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# Analysis of the Characteristics of AC-BC Mixtures Incorporating Extracted Asbuton Modified with Waste Engine Oil and Low-Density Polyethylene (LDPE) Using the Marshall Method

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**Abstract:** Asbuton is an abundant indigenous resource in Indonesia. However, its application in road construction remains limited due to its non-uniform physical properties. Variations in bitumen content, hardness, and mineral composition resulting from natural formation processes reduce its effectiveness as an asphalt binder. This study aimed to evaluate the mechanical and volumetric properties of Asphalt Concrete–Binder Course (AC-BC) mixtures incorporating extracted Asbuton modified with waste engine oil and Low-Density Polyethylene (LDPE) using the Marshall method. The test results showed that the extracted Asbuton did not satisfy the technical specifications and was therefore modified with 7% waste engine oil and LDPE contents of 0%, 0.5%, 1.0%, 1.5%, and 2.0%. The combination of 7% waste engine oil and 0.5% LDPE exhibited the best binder performance. Subsequently, the Optimum Asphalt Content (OAC) was determined through Marshall testing of AC-BC mixtures incorporating of 50% Modified Asbuton (MA) using 15 specimens. The determined OAC was then used to evaluate the properties of AC-BC mixtures with varying MA contents of 0%, 25%, 50%, 75%, and 100%, with 15 specimens prepared for each binder ratio. The results indicated that the mixture containing 50% MA exhibited the best overall mechanical and volumetric performance, achieving the highest stability and Marshall Quotient (MQ).

**Keywords:** LDPE; Marshall Method; Modified Asbuton; Waste Engine Oil

## Introduction

Road infrastructure development in Indonesia continues to expand in line with economic growth and increasing population mobility, leading to a growing demand for asphalt. However, the domestic production capacity of petroleum asphalt remains insufficient to meet national demand, highlighting the importance of utilizing locally available resources. One of the most promising indigenous resources is Buton asphalt (Asbuton), as Indonesia possesses abundant natural asphalt reserves on Buton Island with a high bitumen content (Pratama et al., 2022; Syahputra, 2019).

Numerous studies have demonstrated that semi-extracted, fully extracted, and modified Asbuton can be used as a binder in asphalt mixtures, improving mixture stability, rutting resistance, and pavement durability (Gusty et al., 2024; Irianto et al., 2020; Maha et al., 2024; Rahman et al., 2024; Sihombing et al., 2021). Nevertheless, the utilization of Asbuton remains constrained by the non-uniform quality of its bitumen, resulting from variations in bitumen content, hardness, and mineral composition (Arisona, 2021; Karyawan et al., 2023). In addition, its relatively stiff binder characteristics make asphalt mixtures more susceptible to cracking due to aging and repeated traffic loading (Abualia et al., 2024; Karakas, 2026; Safaei et al., 2016). Therefore, binder modification is required to achieve an appropriate balance between stiffness and flexibility.

Waste Engine Oil (WEO) has been widely investigated as a rejuvenator because it enhances binder flexibility while restoring and improving the properties

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of aged asphalt (Wildansyah, 2020; Yandes et al., 2021). Meanwhile, Low-Density Polyethylene (LDPE) has been extensively used as a modifier due to its ability to improve bitumen properties, Marshall stability, and the deformation resistance of asphalt mixtures (Afriyanto et al., 2019; Hidayati et al., 2021; Iqbal et al., 2024; Poudel et al., 2024; Singh & Gupta, 2024). The utilization of these two materials also contributes to more sustainable waste management practices (Aljarmouzi & Dong, 2022; Khan et al., 2016; White, 2020).

Previous studies have reported that modifying Asbuton with polymer additives and rejuvenators improves binder characteristics, while the application of modified Asbuton in Asphalt Concrete–Binder Course (AC-BC) mixtures produces Marshall properties that satisfy the required specifications (Agustin, 2023; Karyawan et al., 2023). Likewise, LDPE has been widely applied as an asphalt modifier and has demonstrated considerable potential for enhancing both binder properties and asphalt mixture performance (Ghani et al., 2022; Nisar et al., 2024). However, the application of LDPE in extracted Asbuton modified with waste engine oil for AC-BC mixtures has received limited attention.

Based on the foregoing, this study aims to evaluate the effects of extracted Asbuton modified with waste engine oil and LDPE on the volumetric and mechanical properties of AC-BC mixtures using the Marshall method and to determine the optimum proportion of modified Asbuton that provides the best overall mixture performance.

## Method

This study employed a laboratory experimental method to evaluate the characteristics of Asphalt Concrete–Binder Course (AC-BC) mixtures incorporating extracted Asbuton modified with Waste Engine Oil (WEO) and Low-Density Polyethylene (LDPE). The experimental program was conducted at the Transportation and Highway Engineering Laboratory, Faculty of Engineering, University of Mataram.

*Materials Preparation*

The initial stage of the study involved preparing all materials required for the production of modified Asbuton and AC-BC mixtures. The materials used in this study are presented in Figure 1.

