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# Improving the Performance of Bitumen Mixtures Modified with Waste Engine Oil

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## ABSTRACT

Waste engine oil, a by-product of engine wear and tear, is annually discarded in environmentally harmful ways. Prior modifications of asphalt binder with waste engine oil resulted in lower consistency, reduced moisture damage resistance, and impaired high-temperature performance. To address these issues, three additives—Elvaloy, Eaton's Reagent (ER), and hydrated lime (H-L) were used to enhance waste engine oil-modified bitumen in the asphalt mixture. This modified bitumen underwent tests for binder and mixture like Softening point, Penetration and Marshall stability test. The findings show that both Waste Engine Oil (WEO) and Hydrated Lime (HL) can impact the Marshall stability of asphalt mixtures. The introduction of 2% Waste Engine Oil (WEO) leads to a 0.66% decrease in the stability of the asphalt mixture, while stability experiences a more significant reduction of 25.21% with the inclusion of 6% WEO. On the other hand, the addition of HL results in a significant 6.1% increase in stability; nevertheless, the addition of additional HL may cause the stability to decline. The introduction of Elvaloy resulted in a notable increase in stability, with a 2.5% incline. In the same way, Eaton's Reagent shows a significant effect, leading to a noteworthy 7.2% increase in stability in the asphalt mixture. These results emphasize the overall effectiveness of binder modification with waste engine oil when combined with suitable additives.

