

Research Article

Effect of Styrofoam Waste Substitution on the Performance of Asphalt Concrete Wearing Course in Cattle Manure Immersion

Liza Afra, Nura Usrina*, Khairul Amna, Zulfhazli Abdullah, Mukhlis

Department of Civil Engineering, Faculty of Engineering, Universitas Malikussaleh, Aceh, Indonesia, 24351

*Corresponding Author: nurausrina@unimal.ac.id | Phone: +6285277225166

ABSTRACT

The presence of cattle manure on road surfaces contributes to the deterioration of asphalt pavement on highways due to its high nutrient content. The incorporation of Styrofoam into the asphalt mixture is anticipated to enhance its engineering properties. This research aims to analyze the Marshall characteristics of Asphalt Concrete-Wearing Course (AC-WC) mixtures, utilizing 60/70 penetration grade asphalt, with the addition of 5%, 7%, and 9% waste Styrofoam by weight of asphalt. These mixtures were subjected to immersion in cattle manure for durations of 30 minutes, 24 hours, and 48 hours. The optimal stability value of 1972.55 kg was achieved with a 5% Styrofoam substitution. All evaluated parameters for mixtures, both with and without Styrofoam including stability, flow, Marshall Quotient (MQ), density, Void in the Mix (VIM), Voids in Mineral Aggregate (VMA), and Voids Filled with Asphalt (VFA)—were found to comply with the 2018 Bina Marga specifications. The durability value for the control mixture (without substitution) was 92.64% under standard water immersion and 90.80% under cattle manure immersion. Furthermore, the mixture with a 5% Styrofoam addition exhibited a durability value of 95.56%, which also satisfies the Bina Marga 2018 requirement of being greater than or equal to (\geq) 90%.

Keywords: Styrofoam; Laston; Asphalt Mix; Polymer

1. INTRODUCTION

The presence of free-roaming cattle on public roads not only poses a disturbance and potential hazard to traffic but also results in the deposition of manure on pavement surfaces, which generates unpleasant odors. Furthermore, cattle manure contributes to the deterioration of road infrastructure. It contains significant concentrations of nutrients and chemical compounds, including methane (CH_4), carbon dioxide (CO_2), nitrogen, propane (C_3H_8), and possesses a pH level ranging from 6.5 to 7.5%. These properties can degrade the adhesive bond within the asphalt mixture (Hamzani, 2021). Similar studies on asphalt treated base mixtures under submersion conditions reported a significant influence on Marshall stability (Alamsyah & Mahabella, 2024). Consequently, enhancing the road infrastructure in Aceh Province, specifically the quality of the pavement, is imperative to mitigate premature road surface damage induced by exposure to cattle manure. Case studies of flexible pavement deterioration and repair costs highlight the economic impact of premature failures. Case studies of flexible pavement deterioration and repair costs highlight the economic impact of premature failures (Muzhaffar et al., 2023). A strategic approach to prevent such damage involves improving the performance of asphalt, which serves as the binding agent for aggregates in flexible pavements. Numerous studies have focused on modifying asphalt to enhance the quality of Hot Mix Asphalt Concrete. A prevalent modification technique involves the incorporation of additives, such as Styrofoam. Styrofoam, a foam plastic polymer, is extensively utilized as protective and shock-absorbing packaging for fragile goods like electronics, as well as for food and beverage containers. As a derivative of polystyrene, Styrofoam is characterized by its very low density, rigidity, and low cost; however, it is also non-biodegradable, presenting a significant waste management challenge. The integration of Styrofoam into asphalt mixtures is hypothesized to reduce the overall density and enhance the stability of the resulting asphalt composite (Fitriansyah et al., 2024). In addition, PET waste has been applied successfully as an additive in HRS-WC asphalt mixtures (Damopolii et al., 2022). LDPE-modified asphalt has also been reported to improve the mechanical properties of AC-WC (Razak & Erdiansa, 2016). LDPE modification has also been extended to AC-BC mixtures with improved strength characteristics (Sulianti et al., 2020). HDPE substitution has been tested using both BM and BBA gradations with favorable outcomes (Larasati et al., 2023).

