Smart Green Materials

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Research Article

Fiber from Coconut as Smart Materials in Road Construction

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Abstract

This study investigates the effects of incorporating coconut fiber as a sustainable modifier in bitumen mixtures, focusing on its impact on mechanical properties such as Marshall stability, indirect tensile strength (ITS), flow, stiffness, and abrasion resistance. Coconut fiber was added at varying percentages (0%, 0.50%, 0.75%, and 1%) to evaluate its performance. The Marshall stability results revealed a significant improvement at 1% fiber content, achieving the highest stability of 11.978 kN, while ITS exhibited a strong polynomial correlation (R^2 = 0.9818) with fiber content, peaking at 423 kPa for the same fiber percentage. Flow and stiffness showed non-linear trends, with optimal results observed at specific fiber levels, reflecting the complex interaction between fiber dispersion and matrix bonding. Abrasion loss analysis indicated that lower fiber percentages (0.50%) enhanced wear resistance, while higher contents (1%) improved structural integrity but increased susceptibility to wear. The findings highlight that 1% coconut fiber content provides the best balance between mechanical strength and durability, offering a promising approach for enhancing bitumen performance in sustainable road construction. These results underscore the potential of coconut fiber as a cost-effective and environmentally friendly material for improving the performance of bituminous mixtures, aligning with sustainable development goals.

Keywords: Coconut Fiber, Marshall Stability, Tensile Strength, Abrasion Loss

Introduction

The increasing demand for durable and cost-effective pavements has highlighted several challenges faced by modern bitumen roads. Over time, bitumen pavements are subjected to harsh environmental conditions and traffic loads, resulting in common issues such as rutting, cracking, fatigue, and stripping [1, 2]. These distresses lead to reduced pavement performance and increased maintenance costs, placing a financial strain on infrastructure budgets. Furthermore, the need for more sustainable and environmentally friendly construction practices has grown, pushing researchers to explore innovative materials and techniques to enhance pavement durability and reduce its environmental impact [3].

Modified bitumen binders and mixtures incorporating waste materials have gained attention as sustainable alternatives in addressing these challenges [4, 5, 6]. Numerous studies have evaluated the performance of materials such as palm oil fuel ash [7], sawdust [8], fibers [9], nanomaterials [10], and waste cooking oil [11, 12] in enhancing bitumen properties. Fibers, including synthetic and natural types, are widely used to increase tensile strength and reduce cracking susceptibility in bitumen mixtures, offering sustainable and cost-effective solutions for pavement constructionavailable natural material, has emerged as a potential modifier for bitumen in recent years [13].

Previous studies have demonstrated that coconut fiber can improve the mechanical and chemical properties of bitumen mixtures. For instance, researchers have reported that adding coconut fiber enhances the tensile strength and Marshall stability of bitumen mixtures, providing better resistance to deformation and cracking [14]. In terms of chemical properties, coconut fiber improved bonding within the bitumen matrix due to its lignocellulosic composition, which interacts effectively with bitumen [15]. Tan et al. [16] focused on the chemical treatment of coconut fibers through mercerization (NaOH) and acetylation (CH_3COOH) and their study revealed that treated fibers exhibited lower penetration values and higher softening points, with 10% NaOH and 50% CH_3COOH-treated fibers showing optimal enhancement for bitumen performance in warmer climates. Che Wan et al. [15] further demonstrated that chemically treating CF with NaOH enhances binder properties by lowering penetration values and increasing the softening point, indicating improved stiffness and resistance to deformation. Additionally, their study revealed that adding 0.7% CF effectively prevents flow at high mixing and compaction temperatures, ensuring stability during construction. These findings collectively highlight the multifaceted benefits of CF in bitumen modification, from improving binder performance to addressing thermal sensitivity.