**KEYWORDS:** Waste Engine Oil, Hydrated Lime, Eaton's Reagent, Elvaloy, Modified Asphalt Mixture

## 1 INTRODUCTION

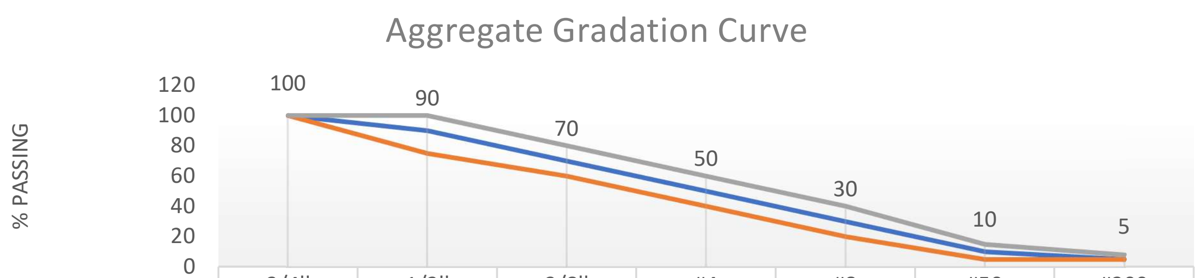
Hot Mix Asphalt (HMA) is common in flexible pavements for strength, durability, and easy repair. About 90% of pavements use flexible asphalt. Bitumen, the asphalt binder, shows viscoelastic behavior, acting as an elastic solid at low temperatures and a viscous liquid at higher temperatures [1]. Global bitumen demand is approximately 700 million barrels annually. It's a dark brown, non-crystalline, viscous material primarily composed of hydrocarbons (15% carbon, 80% hydrogen) and sourced from natural resources through crude oil fractional distillation [2]. Depleted resources lead to higher prices and environmental pollution. To address this, asphalt binders are modified with additives, offering cost-effective, eco-friendly alternatives. (Liu, Meng, Xu, Zhou, & Technology, 2018) studied WEO-modified bitumen, revealing reduced elasticity. Three additive categories—polymer-type (ELVALOY), filler-type (Hydrated Lime), and chemical-type (Eaton's Reagent, ER)—aim to enhance properties. The study focuses on waste engine oil as a partial bitumen replacement with three additives for an environmentally sustainable mixture, reducing binder use in pavement construction. Alternative binders prove cost-effective and environmentally sustainable [3]. Recent research has focused on integrating waste engine oil (WEO) into asphalt binder for performance evaluation. While some WEO is recycled, a significant portion is discarded [4]. WEO, a petroleum product, shares a molecular structure similar to bitumen, despite variations in production sources. According to [5], their evaluation of waste engine oil (WEO)-modified bitumen found that WEO reduces the binder's softening point and viscosity, while increasing penetration. However, an excessive amount of WEO has an adverse impact on binder properties. In their study, [6]found WEO-modified bitumen enhances fatigue resistance and low-temperature performance, recommending a modification range of 4-8%. In their research [7], examining WEO-modified bitumen, it reduces elastic properties, resulting in lower complex modulus values and higher phase angles. While enhancing fatigue performance, WEO hinders rutting resistance. Extensive evaluations confirm that WEO inclusion diminishes high-temperature performance. Various additives with virgin and modified binders aim to address this, enhancing rutting resistance [8]. The study uses three additives: Polymer (ELVALOY), filler (Hydrated Lime), and Chemical (Eaton's Reagent, ER) to enhance the properties of WEO-modified bitumen. The chemical analysis of ER showed increased asphaltene content in bitumen, reducing saturates and resins, and enhancing fundamental properties like penetration index and viscosity values.[9]. In another study conducted by F. Zhang, PPA addition significantly enhances bitumen's high-temperature performance, notably improving it by up to 1% with minimal adverse effects on fatigue characteristics [10]. The study explored hydrated lime as a filler in bituminous mixes, finding it enhances moisture, rutting, fatigue resistance, aging, and moisture sensitivity in asphalt mixes [11]. Additionally, the study evaluated asphalt binder modified with Elvaloy polymer, [12] observed that the addition of Elvaloy enhances bitumen stiffness, leading to improved viscosity and penetration resistance. Furthermore, it reduces moisture susceptibility, making the binder suitable for high-temperature regions [13]. Another study revealed Elvaloy significantly improves bitumen's high-temperature performance, increasing complex modulus values and decreasing phase angle values, confirming its stiffening effects on the binder[14]. Bitumen being a petroleum reserve depleting continuously, hence in turn its replacement with waste material or more sustainable material is needed. This study aims to investigate the impact of waste engine oil (WEO) on the stability and physical properties of Hot Mix Asphalt (HMA). Additionally, the research aims to explore the influence of different types of additives such as, chemical-based, filler-based, and polymer-based additives—on the overall performance of bitumen when partially replaced with waste engine oil in asphalt mixtures. By comprehensively evaluating these different additive types, the study seeks to understand their influence on the stability and physical properties of Hot Mix Asphalt (HMA), thereby contributing valuable insights to the field of asphalt technology, leading to more resilient and environmentally friendly asphalt materials.

## 2 RESEARCH METHODOLOGY

### 2.1 Materials

The control binder Bitumen used is a 60/70 penetration-grade. It was obtained from Pak Arab Refinery Limited (PARCO). Waste engine oil was sourced locally and then filtered as it exhibits variable chemical composition due to contaminants introduced during engine operation [15].

Elvaloy, Hydrated lime, and Eaton's Reagent were acquired from Rawalpindi Pakistan. Aggregates for this study were sourced from the Margalla quarry in Pakistan. Physical property testing was conducted on these aggregates, and the results demonstrated compliance with the specified limits. The blend of aggregates followed NHA gradation class B, with a maximum aggregate size of 19 mm, as depicted in **Figure 1**.