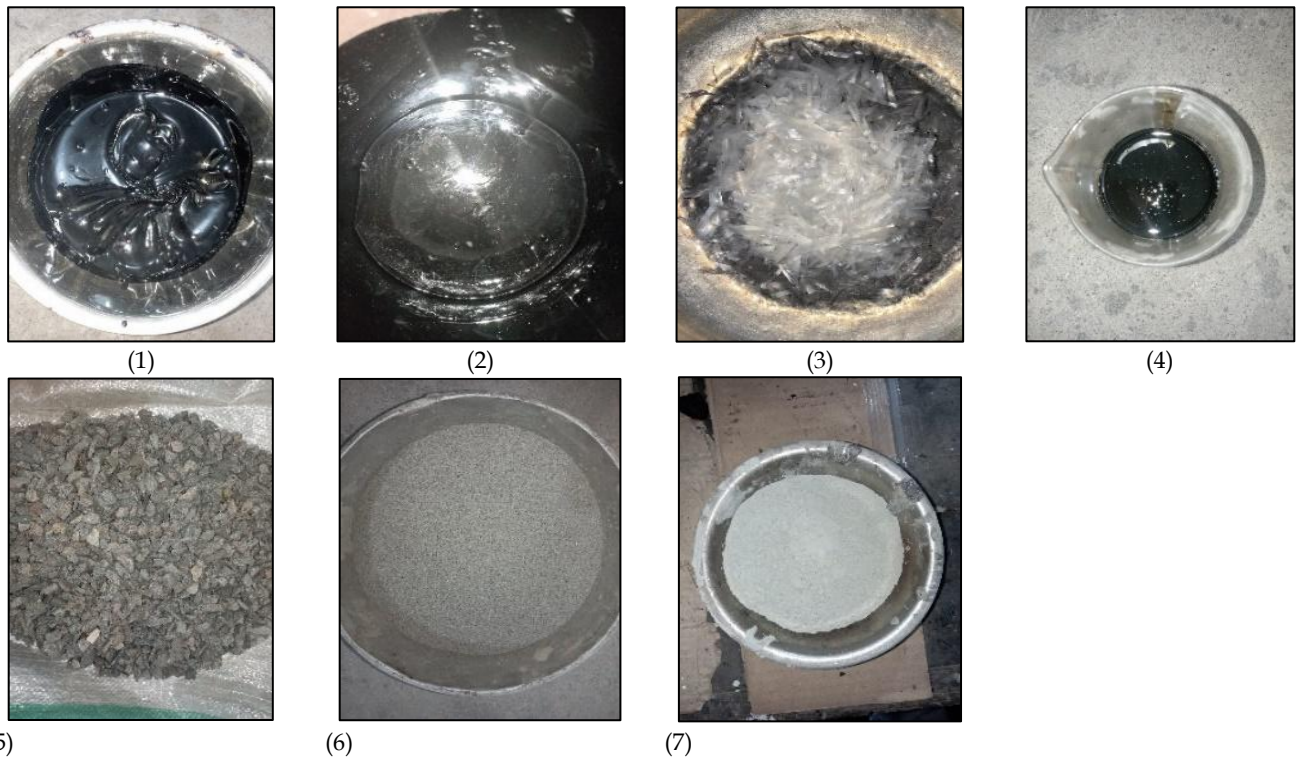


**Figure 1**. Research materials: (1) Extracted Asbuton, (2) 60/70 penetration grade asphalt, (3) Waste Low-Density Polyethylene (LDPE), (4) Waste engine oil, (5) Coarse aggregate, (6) Fine aggregate, and (7) Filler.

Extracted Asbuton was modified with waste engine oil and LDPE before being used as the binder in the AC-BC mixtures. The coarse and fine aggregates consisted of local crushed stone, with Portland cement used as the filler. The combined aggregate gradation met the required specifications for AC-BC mixtures, as shown in Figure 2, where the gradation curve remains within the upper and lower limits.

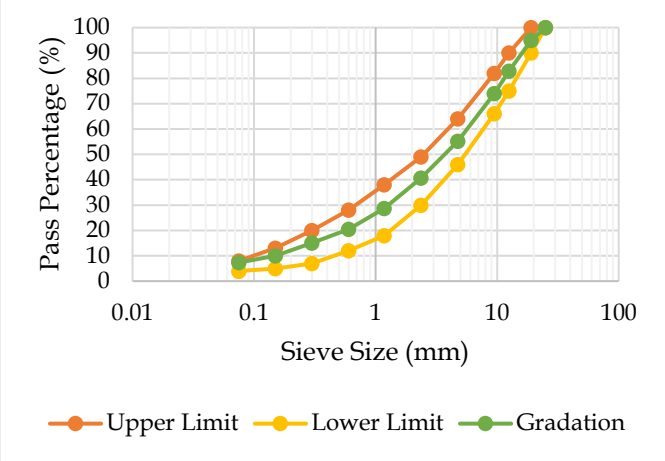


**Figure 2**. Aggregate gradation of AC-BC mixtures

*Material Testing*

The subsequent stage involved evaluating the characteristics of the constituent materials used in the asphalt mixtures. The tests conducted on the coarse aggregate, fine aggregate, and filler included sieve analysis, bulk specific gravity, saturated surface-dry specific gravity, apparent specific gravity, effective specific gravity, water absorption, and aggregate impact value. The 60/70 penetration grade asphalt, extracted Asbuton, and modified Asbuton were characterized through penetration, softening point, ductility, flash point, specific gravity, and loss on heating tests. The test results were used to verify that all materials satisfied the technical requirements specified in the General Specifications for Road and Bridge Construction, Bina Marga 2018 Revision 2 (2020) before being incorporated into the AC-BC mixtures (Kementerian Pekerjaan Umum dan Perumahan rakyat & Direktorat Jenderal Bina Marga, 2020).

Following the characterization of the extracted Asbuton as the basis for the modification process, a preliminary study was conducted using waste engine oil as a rejuvenator at dosages of 5%, 6%, and 7% by weight of the extracted Asbuton. The selected waste engine oil contents were adapted and further developed from the study conducted by Karyawan et al. (2023). Subsequently, the extracted Asbuton modified with the selected waste engine oil content that satisfied the specification requirements was further modified by incorporating LDPE at dosages of 0%, 0.5%, 1.0%, 1.5%, and 2.0% by weight of the extracted Asbuton. The LDPE dosage range was established by adapting the additive proportions reported by Maniagasi (2020).

The modified Asbuton binder was prepared using the wet mixing process, in which the asphalt binder and LDPE were heated separately in different containers until fully melted. The molten asphalt was then poured into the molten LDPE and thoroughly mixed until a homogeneous and uniform blend was obtained. The mixing temperature required to achieve a homogeneous binder was also recorded as part of the experimental observations (Sistra et al., 2016). Mixing was carried out under continuous stirring until no agglomeration was observed. The homogeneity of the modified binder was assessed visually to ensure that the asphalt binder and LDPE were uniformly blended without the presence of plastic agglomerates (Afriyanto et al., 2019). At this stage, the waste engine oil was added simultaneously with the heating of the LDPE.

*Specimen Preparation for Optimum Asphalt Content (OAC) Determination*

The AC-BC mixtures were designed using a binder blend consisting of 50% modified Asbuton and 50% 60/70 penetration grade asphalt. The selection of this binder proportion was based on the findings of previous studies Agustin (2023) which reported the best overall mixture performance at this binder composition. Subsequently, Marshall testing was conducted to determine the Optimum Asphalt Content (OAC), with the asphalt content calculated based on a total mixture mass of 1,200 grams. The number of specimens and the selected asphalt contents are presented in Table 1.

**Table 1.** Number of Specimens and Design Asphalt Contents

| Aggregate and Asphalt Mixing | |
|---|---|
| Asphalt Content (%) | Number of Specimens |
| Pb – 1% | 3 |
| Pb – 0.5 % | 3 |
| Pb % | 3 |
| Pb + 0.5% | 3 |
| Pb + 1% | 3 |
| Total | 15 |

The AC-BC specimens were prepared by mixing the binder with the aggregate blend according to the predetermined aggregate gradation and trial asphalt contents. The specimen preparation procedure consisted of the following steps:

1) The required amount of shredded LDPE was weighed and heated together with waste engine oil at a temperature of 105–115°C.
2) The required amount of extracted Asbuton was weighed and heated to 140–160°C.
3) The heated extracted Asbuton was poured into the container containing the molten LDPE and waste engine oil, followed by continuous mixing until a homogeneous modified binder was obtained.
4) The modified Asbuton binder was allowed to cool to room temperature.
5) The pre-weighed coarse aggregate, fine aggregate, and mineral filler were combined and heated to 170°C while being thoroughly mixed.