Other natural materials such as coconut shell have also been incorporated into asphalt mixtures to enhance engineering properties (Manap et al., 2016). Similarly, coconut charcoal powder has been employed as filler in asphalt concrete with promising results (Nur et al., 2017). Binder modifications have also been reported to significantly improve resistance to low-

temperature cracking (Teltayev et al., 2019). A critical review has emphasized the effectiveness of plastic waste in improving Marshall properties of asphalt mixes (Heydari et al., 2021). Such innovations in asphalt modification are aligned with sustainable infrastructure development strategies (Ferliansyah & Aini, 2025). Similar waste-to-resource practices have been emphasized in international case studies on solid waste management (Ajinawo & Aribasoye, 2023). Incorporating waste materials into asphalt not only enhances performance but also supports environmental innovation with financial benefits (Yuniarti et al., 2023). Given that cattle primarily affect the uppermost layer of the road pavement with their manure, this research specifically investigates the Asphalt Concrete-Wearing Course (AC-WC). The AC-WC layer constitutes the surface course of highway pavement systems and is, therefore, the component most directly exposed to cattle manure.

2. RESEARCH METHOD

2.1 Asphalt

Asphalt is a thermoplastic material that softens upon heating and solidifies upon cooling. When combined with aggregates, it forms the fundamental binding component in asphalt pavement mixtures. The typical asphalt content in such mixtures, ranges from 4% to 10% by weight, or 10% to 15% by volume (Sukarman, 2025).

Table 1. Physical Properties Requirements for 60/70 Penetration Asphalt

Physical Properties of Asphalt	Standard	Requirement
Specific Gravity (25°C)	SNI 2441-2011 (Badan Standardisasi Nasional, 2011b)	≥ 1.0
Penetration (25°C; 5 sec; 0.1 mm; 100 g)	SNI 06-2456-2011 (Badan Standardisasi Nasional, 2011c)	60–70
Ductility (25°C; 5 cm/min)	SNI 2432-2011 (Badan Standardisasi Nasional, 2011a)	≥ 100
Softening Point (°C)	SNI 2432-2011 (Badan Standardisasi Nasional, 2011a)	≥ 48
Solubility in Trichloroethylene (%)	AASHTO T44-03 (AASHTO, 2015)	≥ 99
Weight Loss (TFOT) (% mass)	SNI 2441-2011 (Badan Standardisasi Nasional, 2011b)	≥ 1.0
Retained Penetration (% of original)	SNI 06-2456-2011 (Badan Standardisasi Nasional, 2011c)	60–70
Retained Ductility (% of original)	SNI 2432-2011 (Badan Standardisasi Nasional, 2011a)	≥ 100

Source: (Direktur Jenderal Bina Marga, 2018)

The specific gravity and absorption test for coarse aggregates follows SNI 1969-2016 (Badan Standardisasi Nasional, 2016), Aggregate abrasion resistance is determined using the Los Angeles Abrasion method that available on (Badan Standardisasi Nasional, 2008).

2.2 Modified Styrofoam Asphalt

Styrofoam, or expanded polystyrene (EPS) foam, is a polymeric material characterized by a closed-cell structure, low density, and light weight. Its interstitial spaces are filled with air, granting it low thermal conductivity and making it an effective thermal insulator. Key properties of Styrofoam include resistance to acids, bases, and corrosive substances, a melting point between 1020–1060°C, high compressive strength, and the ability to retard the rate of heat hydration (Arianto et al., 2019).

2.3 Cattle Manure

Cattle manure is an agricultural by-product with a high fibrous cellulose content, existing in both solid and liquid states. It is a complex carbon-based compound that undergoes microbial decomposition, a process facilitated by the significant nitrogen content present in the manure. Beyond its high organic fiber and moisture content, cattle manure is also rich in macro and micronutrients. Its typical composition includes a maximum C/N ratio of 20, Nitrogen (N) > 1.81%, P₂O₅ > 1.89%, K₂O > 1.96%, CaO > 2.96%, MgO > 0.70%, a Cation Exchange Capacity > 75 me/100 g, and a pH range of 6.5–7.5%. Solid manure typically contains 0.3% N, 0.2% P₂O₅, 0.15% K₂O, and 0.2% CaO. The precise nutrient profile is highly dependent on the livestock's diet and environment (Afra et al., 2018). As an organic amendment, cattle manure specifically enhances phosphorus and micronutrient availability, containing substantial levels of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and boron (Weil & Brady, 2017).