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| %age passing | 100 | 90 | 70 | 50 | 30 | 10 | 5 |
| Lower limit | 100 | 75 | 60 | 40 | 20 | 5 | 5 |
| Upper limit | 100 | 100 | 80 | 60 | 40 | 15 | 8 |

*Figure 1*: *Class B Gradation (NHA)*

## 2.2 Preparation and optimization of binder and mixture tests

Bitumen sample preparation was one by collecting Bitumen of 60/70 penetration grade. It was then heated to a fluid state, and divided into four equal portions. The first sample was virgin Bitumen while the waste Engine Oil (WEO) in proportions of 2%, 4%, and 6% was added respectively in the remaining three prepared Bitumen samples. Conventional testing was carried out on four samples i.e virgin bitumen, bitumen +2% WEO, bitumen +4% WEO, and bitumen +6% WEO. Further experimentation introduced Elvaloy (Polymer-Based Additive), Eaton's Reagent (Chemical-Based Additive), and Hydrated Lime (Filler-Based Additive) to Waste engine oil (WEO)-modified bitumen, followed by additional testing. To restore consistency and stiffness of bitumen modified with 2%, 4%, and 6% WEO, various additive percentages were introduced: 0.5%, 0.75%, and 1% for Elvaloy, 0.5%, 0.75%, and 1% for Eaton's Reagent, and 2%, 5%, and 8% for hydrated lime, based on trial results and research recommendations. Asphalt mixture preparation involved heating aggregates according to specified Hot Mix Asphalt (HMA) gradations, then mixing it with heated bitumen and WEO combination already prepared at the desired temperature. Various sample types, incorporating different WEO percentages (2%, 4%, 6%) and additives, were prepared. A total sixty-five number samples were prepared for testing and analysis. Optimum Binder Content (OBC) was determined by the Marshall mix design method, testing different binder contents (3.5% to 5.5%) with three Marshall cakes and a loose sample for each percentage. The average OBC obtained was 4.6%, ensuring consistency in preparing modified asphalt mixtures at the same Optimum Asphalt Content (OAC). The specification for binder and asphalt mixture testing is mentioned in table No. 1.

*Table 1:Test Specifications*

| S.No | Test Name | Standard | Specification |
|---|---|---|---|
| 1 | Penetration | ASTM D36-37 | 60-70 dmm |
| 2 | Softening point | ASTM D5-13 | 49 to 56°C (120 to 133°F) |
| 3 | Marshall Stability | ASTM D1559 | 800 to 2500 Newtons |

*Figure 2:Demolding of Marshall Sample*

*Figure 3:Marshall Samples*

## 3 RESULTS AND DISCUSSION

The following results were obtained for different physical tests performed for virgin bitumen binder, and the same test procedures were followed for the modified bitumen binders.

### 3.1 Conventional Binder Results

*Table 2 Conventional binder test results*

| Physical property | Test Value | Standards |
|---|---|---|
| Penetration Test (0.1mm, 25°C) | 66 | ASTM D5 |
| Softening Point Test (°C) | 49 | ASTM D36 |
| Ductility Test (cm) (25°C) | 103 | ASTM D113 |
| Viscosity Test (Pa. s) | 336 | ASTM D4402 |

### 3.2 Modified binder results

The incorporation of waste materials like waste engine oil and various additives notably impacts the Penetration and Softening point of the virgin binder. As shown in **Table 3**, adding waste engine oil elevates the Penetration values of the control binder, reducing its consistency and softening point. These changes align with findings from earlier research carried out by Shayan Abbas at al, 2022 [5].

*Table 3: Modified binder test results*

| Bitumen type | **Penetration (ASTM D5)** | **Softening Point (ASTM D36)** |
|---|---|---|
| V-B | 66 | 46 |
| V-B2%WEO | 88 | 47 |
| V-B4%WEO | 106 | 49 |
| V-B6%WEO | 130 | 51 |
| V-B2%WEO0.5%Elvaloy | 61 | 45 |
| V-B2%WEO0.5ER | 68 | 45 |
| V-B2%WEO2%HL | 71 | 46 |
| V-B4%WEO0.75%Elvaloy | 63 | 47 |
| V-B4%WEO0.75%ER | 65 | 45 |
| V-B4%WEO5%HL | 70 | 46 |
| V-B6%WEO1%Elvaloy | 62 | 45 |
| V-B6%WEO1%ER | 65 | 45 |
| V-B6%WEO8%HL | 75 | 47 |