6) The 60/70 penetration grade asphalt and the modified Asbuton binder were blended according to the specified binder proportions and mixed at 140–160°C until a homogeneous binder blend was achieved.
7) The blended binder was added to the heated aggregate mixture and thoroughly mixed at 140–160°C until all aggregates were uniformly coated.
8) The asphalt mixture was placed into a Marshall mold at a temperature of 120–135°C, with paper discs positioned at the bottom of the mold.
9) The mixture was spaded 25 times using a spatula, covered with a paper disc on the top surface, and compacted with 75 blows on each face (2 × 75 blows) using a Marshall compaction hammer.
10) After compaction, the specimen was removed from the mold using a specimen extractor (ejector).
11) The specimens were allowed to cool at room temperature for 24 h before being labeled according to their respective mixture designations.

*Preparation of Specimens Using the Optimum Asphalt Content (OAC)*

The specimens were prepared using the previously determined Optimum Asphalt Content (OAC), with varying proportions of modified Asbuton and 60/70 penetration grade asphalt according to the experimental design. The mixture specifications adopted in this study were based on the General Specifications for Road and Bridge Construction, Bina Marga 2025, namely Asphalt Concrete–Binder Course (AC-BC) for 60/70 penetration grade asphalt mixtures and Modified Asphalt Concrete–Binder Course (Modified AC-BC) for mixtures incorporating modified Asbuton. (Kementerian Pekerjaan Umum dan Perumahan rakyat & Direktorat Jenderal Bina Marga, 2025). The binder composition design based on the Optimum Asphalt Content (OAC) is presented in Table 2. A total of 15 specimens were prepared for each binder composition, resulting in 75 specimens for the entire experimental program.

**Table 2.** Binder Composition of AC-BC Mixtures

| Modified Asbuton (%) | Asphalt Pen 60/70 (%) |
|---|---|
| 100 | 0 |
| 75 | 25 |
| 50 | 50 |
| 25 | 75 |
| 0 | 100 |

*Marshall Testing*

All compacted specimens were subsequently tested using the Marshall method to determine the mechanical and volumetric characteristics of the AC-BC mixtures. The evaluated parameters included Voids in Mineral Aggregate (VMA), Voids in the Mixture (VIM), Voids Filled with Asphalt (VFA), stability, flow, and Marshall Quotient (MQ). The testing procedures and evaluation criteria were conducted in accordance with the General Specifications for Road and Bridge Construction, Bina Marga 2025.

## Result and Discussion

*Material Test Results*

Before specimen preparation and Marshall testing, the constituent materials were characterized to verify their suitability for use in the asphalt mixtures. The detailed test results are presented in Tables 3–8. The coarse aggregate, fine aggregate, and filler were tested to ensure that their properties complied with the General Specifications for Road and Bridge Construction, Bina Marga 2018 Revision 2 (2020). As shown in Table 3, all tested properties of the coarse aggregate, fine aggregate, and filler satisfied the specified requirements, indicating that these materials were suitable for use as constituents of the pavement mixtures investigated in this study.

**Table 3.** Aggregate and filler test results

| Aggregate testing | Results | Specifications |
|---|---|---|
| Coarse Aggregate | | |
| Bulk Specific Gravity | 2.72 | |
| Saturated Surface-Dry Specific Gravity | 2.77 | ≥ 2.5 |
| Apparent Specific Gravity | 2.86 | |
| Effective Specific Gravity | 2.79 | |
| Water Absorption | 1.76 | < 3% |
| Aggregate Impact Value (%) | 16 | < 30% |
| Fine Aggregate | | |
| Bulk Specific Gravity | 2.66 | |
| Saturated Surface-Dry Specific Gravity | 2.73 | ≥ 2.5 |
| Apparent Specific Gravity | 2.86 | |
| Effective Specific Gravity | 2.76 | |
| Water Absorption | 2.70 | < 3% |
| Filler (Portland Cement) | | |
| Bulk Specific Gravity | 2.61 | |
| Saturated Surface-Dry Specific Gravity | 2.61 | ≥ 2.5 |
| Apparent Specific Gravity | 2.61 | |
| Effective Specific Gravity | 2.61 | |
| Water Absorption | 0.06 | < 3% |

Before the modification process, the extracted Asbuton was characterized to determine its physical properties as a binder for AC-BC mixtures in accordance with the requirements of the General Specifications for Road and Bridge Construction, Bina Marga 2018 Revision 2 (2020). The evaluated properties included penetration, softening point, ductility, flash point, specific gravity, and loss on heating. The test results for the physical characteristics of the Extracted Asbuton (EA) are presented in Table 4.

**Table 4.** Test results of extracted Asbuton

| Types of Testing | Extracted Asbuton | Specification |
|---|---|---|
| Penetration at 25°C (0.1 mm) | 19.8 | 50-60 |
| Softening Point (°C) | 54 | ≥ 51 |
| Ductility at 25°C (cm) | 124 | ≥ 100 |
| Flash Point (°C) | 268 | ≥ 232 |
| Specific Gravity | 1.06 | ≥ 1.0 |
| Loss on Heating (%) | 0.09 | ≤ 0.8 |

The test results presented in Table 4 indicate that most of the physical properties of the extracted Asbuton complied with the requirements of the General Specifications for Road and Bridge Construction, Bina Marga 2018 Revision 2 (2020). However, the penetration value did not satisfy the specified requirement, necessitating modification using waste engine oil. The use of waste engine oil was based on the study by Karyawan et al. (2023) which demonstrated that the incorporation of waste engine oil can increase the penetration value of Extracted Asbuton (EA) . The test results for the physical properties of the Modified Asbuton (MA) are presented in Table 5.

**Table 5.** Test results of modified Asbuton with different waste engine oil contents

| Penetration Test | Result | Specification |
|---|---|---|
| EA 100% | 19.8 | 50-60 |
| EA 95% + WEO 5% | 39.6 | |
| EA 94% + WEO 6% | 49.7 | |
| EA 93% + WEO 7% | 90.4 | |

As shown in Table 5, the penetration value of the extracted Asbuton increased progressively with increasing waste engine oil content. However, at a waste engine oil content of 7%, the penetration value exceeded the specified limit. Therefore, LDPE was incorporated to obtain binder properties that satisfied the specification requirements. This finding is consistent with the study by Al-Gurah et al. (2023) which reported that the addition of LDPE reduces the penetration value of asphalt binders. The test results for the modified binder incorporating LDPE are presented in Table 6.

**Table 6.** Test results of modified Asbuton incorporating waste engine oil and LDPE

| Penetration Test | Result | Specification |
|---|---|---|
| EA 93% + WEO 7% + LDPE 0% | 90.4 | 50-60 |
| EA 92.5% + WEO 7% + LDPE 0.5% | 51.7 | |
| EA 92% + WEO 7% + LDPE 1% | 42.9 | |
| EA 91.5% + WEO 7% + LDPE 1.5% | 34.6 | |
| EA 91% + WEO 7% + LDPE 2% | 26.2 | |

As shown in Table 6, the modified Asbuton containing 7% waste engine oil and 0.5% LDPE satisfied the requirements of the General Specifications for Road and Bridge Construction, Bina Marga 2018 Revision 2 (2020). This binder composition was subsequently selected for use in the AC-BC mixtures. The test results for the physical properties of the selected modified Asbuton are presented in Table 7.