2.4 Design Asphalt Content (Pb)

The initial design of an asphalt mixture requires an estimated asphalt content. This midpoint or ideal content (a, %) is then varied to produce five trial blends: (a-1)%, (a-0.5)%, a%, (a+0.5)%, and (a+1)%. The median asphalt content, termed the design asphalt content (Pb), can be calculated using the following empirical formula (Asphalt Institute, 2015):

$$Pb = 0.035(\%CA) + 0.045(\%FA) + 0.18(\%Filler) + K$$

Where:

Pb = Design asphalt content (% by total mix weight)

CA = Percentage of coarse aggregate retained on the No. 8 sieve

FA = Percentage of fine aggregate passing the No. 8 sieve and retained on the No. 200 sieve

Filler = Percentage of material passing the No. 200 sieve ($\geq 6.5\%$)

K = Constant, typically between 0.5–1.0 for AC and HRS mixtures

2.5 Marshall Test

According to (Sukarman, 2025), the most prevalent empirical mix design method in Indonesia utilizes the Marshall apparatus (Hamzani et al., 2023). The Marshall test is employed to characterize asphalt mixtures by evaluating key parameters: stability, flow, Marshall Quotient (MQ), density, Void in the Mix (VIM), Voids in Mineral Aggregate (VMA), and Voids Filled with Asphalt (VFA). The stability (S) value can be calculated using the following equation (Badan Standardisasi Nasional, 1991):

$$S = p \times q \times r$$

Where:

S = Stability (kg)

p = Apparatus calibration factor

q = Dial gauge reading (kg)

r = Specimen correction factor

The Marshall Quotient (MQ), an indicator of the mixture's stiffness and resistance to deformation, is derived from the ratio of stability to flow (Elnihum et al., 2024):

$$MQ = S / Flow$$

Where:

MQ = Marshall Quotient (kg/mm)

S = Stability value (kg)

Flow = Deformation at failure (mm)

3. RESULTS AND DISCUSSION

A comprehensive analysis of aggregate physical properties was conducted, encompassing specific gravity, water absorption, bulk density, abrasion resistance, aggregate shape (including the flat and elongation indices), impact value, and adhesion to asphalt. The results, which conform to specified requirements, are presented in **Table 2**.

Table 2. Physical Properties of Aggregates

Physical Properties of Asphalt	Unit	Results	Requirement
Specific Gravity	-	2.775	Min. 2.5
Water Absorption	%	1.119	Max. 3.0
Bulk Density	kg/m ³	1,656	Min. 1,000
Flakiness Index	%	17.18	Max. 10
Elongation Index	%	15.38	Max. 10
Aggregate Impact Value	%	8.94	Max. 30
Los Angeles Abrasion	%	15.00	Max. 40
Adhesion to Asphalt	%	95	Min. 95

Subsequent Marshall testing across a range of asphalt contents (4.5%, 5.0%, 5.5%, 6.0%, and 6.5%) was performed to determine the Optimum Asphalt Content (OAC) for the AC-WC mixture. Analysis of these results, as illustrated in Figure 1, established an OAC of 5.52%, which was subsequently used to fabricate all test specimens with varying Styrofoam substitution percentages.

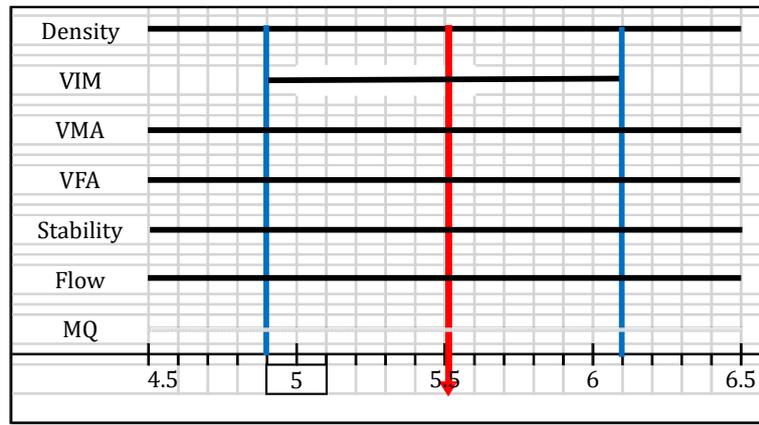


Figure 1. Optimum Asphalt Content 5.52%

3.1 Review of the Physical Properties of Asphalt

The fundamental properties of the 60/70 penetration grade asphalt, namely specific gravity, penetration, softening point, and ductility, were evaluated with Styrofoam substitutions of 0% (control), 5%, 7%, and 9%. The results are summarized in Figure 2.