### 3.3 Marshall Test Results

The addition of waste engine oil (WEO) to the asphalt mix has a significant impact on Marshall stability. The "Virgin" asphalt mix exhibits the highest stability, while higher percentages of WEO result in decreasing stability values as shown in **Figure 4**. The optimal WEO content depends on specific project requirements, considering factors like stability, workability, and environmental considerations. Lower WEO percentages might be preferred when balancing stability and workability, while higher percentages may be suitable for projects prioritizing environmental benefits over maximum stability. Additional analysis is required to determine the ideal WEO content for a particular asphalt application.

As reported in prior research [16], the "Virgin" asphalt mix exhibits the highest stability, as expected, given its standard composition. However, as the percentage of WEO in the mix increases, there is a corresponding decrease in Marshall stability. The addition of WEO modifies the properties of the asphalt binder, making it softer compared to the virgin binder. This inherent softness can contribute to a reduction in the overall stability of the mix. Furthermore, higher percentages of WEO may lead to a decrease in cohesion between the aggregate particles and the binder, further impacting stability due to potential incompatibility between WEO and the original asphalt binder [17].

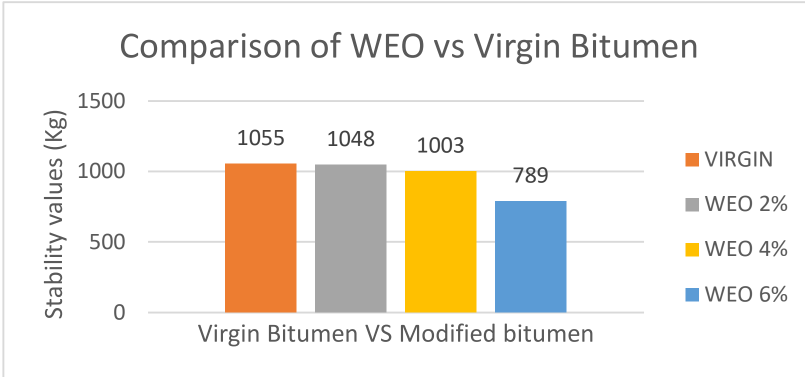


*Figure 4 : Marshall Stability of WEO vs Virgin binder*

The results indicate that the addition of both Waste Engine Oil (WEO) and Hydrated Lime (HL) can influence the Marshall stability of asphalt mixtures as shown in **Figure 5**. The "Virgin" mix exhibits good stability, while the 2% WEO + 2% HL mix shows an increase in stability. However, as the HL content is further increased in the 4% WEO + 5% HL mix, the stability significantly drops. This suggests that a higher proportion of HL has a detrimental effect on the mix's resistance to deformation. In the 6% WEO + 8% HL mix, the stability improves slightly compared to the 4% WEO + 5% HL mix, but it still falls short of the virgin mix. This indicates that even with higher WEO content, the negative influence of a substantial HL proportion persists. The behavior of these asphalt mixtures is a result of the complex interplay between the modified binder properties due to WEO, the dilution effect and reduced flexibility caused by high HL content, and the optimal balance between these additives. These results show that while WEO can enhance stability, the addition of HL in larger proportions can reduce stability. Balancing the benefits of these additives with consideration of workability and environmental factors is crucial in making informed decisions for asphalt mix design [18].