**Table 7** Test results of modified Asbuton with 7% waste engine oil and 0.5% LDPE

| Types of Testing | Modified Asbuton | Specification |
|---|---|---|
| Penetration at 25°C (0.1 mm) | 51.7 | 50-60 |
| Softening Point (°C) | 52 | ≥ 51 |
| Ductility at 25°C (cm) | 130.5 | ≥ 100 |
| Flash Point (°C) | 265 | ≥ 232 |
| Specific Gravity | 1.05 | ≥ 1.0 |
| Loss on Heating (%) | 0.10 | ≤ 0.8 |

As presented in Table 7, the modified Asbuton containing 7% waste engine oil and 0.5% LDPE satisfied the requirements of the General Specifications for Road and Bridge Construction, Bina Marga 2018 Revision 2 (2020) and was therefore selected as a binder for the AC-BC mixtures. The properties of the 60/70 penetration grade asphalt binder were also evaluated to verify its compliance with the technical specifications before incorporation into the asphalt mixtures. The evaluated properties included penetration, softening point, ductility, flash point, specific gravity, and loss on heating in accordance with the General Specifications for Road and Bridge Construction, Bina Marga 2025. The test results for the physical properties of the 60/70 penetration grade asphalt are presented in Table 8.

**Table 8.** Test results 60/70 penetration grade asphalt

| Types of Testing | Asphalt Pen 60/70 | Specification |
|---|---|---|
| Penetration at 25°C (0.1 mm) | 66.2 | 60-70 |
| Softening Point (°C) | 48 | ≥ 48 |
| Ductility at 25°C (cm) | 140 | ≥ 100 |
| Flash Point (°C) | 290 | ≥ 232 |
| Specific Gravity | 1.04 | ≥ 1.0 |
| Loss on Heating (%) | 0.08 | ≤ 0.8 |

As shown in Table 8, the 60/70 penetration grade asphalt binder satisfied all the requirements specified in the General Specifications for Road and Bridge Construction, Bina Marga 2025. These results indicate that the binder possessed the required properties for use in the AC-BC mixtures.

*Determination of the Design Asphalt Content (Pb) and the Optimum Asphalt Content (OAC)*

The initial asphalt content was determined based on the total mixture mass, taking into account the

proportions of each aggregate fraction, namely 44.79% coarse aggregate, 47.87% fine aggregate, and 7.34% filler.

$$Pb = 0.035(\%CA) + 0.45(\%FA) + 0.18(\%FF) + K$$
$$Pb = 0.035(44.79) + 0.045(47.87) + 0.18(7.34) + 0.75$$
$$Pb = 5.79\% \approx 6\%$$

Based on the calculation results, the design asphalt content (Pb) was determined to be 6.0%. Additional trial asphalt contents were subsequently established, as presented in Table 1. After all trial asphalt content levels had been defined, the Optimum Asphalt Content (OAC) was determined. Based on the results of the volumetric and mechanical tests, the data were compiled and analyzed to determine the Optimum Asphalt Content (OAC).

**Table 9.** Summary of Volumetric and Mechanical Properties for Optimum Asphalt Content (OAC) Determination

| Parameter | Modified AC-BC Mixture Specifications | Asphalt Content (%) | | | | |
|---|---|---|---|---|---|---|
| | | 5.0% | 5.5% | 6.0% | 6.5% | 7.0% |
| VMA (%) | ≥ 14% | 12.03 | 13.29 | 14.50 | 15.87 | 17.01 |
| VIM (%) | 3-5% | 2.69 | 2.84 | 2.96 | 3.29 | 3.37 |
| VFA (%) | ≥ 65% | 77.76 | 78.67 | 79.69 | 79.72 | 80.23 |
| Stability (kg) | ≥ 1000 kg | 2773.94 | 2776.78 | 2671.65 | 2531.44 | 2038.06 |
| Flow (mm) | 2-4 mm | 2.13 | 3.32 | 3.35 | 3.47 | 5.17 |
| Marshall Quotient (kg/mm) | ≥ 300 kg/mm | 1333.21 | 845.87 | 813.18 | 744.71 | 392.00 |

Note:

: Does not satisfy the specifications

: Satisfies the specifications

Based on the summarized test results, an asphalt content of 6.5% satisfied all the requirements specified in the General Specifications for Road and Bridge Construction, Bina Marga 2025 for Modified AC-BC. In contrast, asphalt contents of 5.0%, 5.5%, and 6.0% did not satisfy the specified volumetric requirements, whereas an asphalt content of 7.0% failed to meet the required mechanical performance criteria. Therefore, the Optimum Asphalt Content (OAC) adopted in this study was 6.5%.

*Marshall Test Results for Mixtures with Different Proportions of 60/70 Penetration Grade Asphalt and Modified Asbuton*

The Optimum Asphalt Content (OAC) determined in the previous section was used as the basis for the Marshall testing of AC-BC mixtures incorporating different proportions of Modified Asbuton (MA).

Figure 3 shows that the Voids in Mineral Aggregate (VMA) tended to increase with increasing proportions of MA. The polynomial regression model produced a high coefficient of determination ($R^2$), indicating a strong relationship between the proportions of MA and the corresponding VMA values. The increase in VMA indicates that the incorporation of the modified binder influenced the volumetric characteristics of the asphalt mixtures. A VMA value that is too low may make the mixture more susceptible to traffic-induced damage, whereas an excessively high VMA value can reduce mixture stability and increase asphalt binder demand, resulting in lower technical and economic efficiency (Firda et al., 2022).