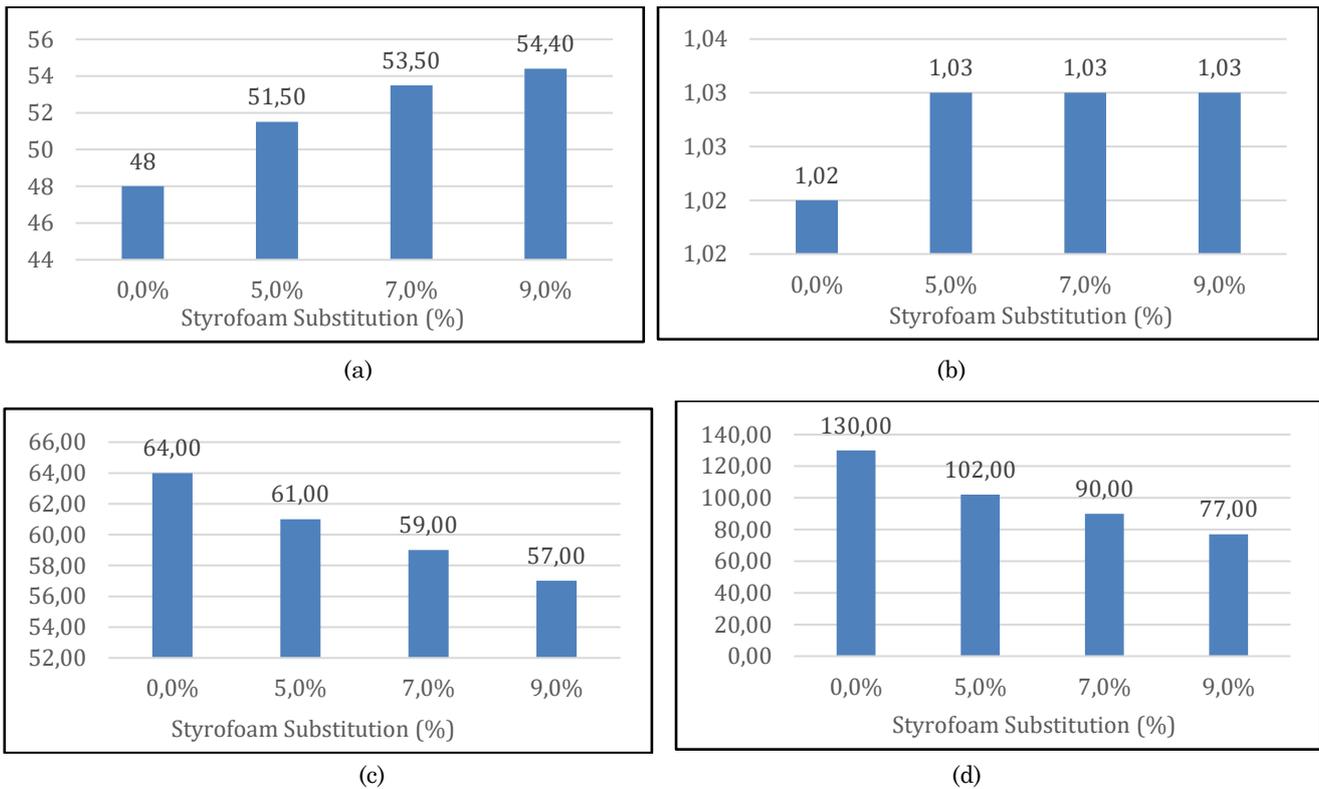


Figure 2. Effect of Styrofoam substitution percentage on (a) softening point, (b) specific gravity of asphalt, (c) penetration and (d) ductility of asphalt.

The softening point elevated proportionally with the percentage of Styrofoam substitution. This suggests enhanced thermal stability and improved resistance to temperature-related deformation (rutting). A decrease in penetration value was observed with increasing Styrofoam content, indicating a hardening effect on the asphalt binder. The ductility value decreased as the Styrofoam content rose, a consequence of the increased binder stiffness which reduces its plasticity. Despite this reduction, all values remained above the minimum specification requirement of 50 cm. Stability, which reflects the mixture's maximum load-bearing capacity, is shown in Figure 3.