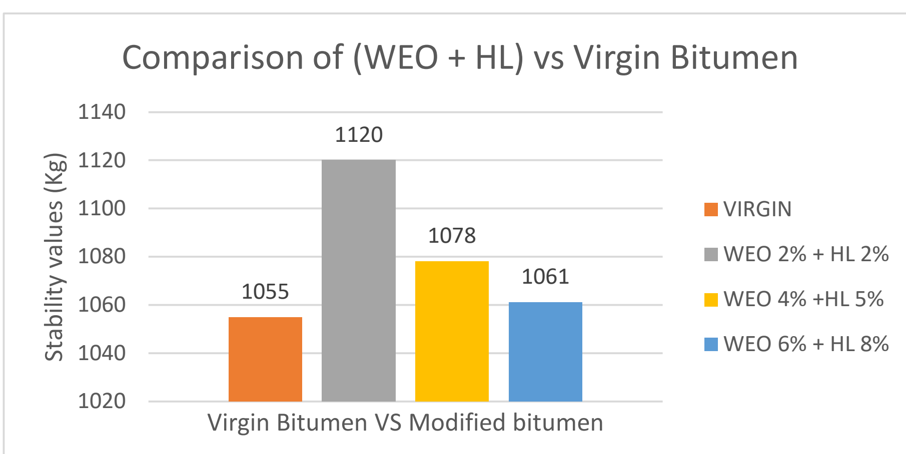


*Figure.5 Marshall Stability of WEO+HL vs Virgin binder*

Different asphalt mixtures have different Marshall stability because of the complex interactions between the amounts of waste engine oil (WEO) and Elvaloy (Elv). The virgin mix's stability of 1055 kg is higher than the ASTM standard, demonstrating the base composition's essential stability. The mixture of WEO 2% + Elv 0.5% exhibits a favorable effect, attaining stability of 1081 kg, suggesting that an equitable blend of WEO and Elv amplifies the overall stability. Nevertheless, stability decreases in subsequent combinations when the WEO percentage rises. The combination of WEO 4% + Elv 0.75% is below the ASTM minimum weight at 902 kg, indicating that the higher WEO percentage adds instability-inducing components as shown in the **Figure 6**. The likely explanation for the diminishing stability could involve changes in the rheological properties of the asphalt binder, affecting its ability to withstand loading and environmental stresses. Higher percentages of WEO and Elv might alter the binder-aggregate interaction, leading to a decrease in overall cohesion and, consequently, a reduction in Marshall stability [19].