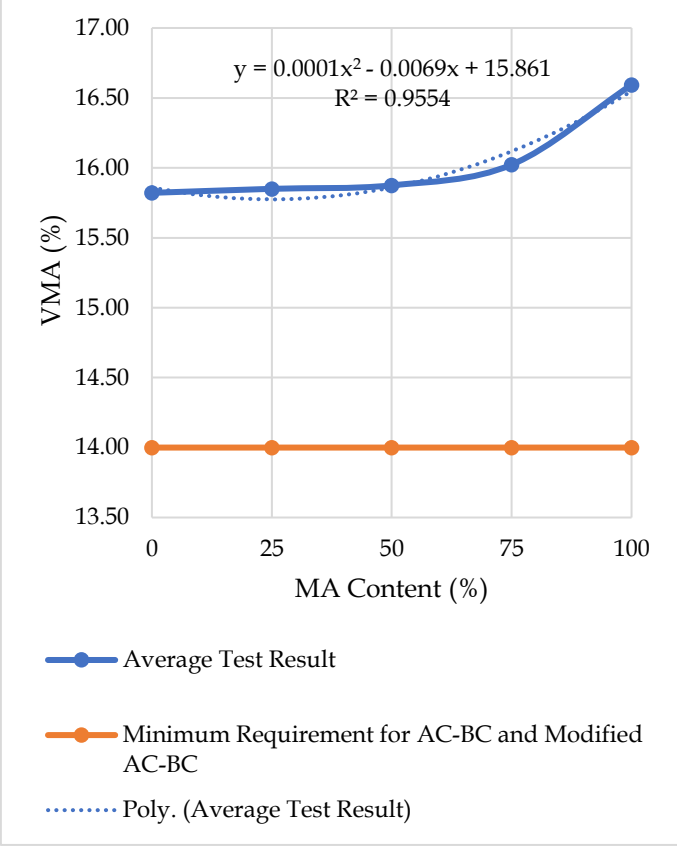


**Figure 3**. Effect of the MA Content on VMA

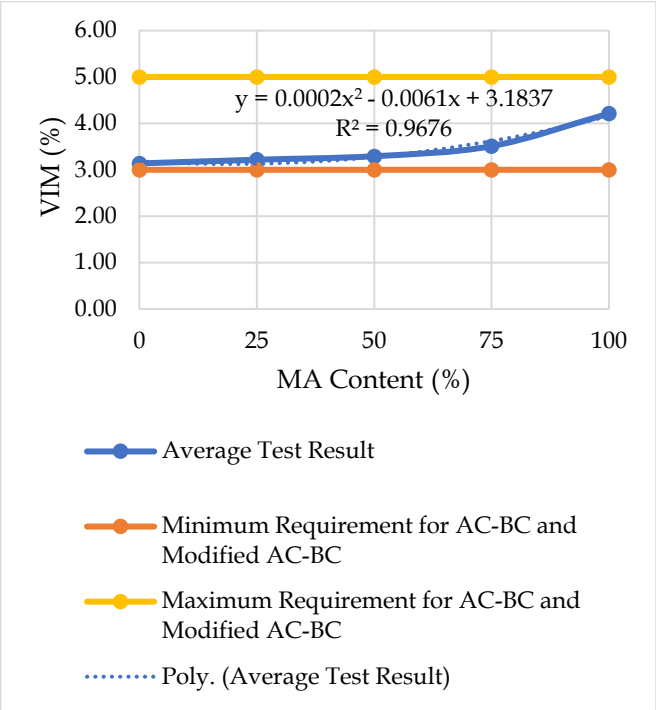


**Figure 4**. Effect of the MA Content on VIM

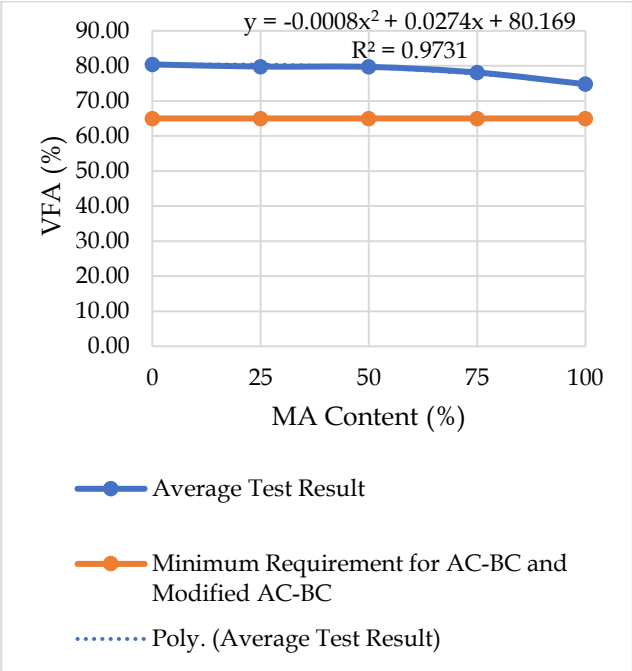


**Figure 5**. Effect of the MA Content on VFA

As shown in Figure 4, the Voids in the Mixture (VIM) tended to increase with increasing proportions of MA, exhibiting a strong regression relationship. The high coefficient of determination ($R^2$) indicates that variations in binder composition had a significant influence on the VIM values. According to Sulandari et al. (2024), excessively low VIM values may lead to bleeding, where asphalt migrates to the pavement surface under traffic loading at elevated temperatures due to insufficient void space within the mixture. Conversely, Wantoro et al. (2013), reported that excessively high VIM values make asphalt mixtures more brittle, increasing their susceptibility to premature cracking and particle loss (stripping).

As shown in Figure 5, the Voids Filled with Asphalt (VFA) values tended to decrease with increasing proportions of MA. The polynomial regression model indicated a strong relationship between the binder composition and the corresponding VFA values. Firda et al. (2022) reported that excessively high VFA values may lead to bleeding due to an excessive amount of asphalt binder filling the aggregate voids. VFA represents the percentage of aggregate voids occupied by asphalt binder within the mixture. Higher VFA values generally improve the impermeability of asphalt mixtures to water and air. However, excessively high values increase the risk of bleeding. Conversely, low VFA values result in a thinner asphalt film, making the mixture more susceptible to oxidation, cracking, and a reduction in pavement service life (Sumiati et al., 2019).

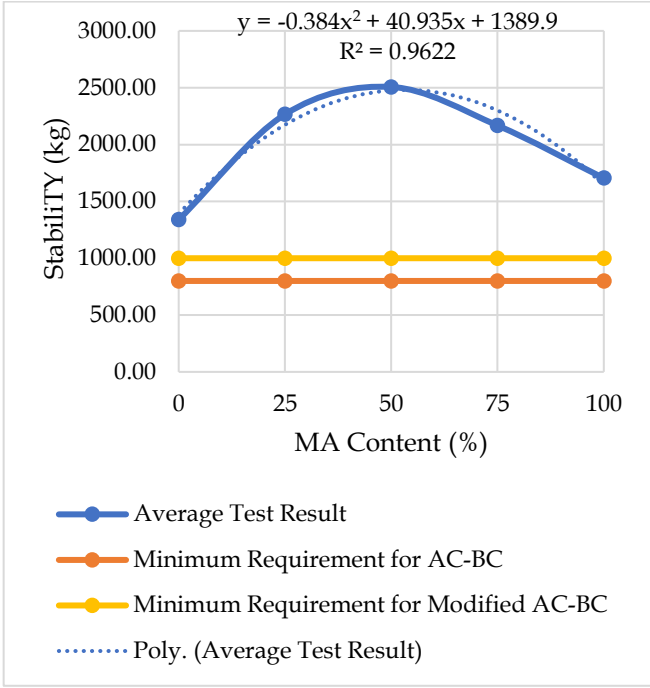


**Figure 6**. Effect of the MA Content on stability

As shown in Figure 6, the Marshall stability increased with increasing proportions of MA, reaching a maximum at an MA content of 50%, before decreasing at higher MA proportions. The high coefficient of determination ($R^2$) indicates a very strong relationship between binder composition and stability. The stability of asphalt mixtures is governed by aggregate characteristics, including particle shape, quality, surface texture, and gradation, as well as the interaction between aggregate particles through internal friction

and interlocking. Furthermore, the cohesion of the asphalt binder and the asphalt content of the mixture also play important roles in determining stability (Sumiati et al., 2019). The incorporation of LDPE as a modifier has been reported to enhance stability, with the stability generally increasing to an optimum level before declining at higher LDPE contents (Lubis et al., 2020).