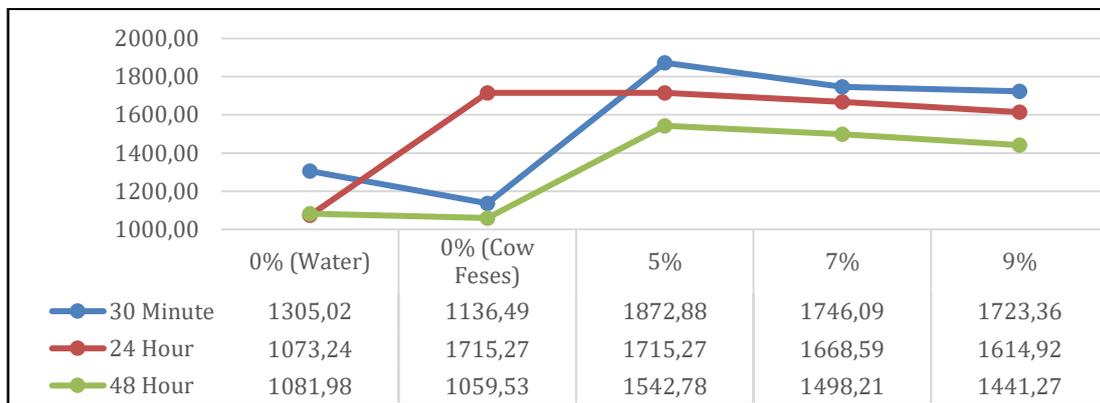


Figure 3. Effect of soaking time on stability value

The results indicate that stability is influenced by both the immersion duration in cattle manure and the percentage of Styrofoam substitution. Flow represents the plastic deformation a mixture undergoes at its maximum load. As depicted in Figure 4 as shown below:

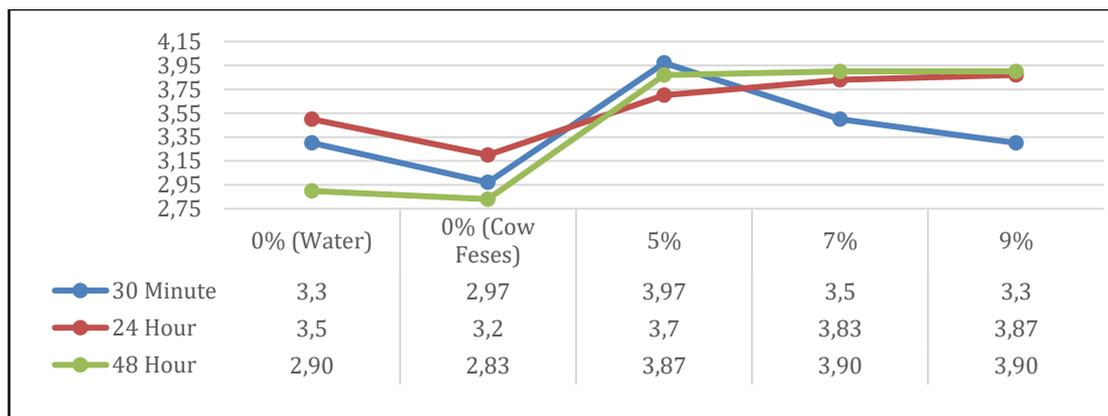


Figure 4. The effect of soaking time on flow value

As shown from Figure 4, the flow value increases with higher asphalt content. This is attributed to the thermoplastic nature of asphalt, which is susceptible to the combined effects of temperature and chemical exposure from cattle manure immersion. Mixtures with higher Styrofoam content also exhibited an increase in flow with longer immersion times. The Marshall Quotient (MQ), calculated as the ratio of stability to flow ($MQ = \text{Stability} / \text{Flow}$), is an indicator of the mixture's stiffness and resistance to permanent deformation. A higher MQ denotes a more rigid mixture, while a lower MQ suggests greater flexibility. The results, presented in Figure 5.