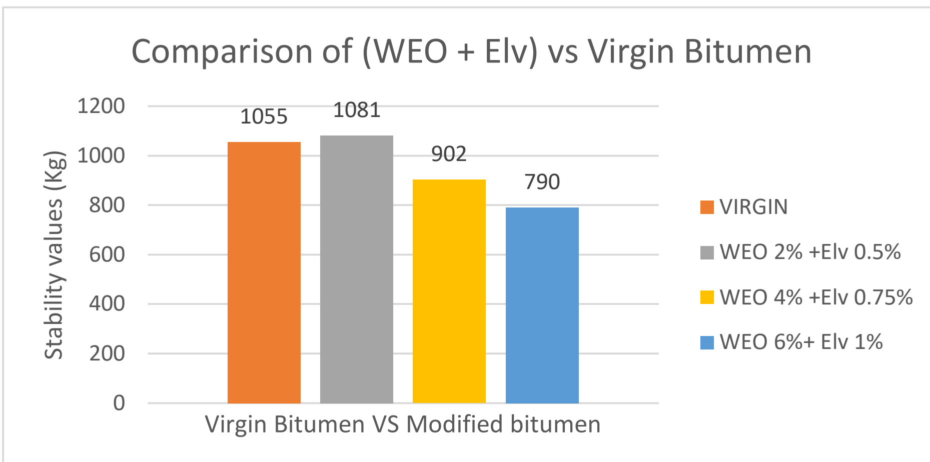


*Figure 6: Marshall Stability of WEO+Elv vs Virgin binder*

The provided data shown in **Figure 7** offers insights into The Marshall stability test results for asphalt mixtures incorporating waste engine oil (WEO) and Eaton's Reagent (ER) reveal distinctive trends in the impact of ER proportions on mixture stability. The virgin mix establishes a baseline stability of 1055 kg, exceeding the ASTM minimum requirement of 1000 kg. However, the addition of ER to the WEO mixture in the 2% + 0.5% proportion significantly reduces stability to 811 kg, falling below the ASTM standard. This suggests that the combination of 2% waste engine oil and 0.5% Eaton's Reagent has an adverse effect on asphalt mixture stability, indicating a potentially unfavorable interaction between these components. Conversely, the WEO 4% + ER 0.75% and WEO 6% + ER 1% mixtures exhibit increased stability at 1131 kg and 1079 kg, respectively. The higher stability in these mixtures suggests a positive impact of increased proportions of both waste engine oil and Eaton's Reagent. Eaton's Reagent, known for its asphalt rejuvenating properties, may enhance the flexibility of the asphalt binder, contributing to improved stability. The observed behavior underscores the importance of finding a suitable balance between waste engine oil and Eaton's Reagent to optimize asphalt mixture stability. The decrease in stability in the 2% + 0.5% mixture could be attributed to an unfavorable combination of proportions, affecting binder cohesion or rheological properties. The introduction of Eaton's Reagent in this specific proportion may have disrupted the optimal interaction between the binder and aggregates, leading to reduced stability. In contrast, the positive impact observed in the 4% + 0.75% and 6% + 1% mixtures suggests that a more favorable balance has been achieved, enhancing the overall cohesion and performance of the asphalt mixture [20].

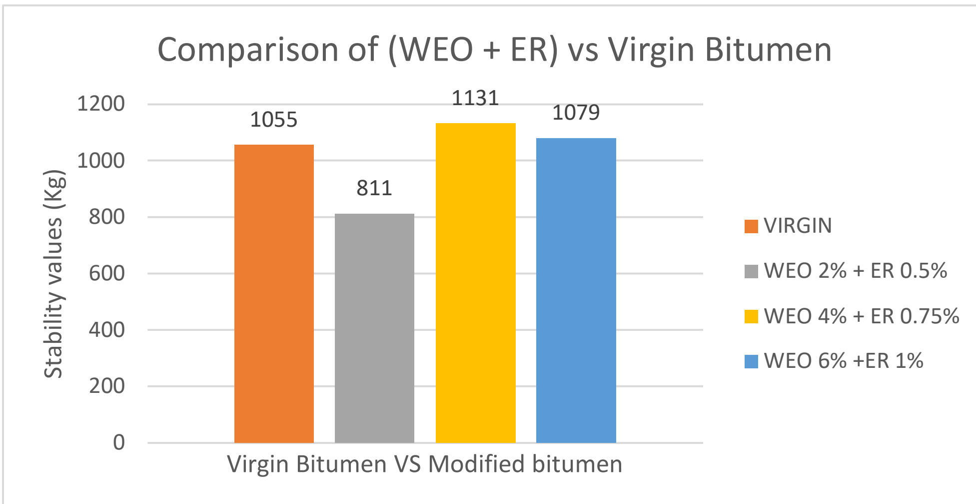


*Figure 7 : Marshall Stability of WEO+ER vs Virgin binder*

## 4 CONCLUSION AND RECOMMENDATIONS

- The study evaluates the influence of various additives, such as WEO, HL, Elvaloy, and ER, on the Marshall stability of asphalt mixtures, highlighting the need for a well-informed approach.
- WEO addition is shown to reduce stability as its concentration increases. Therefore, careful consideration is required to balance factors like stability, workability, and environmental concerns when determining the optimal WEO content.
- The inclusion of HL in the asphalt mix reveals a more complex relationship. While a 2% WEO + 2% HL mixture improves stability. This may happen due to binding properties of HL The addition of hydrated lime can also modify the rheological properties of the asphalt binder, making it more resistant to temperature-related changes and deformation. This contributes to better stability and performance of the asphalt mixture under varying environmental conditions. However, higher HL percentages have an adverse impact. This underscores the importance of maintaining a delicate balance between these additives to optimize asphalt mix stability effectively.