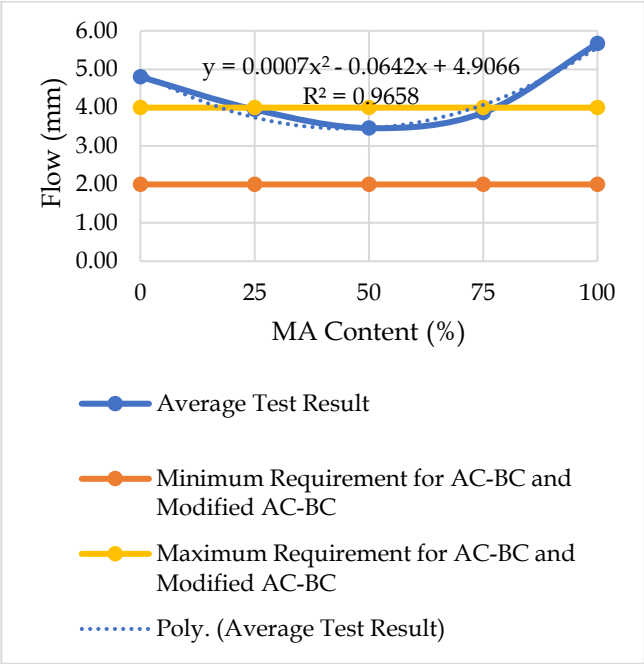


**Figure 7**. Effect of the MA Content on flow

As shown in Figure 7, the Flow value decreased with increasing proportions of MA until reaching an MA content of 50%, after which it increased at higher MA proportions. The polynomial regression model indicated a strong relationship between binder composition and the corresponding flow values. Asphalt mixtures with low flow values combined with high stability tend to exhibit greater stiffness and brittleness. In contrast, mixtures with high flow values and low stability are generally more plastic and therefore more susceptible to deformation, such as washboarding and rutting, under repeated traffic loading (Sumiati et al., 2019).

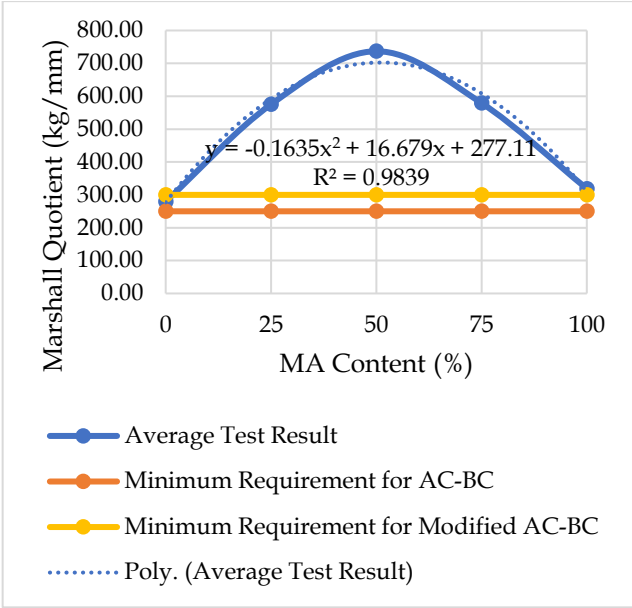


**Figure 8**. Effect of the MA Content on Marshall Quotient (MQ)

As shown in Figure 8, the Marshall Quotient (MQ) increased with increasing proportions of modified Asbuton, reaching a maximum at an MA content of 50%, before decreasing at higher MA proportions. The polynomial regression model indicated a strong relationship between binder composition and the corresponding MQ values. A low MQ indicates that the asphalt mixture is relatively more plastic and flexible. In contrast, a high MQ value reflects a stiffer mixture with lower flexibility (Nugroho, 2019).

**Table 10**. Summary of the Volumetric and Mechanical Properties of AC-BC Mixtures with Different Proportions of 60/70 Penetration Grade Asphalt and Modified Asbuton

| Parameter | Specifications | | Asphalt Content | | | | |
|---|---|---|---|---|---|---|---|
| | AC-BC Mixture | Modified AC-BC Mixture | 0% MA | 25% MA | 50% MA | 75% MA | 100% MA |
| VMA (%) | ≥ 14% | ≥ 14% | 15.82 | 15.85 | 15.87 | 16.02 | 16.59 |
| VIM (%) | 3-5% | 3-5% | 3.14 | 3.22 | 3.29 | 3.51 | 4.21 |
| VFA (%) | 65-75% | ≥ 65% | 80.42 | 79.80 | 79.72 | 78.11 | 74.78 |
| Stability (kg) | ≥ 800 kg | ≥ 1000 kg | 1338.78 | 2265.48 | 2506.57 | 2167.76 | 1704.34 |
| Flow (mm) | 2-4 mm | 2-4 mm | 4.80 | 3.95 | 3.47 | 3.87 | 5.67 |
| Marshall Quotient (kg/mm) | ≥ 250 kg/mm | ≥ 300 kg/mm | 279.76 | 575.13 | 736.77 | 579.16 | 318.85 |

Note:

: Does not satisfy the specifications

: Satisfies the specifications

Table 10 shows that the asphalt mixtures with 25%, 50%, and 75% MA content satisfied all the requirements specified in the General Specifications for Road and Bridge Construction, Bina Marga 2025 for Modified AC-BC. In contrast, the mixture with 0% MA content did not satisfy the flow requirement for AC-BC Mixture and failed to meet the VFA requirement. Meanwhile, the mixture with 100% MA content did not satisfy the flow requirement for Modified AC-BC.

## Conclusion

Based on the findings of this study, the use of extracted Asbuton modified with 7% waste engine oil and 0.5% LDPE significantly influenced the volumetric and mechanical properties of AC-BC mixtures. The incorporation of the modified Asbuton improved mixture performance up to an optimum binder proportion. However, excessive amounts of modified Asbuton resulted in a deterioration of several mixture properties, causing some binder compositions to fail to satisfy the requirements of the General Specifications for Road and Bridge Construction, Bina Marga 2025. A binder composition consisting of 50% MA was identified as the optimum proportion, providing the best balance between volumetric and mechanical properties while satisfying all specification requirements. These findings demonstrate that extracted Asbuton modified with waste engine oil and LDPE has considerable potential as an alternative binder, reducing dependence on 60/70 Penetration Grade Asphalt (PGA) while enhancing the utilization of Asbuton as a valuable local resource. Furthermore, the use of waste engine oil and waste LDPE as modifying agents contributes to more sustainable waste management practices and supports the development of environmentally sustainable pavement technologies.