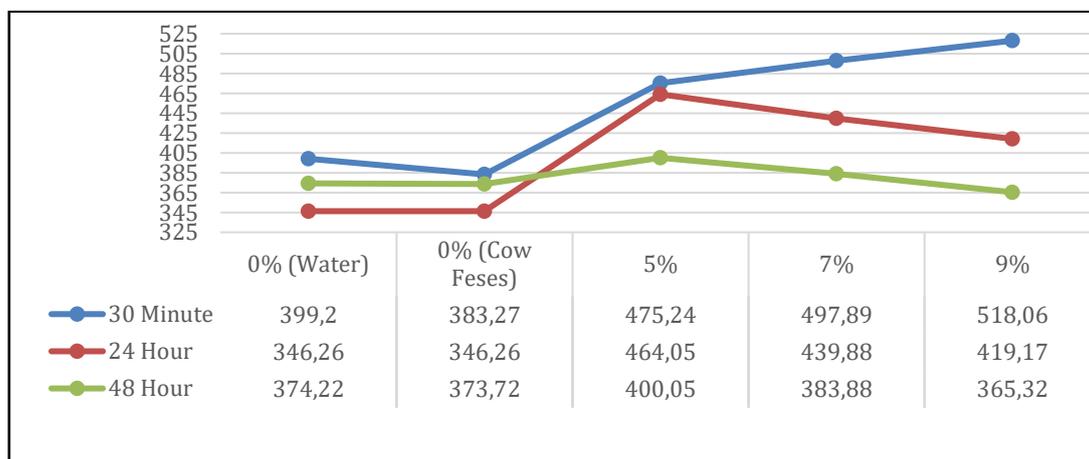


Figure 5. The effect of soaking time on the Marshall Quotient

The Figure 6 show that MQ is intrinsically linked to the stability and flow behavior. The bulk density of the compacted specimens is shown in Figure 6.

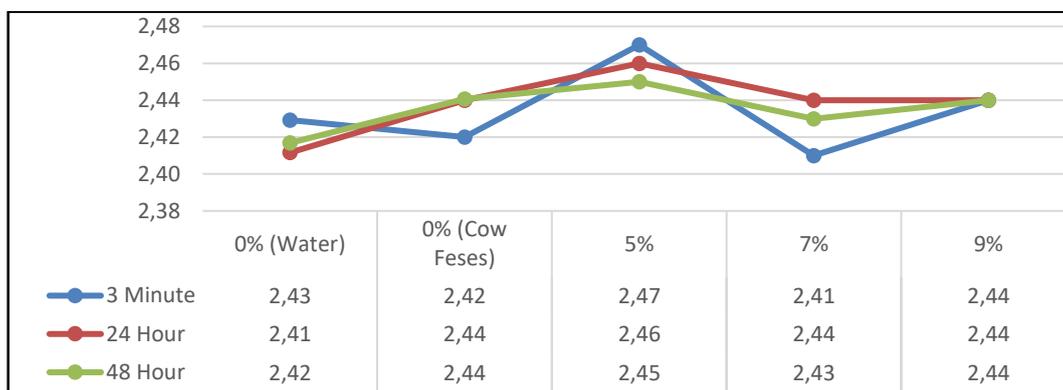


Figure 6. The effect of soaking time on density value

The data demonstrates an inverse relationship between density and Styrofoam content. This is due to the lower specific gravity of Styrofoam and its potential effect on the binder's ability to fully coat and fill the voids between aggregate particles. The volume of air voids trapped within the compacted mixture (VIM) is presented in Figure 7 as shown below:

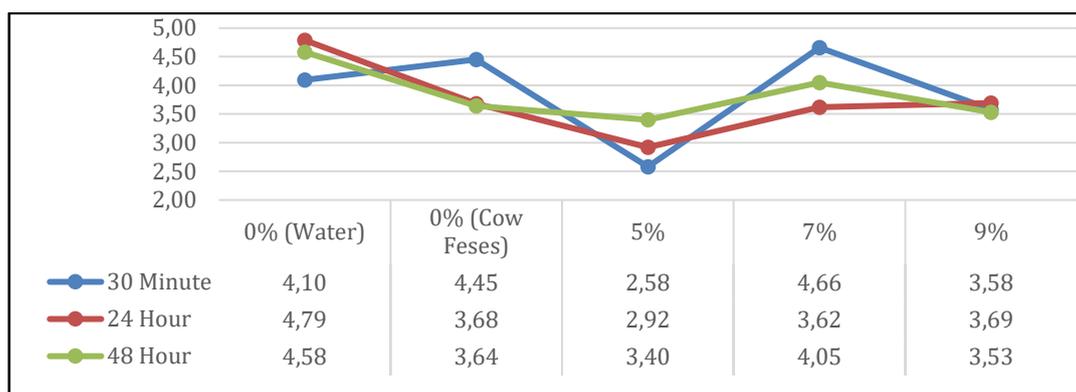


Figure 7. The effect of soaking time on VIM value

The VIM value exhibited a positive correlation with the percentage of Styrofoam substitution. This increase is likely due to the absorption of the maltene oil fraction by the Styrofoam, which increases the binder's viscosity, making it less efficient at filling voids during compaction, and the inherent lower density of the modifier. VMA represents the void space between the aggregate particles that is available to be filled by asphalt. As shown in Figure 8.

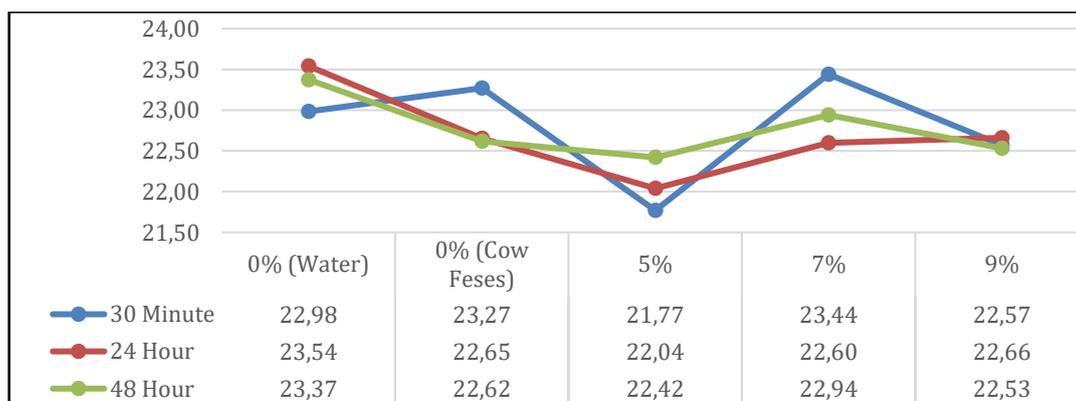


Figure 8. The effect soaking time on VMA value

As shown in Figure 8, the VMA value increased with higher Styrofoam content. This can be attributed to the combined effects of the observed increase in VIM and the volumetric displacement caused by the additive. VFA is a critical parameter for mixture durability, indicating the proportion of the inter-aggregate void space that is filled with asphalt binder. A higher VFA generally correlates with improved durability. The results as shown on Figure 9.

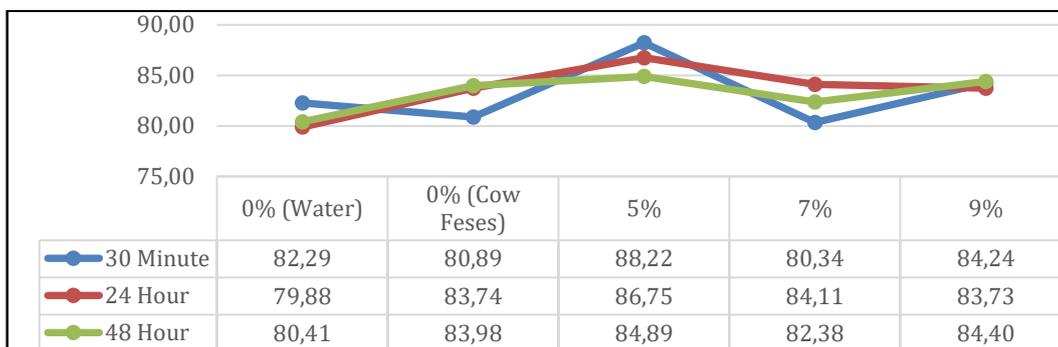


Figure 9. The effect soaking time on VFA value

Figure 9 show the effect of immersion conditions and Styrofoam content on this parameter. The Index of Retained Strength (IRS), a measure of the mixture's resistance to moisture-induced damage, is shown in Figure 10.