- Waste Engine Oil (WEO) and Elvaloy work best together in combinations that have balanced ratios and exhibit better stability—WEO 4% is one example of this. However, going over predetermined limits, as the WEO 6% mixture does, results in a significant loss of stability. Elvaloy's effect promotes stability by highlighting the significance of proportionality with awareness.
- The addition of Eaton's reagent to WEO mixtures shows varied effects: the 2% + ER 0.5% mixture exhibits decreased stability, while the 4% + ER 0.75% and 6% + ER 1% mixtures demonstrate increased stability.
- The study concludes the significance of informed decision-making when it comes to selecting additives. The optimal combination of additives, including WEO, HL, Elvaloy, and ER, should be carefully chosen based on project goals, considering factors like stability, workability, and environmental considerations. This approach ensures that asphalt mix designs are tailored to meet specific project requirements, resulting in the desired performance and properties while minimizing potential negative effects.

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## REFERENCES

[1] Hafeez, M. Ahmed Kamal, M. Reza Ahadi, Q. Shahzad, N. Bashir, and A. Professor, "*Performance Prediction of Hot Mix Asphalt from Asphalt Binders," J. Engg. & Appl. Sci*, vol. 11, pp. 104–113, 2012.

[2] K. Anupam, D. Akinmade, C. Kasbergen, S. Erkens, and F. Adebiyi, "*A state-of-the-art review of Natural bitumen in pavement: Underlining challenges and the way forward," J Clean Prod*, vol. 382, p. 134957, Jan. 2023, doi: 10.1016/J.JCLEPRO.2022.134957.

[3] M. Bilema, C. W. Yuen, M. Alharthai, Z. H. Al-Saffar, A. Al-Sabaeei, and N. I. M. Yusoff, "*A Review of Rubberised Asphalt for Flexible Pavement Applications: Production, Content, Performance, Motivations and Future Directions*," Sustainability 2023, Vol. 15, Page *14481*, vol. 15, no. 19, p. 14481, Oct. 2023, doi: 10.3390/SU151914481.

[4] H. Li, B. Dong, W. Wang, G. Zhao, P. Guo, and Q. Ma, *"Effect of Waste Engine Oil and Waste Cooking Oil on Performance Improvement of Aged Asphalt,"* Applied Sciences 2019, Vol. 9, Page 1767, vol. 9, no. 9, p. 1767, Apr. 2019, doi: 10.3390/APP9091767.

[5] S. Abbas, S. B. A. Zaidi, and I. Ahmed, *"Performance evaluation of asphalt binders modified with waste engine oil and various additives,"* International Journal of Pavement Engineering, 2022, doi: 10.1080/10298436.2022.2128353.

[6] S. Liu, H. Meng, Y. Xu, and S. Zhou, "*Evaluation of rheological characteristics of asphalt modified with waste engine oil (WEO),*" Pet Sci Technol, vol. 36, no. 6, pp. 475–480, Mar. 2018, doi: 10.1080/10916466.2018.1430157.

[7] W. Wang *et al.*, "*High temperature property and modification mechanism of asphalt containing waste engine oil bottom,"* Constar Build Mater, vol. 261, p. 119977, Nov. 2020, doi: 10.1016/J.CONBUILDMAT.2020.119977.

[8] D. Singh, P. K. Ashish, A. Kataware, and A. Habal, *"Effects of WMA additives and hydrated lime on high-stress and high-temperature performance of Elvaloy®- and PPA-modified asphalt binder,"* Road Materials and Pavement Design, vol. 20, no. 6, pp. 1354–1375, Aug. 2019, doi: 10.1080/14680629.2018.1446040.

[9] S. Alam and Z. Hossain, *"Changes in fractional compositions of PPA and SBS modified asphalt binders,"* Constr Build Mater, vol. 152, pp. 386–393, Oct. 2017, doi: 10.1016/J.CONBUILDMAT.2017.07.021.