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Conceptualization, D.A.D., I.D.M.A.K., R.Y., and H.; methodology, writing original draft preparation, D.A.D. and I.D.M.A.K.; validation, I.D.M.A.K; resources, D.A.D. All authors have read and agreed to published version of the manuscript.

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**Conflicts of Interest**
The authors declare no conflict of interest.

## Reference

Abualia, A., Akentuna, M., Mohammad, L. N., Cooper, S. B. III., & Cooper, S. B. Jr. (2024). Improving Asphalt Binder Durability Using Sustainable Materials: A Rheological and Chemical Analysis of Polymer-, Rubber-, and Epoxy-Modified Asphalt Binders. *Sustainability*, *16*(13), 5739. https://doi.org/10.3390/su16135379

Afriyanto, B., Indriyati, E. W., & Hardini, P. (2019). Pengaruh Limbah Plastik Low Density Polyethylene Terhadap Karakteristik Dasar Aspal. *Jurnal Transportasi*, *19*(1), 59–66. https://doi.org/10.26593/jt.v19i1.3263.59-66

Agustin, D. Y. (2023). *Analisis Kinerja Campuran AC – BC Menggunakan Aspal Ekstraksi Asbuton Yang Dimodifikasi Oli Bekas Dan HDPE.* Universitas Mataram Repository. Retrieved from https://eprints.unram.ac.id/43536/2/ARTIKEL_DITA%20YUNIARTI%20AGUSTIN_F1A019045.pdf.

Al-Gurah, E. R., Al-Ghurabi, S. J., & Al-Humeidawi, B. H. (2023). Laboratory evaluation of properties of modified asphalt binder with different types of additives. *IOP Conference Series: Earth and Environmental Science*, *1232*(1). https://doi.org/10.1088/1755-1315/1232/1/012043

Aljarmouzi, A., & Dong, R. (2022). Sustainable Asphalt Rejuvenation by Using Waste Tire Rubber Mixed with Waste Oils. *Sustainability*, *14*(14), 8246. https://doi.org/10.3390/su14148246

Arisona. (2021). *Mengenal Potensi Kearifan Lokal Batuan Aspal Alam Pada Cekungan Pulau Buton Indonesia Bagian Timur*. Surakarta: CV Kekata Group. Retrieved from https://www.researchgate.net/publication/357630003_Mengenal_Potensi_Kearifan_Lokal_Batuan_Aspal_Alam_Pada_Cekungan_Pulau_Buton_Indonesia_Bagian_Timur.

Firda, A., Djohan, B., Jimmyanto, H., & Febrianty, D. (2022). Pengaruh Penambahan Plastik (Polyethylene Terephthalate) Pada Campuran AC-WC (Asphalt Concrete – Wearing Course) Terhadap Karakteristik Marshall. *Jurnal Deformasi*, *7*(2), 127–144. https://doi.org/doi.org/10.31851/deformasi.v7i2.9439

Ghani, U., Zamin, B., Tariq Bashir, M., Ahmad, M., Sabri, M. M. S., & Keawsawasvong, S. (2022). Comprehensive Study on the Performance of Waste HDPE and LDPE Modified Asphalt Binders for Construction of Asphalt Pavements Application. *Polymers*, *14*(17), 3637.

https://doi.org/10.3390/polym14173673

Gusty, S., Israil, Ahmad, S. N., & Tumpu, M. (2024). Assessing Open-Graded Asphalt'S Resistance To Degradation Via Cantabro Test in Hot-Mix Cold Laid Asbuton. *International Journal of GEOMATE*, *27*(120), 60–68. https://doi.org/10.21660/2024.120.4488

Hidayati, H. N., Rifqi, M. G., & Amin, M. S. (2021). Pengaruh Penambahan Plastik LDPE Pada Campuran Aspal Beton Lapis AC-BC. *Journal of Applied Civil Engineering and Infrastructure Technology*, *2*(2), 1–6. https://doi.org/10.52158/jaceit.v2i2.63

Iqbal, Sukowati, D. G., Rusmin, M., Desembardi, F., & Puspita, K. (2024). Pengaruh Pemanfaatan Limbah Plastik LDPE Terhadap Karakteristik Campuran AC-WC Menggunakan Metode Marshall. *Publikasi Riset Orientasi Teknik Sipil (Proteksi)*, *6*(2), 216–221. https://doi.org/doi.org/10.26740/proteksi.v6n2.p216-221

Irianto, Rachman Djamaluddin, A., Pasra, M., & Arsyad, A. (2020). Experimental study on marshall stability and flow of Asphalt Concrete Wearing Course (AC-WC) mixture using Asbuton semi extracted as binder. *IOP Conference Series: Earth and Environmental Science*, *419*(1), 012074. https://doi.org/10.1088/1755-1315/419/1/012074

Karakas, A. S. (2026). Evaluation of Aging Effects on Asphalt Binders and Pavements: Rheological Responses to Rejuvenators and Numerical Analysis of Polymer Modification. *Polymers*, *18*(6), 0–44. https://doi.org/10.3390/polym18060759

Karyawan, I. D. M. A., Kencanawati, N. N., Hariyadi, H., Hasyim, H., & Rohani, R. (2023). Karakteristik Aspal Buton Ekstraksi yang Dimodifikasi dengan Oli Bekas dan Plastik HDPE. *REKONSTRUKSI TADULAKO: Civil Engineering Journal on Research and Development*, *4*(2), 79–86. https://doi.org/10.22487/renstra.v4i2.596

Kementerian Pekerjaan Umum dan Perumahan rakyat & Direktorat Jenderal Bina Marga. (2020). *Spesifikasi Umum 2018 untuk Pekerjaan Konstruksi Jalan dan Jembatan (Revisi 2)*. Retrieved from https://binamarga.pu.go.id/uploads/files/987/spesifikasi-umum-bina-marga-2018-untuk-pekerjaan-konstruksi-jalan-dan-jembatan-revisi-2.pdf.

Kementerian Pekerjaan Umum dan Perumahan rakyat & Direktorat Jenderal Bina Marga. (2025). *Spesifikasi Umum Bina Marga 2025 untuk Pekerjaan Konstruksi Jalan dan Jembatan*. Retrieved from https://binamarga.pu.go.id/uploads/files/2104/Spesifikasi-Umum-2025-untuk-Pekerjaan-Konstruksi-Jalan-dan-Jembatan.pdf.