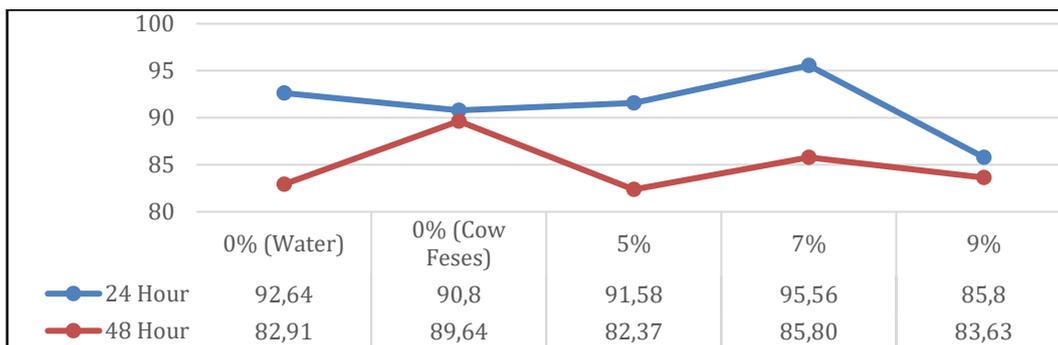


Figure 10. The effect soaking time on IRS

The IRS compares the stability of conditioned specimens (immersed in cattle manure) to the stability of unconditioned specimens, evaluating the detrimental effects of the manure's chemical composition on the asphalt-aggregate bond.

4. CONCLUSION

The obtained stability values satisfy the specified requirements of ≥ 800 kg for AC-Laston mixtures and ≥ 1000 kg for AC-Modified mixtures. Testing of the physical properties of asphalt with varying proportions of Styrofoam waste relative to asphalt weight at the Optimum Asphalt Content (OAC) indicates an enhancement in asphalt rheology with increasing substitution percentage. The incorporation of Styrofoam waste influences density and softening point, while decreasing penetration value and ductility. However, the softening point results remain below the required specification of $\geq 54^\circ\text{C}$. Evaluation of Marshall characteristics in AC-WC mixtures with Styrofoam waste substitution at an OAC of 5.52% revealed that Stability, Marshall Quotient (MQ), Voids in Mineral Aggregate (VMA), and Voids in Mix (VIM) generally increase with higher substitution percentages. Conversely, Density, Flow, and Voids Filled with Asphalt (VFA) exhibit a decreasing trend. Indirect Retained Strength (IRS) values for mixtures with Styrofoam substitution indicated a reduction in strength after 48 hours of immersion, although the 24-hour immersion results remained above the specified threshold of $\geq 90\%$. The effect of Styrofoam waste substitution on Marshall parameters demonstrates a notable influence on Stability, Flow, and MQ with extended immersion duration in cattle manure solution (30 minutes, 24 hours, and 48 hours). A substitution level of 5% Styrofoam waste is identified as optimal for asphalt pavement applications, yielding superior stability performance compared to higher substitution percentages.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed for future research and practical application:

- Implementation of Modified Asphalt: The use of Styrofoam waste as an asphalt modifier at a 5% substitution level is recommended for Asphalt Concrete-Wearing Course (AC-WC) pavements in areas prone to cattle manure exposure. This dosage provides an optimal balance, enhancing stability and Marshall Quotient while maintaining other parameters within acceptable limits.
- Mitigation of Long-Term Exposure: Given the significant reduction in Indirect Retained Strength (IRS) observed after 48 hours of immersion, preventive measures should be implemented to minimize prolonged contact between pavement surfaces and cattle manure. This includes regular road cleaning schedules and strategies for managing free-roaming

cattle near high-traffic infrastructure.

- Further Investigation on Softening Point: Subsequent research should focus on modifying the Styrofoam-asphalt blend to address the deficiency in the softening point property. The investigation of complementary additives or alternative polymer modification processes is necessary to achieve the required specification of $\geq 54^{\circ}\text{C}$.
- Field Validation and Long-Term Performance Study: It is recommended to conduct field trials and long-term performance monitoring of pavements constructed with the 5% Styrofoam-modified asphalt. This will provide critical data on its behavior under real-world traffic loads, environmental conditions, and intermittent manure exposure.
- Exploration of Alternative Waste Materials: Future studies should explore the potential of combining Styrofoam with other waste materials or modifiers to improve the overall performance characteristics, particularly ductility and resistance to chemical attack from organic pollutants like manure.

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