[10] F. Zhang, C. Hu, and Y. Zhang, *"The effect of PPA on performances and structures of high-viscosity modified asphalt,"* J Therm Anal Calorim, vol. 134, no. 3, pp. 1729–1738, Dec. 2018, doi: 10.1007/S10973-018-7740-7.

[11] S. Han, S. Dong, Y. Yin, M. Liu, and Y. Liu, *"Study on the effect of hydrated lime content and fineness on asphalt properties,"* Constr Build Mater, vol. 244, p. 118379, May 2020, doi: 10.1016/J.CONBUILDMAT.2020.118379.

[12] N. F. Rohayzi, H. Y. B. Katman, M. R. Ibrahim, S. Norhisham, and N. A. Rahman, "*Potential Additives in Natural Rubber-Modified Bitumen: A Review,"* Polymers 2023, Vol. 15, Page 1951, vol. 15, no. 8, p. 1951, Apr. 2023, doi: 10.3390/POLYM15081951.

[13] D. Khan, R. Khan, M. T. Khan, M. Alam, and T. Hassan, *"Performance of hot-mix asphalt using polymer-modified bitumen and marble dust as a filler,"* Journal of Traffic and Transportation Engineering (English Edition), vol. 10, no. 3, pp. 385–398, Jun. 2023, doi: 10.1016/J.JTTE.2022.12.002.

[14] J. Cvengroš, T. Liptaj, and N. Prónayová, *"Study of Polyaromatic Hydrocarbons in Current Used Motor Oils,"* International Journal of Petrochemical Science & Engineering, vol. Volume 2, no. Issue 7, Sep. 2017, doi: 10.15406/IPCSE.2017.02.00060.

[15] A. Eltwati *et al.*, *"Effect of Warm Mix Asphalt (WMA) Antistripping Agent on Performance of Waste Engine Oil-Rejuvenated Asphalt Binders and Mixtures,"* Sustainability 2023, Vol. 15, Page 3807, vol. 15, no. 4, p. 3807, Feb. 2023, doi: 10.3390/SU15043807.

[16] N. F. Rohayzi, H. Y. B. Katman, M. R. Ibrahim, S. Norhisham, and N. A. Rahman, *"Potential Additives in Natural Rubber-Modified Bitumen: A Review,"* Polymers 2023, Vol. 15, Page 1951, vol. 15, no. 8, p. 1951, Apr. 2023, doi: 10.3390/POLYM15081951.

[17] X. Zhang, T. Fidai, I. Hoff, B. O. Lerfald, and H. Chen, *"Determination of Rejuvenator Proportion within the Recycled Bitumen: Empirical Double-Logarithmic Formula and Calibration,"* Journal of Materials in Civil Engineering, vol. 34, no. 12, Dec. 2022, doi: 10.1061/(ASCE)MT.1943-5533.0004477.

[18] W. Tang, X. Yu, N. Li, F. Dong, Z. Wang, and Y. Zhang, "*Effect of Rejuvenators on the Workability and Performances of Reclaimed Asphalt Mixtures,"* Materials, vol. 14, no. 21, Nov. 2021, doi: 10.3390/MA14216385.

[19] N. F. Rohayzi, H. Y. B. Katman, M. R. Ibrahim, S. Norhisham, and N. A. Rahman, "*Potential Additives in Natural Rubber-Modified Bitumen: A Review,"* Polymers (Basel), vol. 15, no. 8, Apr. 2023, doi: 10.3390/POLYM15081951.

[20] G. Shafabakhsh, A. Rahmani, and M. Sadeghnejad, *"Evaluation the Effect of Different Kind of Waste and Mineral Filler on the Fatigue Life of Asphalt Mixtures with Dissipated Energy Method,"* Journal of Rehabilitation in Civil Engineering, vol. 10, no. 2, pp. 56–67, Mar. 2022, doi: 10.22075/JRCE.2021.22232.1468.