Khan, I. M., Kabir, S., Alhussain, M. A., & Almansoor, F. F. (2016). Asphalt Design Using Recycled Plastic and Crumb-rubber Waste for Sustainable Pavement Construction. *Procedia Engineering*, *145*, 1557–1564. https://doi.org/10.1016/j.proeng.2016.04.196

Lubis, A. S., Muis, A. Z. &, & Siregar, N. (2020). The effects of low-density polyethylene ( LDPE ) addition to the characteristics of asphalt mixture The effects of low-density polyethylene ( LDPE ) addition to the characteristics of asphalt mixture. *IOP Conference Series: Earth and Environmental Science*, *476*(1), 012063. https://doi.org/10.1088/1755-1315/476/1/012063

Maha, M. R. A., Idham, M. K., & Hainin, M. R. (2024). Full extraction of asbuton bitumen for binder replacement in warm mix asphalt. *IOP Conference Series: Earth and Environmental Science*, *1369*(1). https://doi.org/10.1088/1755-1315/1369/1/012026

Maniagasi, R. A. (2020). *Studi Kekuatan Tarik Tidak Langsung Campuran AC-WC yang Mengandung Aspal Buton dan Menggunakan Limbah Plastik Sebagai Bahan Tambah*. [Master's thesis, Universitas Hasanuddin]. Universitas Hasanuddin Repository. Retrieved from https://repository.unhas.ac.id/id/eprint/878/4/P2304216005_tesis_12-11-2020(FILEminimizer).pdf.

Nisar, J., Mir, M. S., & Vivek. (2024). Comparative analysis of asphalt binder modified with HDPE and LDPE: rheological and compatibility perspectives. *E3S Web of Conferences*, *596*, 01027. https://doi.org/10.1051/e3sconf/202459601027

Nugroho, M. S. (2019). Karakteristik Marshall Quotient Pada Hot Mix Asphalt Menggunakan Agregat Alam Sungai Opak. *INERSIA: LNformasi Dan Ekspose Hasil Riset Teknik SIpil Dan Arsitektur*, *15*(2), 84–91. https://doi.org/10.21831/inersia.v15i2.28627

Poudel, D., Timsina, D., Poudel, M., Acharya, J., Thapa, P., & Khadka, R. (2024). Analysis of the Use of Waste Plastics Low-Density Polyethylene (LDPE) along with Bitumen in the Construction of Asphalt Pavement using the Marshall Test. *International Journal on Engineering Technology*, *1*(2), 202–210. https://doi.org/10.3126/injet.v1i2.66687

Pratama, A. W., Sukwika, T., & Kholil, K. (2022). Strategi Pertamina Dalam Memenuhi Kebutuhan Aspal Domestik Melalui Peningkatan Pangsa Pasar Aspal. *Jurnal Ekonomi Dan Bisnis*, *11*(04), 392–400. https://doi.org/10.34308/eqien.v11i04.1313

Rahman, H., Harnedi, R. A., Siregar, F. T. N., Kim, Y., Lee, K., & Kang, I. (2024). Laboratory Performance of Asphalt Concrete containing Foamed Bitumen from extraction of Buton Natural Asphalt. *Jurnal Teknik Sipil*, *31*(3), 249–254.

https://doi.org/10.5614/jts.2024.31.3.2

Safaei, F., Castorena, C., & Kim, Y. R. (2016). Linking asphalt binder fatigue to asphalt mixture fatigue performance using viscoelastic continuum damage modeling. *Mechanics of Time-Dependent Materials*, *20*(3), 299–323. https://doi.org/10.1007/s11043-016-9304-1

Sihombing, A. V. R., Subagio, B. S., Hariyadi, E. S., & Yamin, A. (2021). Chemical, morphological, and high temperature rheological behaviour of Bioasbuton® as an alternative binder for asphalt concrete in Indonesia. *Journal of King Saud University - Engineering Sciences*, *33*, 308–317. https://doi.org/10.1016/j.jksues.2020.07.006

Singh, A., & Gupta, A. (2024). Mechanical and economical feasibility of LDPE Waste-modified asphalt mixtures: pathway to sustainable road construction. *Scientific Reports*, *14*, 25331. https://doi.org/10.1038/s41598-024-75196-5

Sistra, M. D., Setyawan, A., & Sarwono, D. (2016). Analisis Karakteristik Modifikasi Aspal Penetrasi 60/70 dengan Ethylene Vinyl Acetate (EVA). *E-Jurnal Matriks Teknik Sipil*, *4*(01), 120-127. Retrieved from https://jurnal.uns.ac.id/m.

Sulandari, E., Lestyowati, Y., Felderika, F., & Sutarno, S. (2024). Analisis Pengaruh Sifat Volumetrik pada Campuran AC-WC. *CRANE: Civil Engineering Research Journal*, *5*(2), 41–47. https://doi.org/10.34010/crane.v5i2.14070

Sumiati, Mahmuda, & Syapawi., A. (2019). Perkerasan Aspal Beton (AC-BC) Limbah Plastik HDPE yang Tahan Terhadap Cuaca Ekstrem. *Construction and Material Journal*, *1*(1), 1–11. https://doi.org/10.32722/cmj.v1i1.1322

Syahputra, M. T. (2019). *Analisa Penggunaan Abu Vulkanik Gunung Sinabung Sebagai Bahan Filler pada Campuran Panas AC-WC Menggunakan Aspal Buton*. [Bachelor's thesis, Universitas Medan Area]. Universitas Medan Area Repository. Retrieved from https://repositori.uma.ac.id/handle/123456789/11533.

Wantoro, W., Kusumaningrum, D., Setiadji, B. H., Kushardjoko, W., Sipil, J. T., Teknik, F., & Diponegoro, U. (2013). Pengaruh Penambahan Plastik Bekas Tipe Low Density Polyethylene (LDPE) Terhadap Kinerja Campuran Beraspal. *Jurnal Karya Teknik Sipil*, *2*(4), 366-381. Retrieved from https://ejournal3.undip.ac.

White, G. (2020). A synthesis on the effects of two commercial recycled plastics on the properties of bitumen and asphalt. *Sustainability*, *12*(20), 1–20. https://doi.org/10.3390/su12208594

Wildansyah, A. H. (2020). *Pengaruh Oli Bekas Sebagai Bahan Peremaja Aspal Daur Ulang Terhadap Karakteristik Campuran Split Mastic Asphalt (Sma) 0/11 Dengan Serat Ijuk the Effect of Waste Oil As a Rejuvenator Reclaimed Asphalt Pavement (Rap) To Characteristic of Split Mastic Asphal*. [Bachelor's thesis, Universitas Islam Indonesia]. Universitas Islam Indonesia Repository. Retrieved from https://dspace.uii.ac.id/123456789/29289.

Yandes, A. M., Rismanto, R., Julianto, J., & Jusi, U. (2021). Oli Sisa Sebagai Bahan Peremajaan Reclaimed Asphalt Pavement (RAP) Pada Lapisan Asphalt Concrete Binder Course (AC-BC) Jalan. *SAINSTEK*, *9*(2), 132-136. Retrieved from https://ejournal.sttp-yds.