%. At this level, asphalt modification was also conducted using shredded and powdered forms of LDPE, resulting in improved pavement stability that exceeded the minimum requirement of 800 kg, as stipulated by Bina Marga. Among the three LDPE forms—pellets, shredded, and powder—the highest stability was achieved using LDPE pellets, with a 20% improvement over conventional asphalt. This finding is consistent with the flow results, which also showed greater increases with the use of LDPE pellets. The addition of LDPE increases the flow value, as its elastic properties enhance the flexibility of the asphalt mixture. As more LDPE is incorporated, the mixture becomes more deformable, leading to higher flow values. Further research comparing the effects of different plastic forms on asphalt performance, particularly through advanced tests such as fatigue testing, is strongly recommended to deepen understanding and improve practical applications.

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