Zulkafli et al. [17] investigated the influence of coconut fiber addition (0.5%, 0.75%, and 1%) on the fatigue resistance of bitumen mixtures using penetration-grade 60/70 bitumen. Through indirect tensile fatigue testing, they demonstrated that increasing the coconut fiber content improved the physical properties of bitumen and significantly enhanced the life cycle of the bitumen mixtures, with up to 1% fiber addition yielding the best fatigue resistance. Chin and Charoentham [18] evaluated the impact of coconut fiber lengths (5–20 mm and 20–40 mm) on the performance of stone mastic bitumen mixtures using Marshall stability tests. Their findings indicated that shorter fibers (5–20 mm) yielded approximately 5% higher stability values and better workability during mixing and compaction compared to longer fibers, emphasizing the critical role of fiber dimensions in mixture performance.

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Furthermore, Ting et al. [19] demonstrated that coconut shell and fiber significantly improve the stability, skid resistance, and resilient modulus of bitumen mixtures. However, the study noted that coconut fiber does not enhance the fatigue life of modified bituminous mixes, indicating limitations in long-term performance under repeated loading. Yousif et al. [20] focused on the use of coconut husk powder, passing through sieve no. 200 (0.075 mm), as a fine modifier in bitumen binders. By varying the additive content (0–10% by binder weight), they found that 7–8% replacement yielded the best physical and rheological properties, including improved penetration, softening point, and dynamic shear performance. This highlights the role of fine particle size in achieving enhanced binder characteristics.

Meanwhile, Ashfaq et al. [21] compared coconut fiber to polyethylene terephthalate (PET) as modifiers and found that coconut fiber effectively stabilizes bitumen mixtures, particularly in stone matrix bitumen. Maharaj et al. [22] and Yousif et al. [20] found that adding coconut fiber improves the bitumen binder's resilience to temperature variations and load stresses, making it more adaptable to fluctuating environmental and traffic conditions.

This study addresses the existing research gap by systematically evaluating the effects of varying coconut fiber content on the mechanical, physical, and durability properties of bituminous mixtures. Limitations in prior research include inconsistent results regarding the optimal fiber dosage and insufficient exploration of the balance between durability and mechanical strength. The primary objective of this study is to assess the performance of coconut fiber-modified bitumen mixtures at different fiber contents (0%, 0.50%, 0.75%, and 1%) by analyzing Marshall stability, indirect tensile strength, flow, stiffness, and abrasion resistance. This study aims to provide insights into the potential of coconut fiber as a sustainable and cost-effective modifier for enhancing pavement performance while addressing environmental sustainability goals.

Materials and Methods

Coconut Fiber

Coconut fiber, sourced from the husk of coconuts (Figure 1), is a naturally durable and fibrous material. It is typically light to dark brown, depending on the processing stage, and has a strong, coarse texture. The fabrics are strong and durable. The coconut fiber content used in this experiment is of 0%, 0.50%, 0.75% and 1% of 20 mm and added in discrete manner. The selected fiber content proportions were chosen based on prior studies [16] that identified these levels as effective ranges for enhancing the mechanical properties of bitumen mixtures without causing excessive brittleness or workability issues, ensuring a balance between improved performance and practical application. The fiber lengths of <20 mm were selected to ensure compatibility with bitumen mixing and compaction processes [17], as excessively long fibers could hinder uniform distribution and workability. The chemical composition and physical properties of coconut fibers are characterized according to Table 1 [23] and Table 2, making

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them suitable for improving the structural integrity and toughness of bitumen composites in bitumen applications.

Figure 1. Preparation of coconut fiber and mixture

Table 1. Coconut fiber's chemical properties [23]

Chemical Properties	Composition (%)
Lignin	45.84
Cellulose	43.44
Hemi-cellulose	0.03
Pectin's related compound	3.33
Water soluble	5.25
Ash	2.11

Table 2. Coconut fiber's physical properties

Physical Properties	Composition (%)
Length	< 20 mm
Density	1.40 g/cm^3
Elongation	25%
Diameter	< 1 mm

BITUMEN

Bitumen of grade 60/70 PEN was used as the primary binder and was obtained from the Kemaman Bitumen Company, Terengganu, Malaysia.

AGGREGATE

The coarse aggregate used in this study consists of granite particles passing 12.5 mm and retained on 9.5 mm BS sieves, while the fine aggregate used in the study is river bed sand with particle sizes fractions passing 4.25 mm and retained on 0.075 mm BS sieves. The aggregate characteristics and gradation for the blend used in this study are shown in Figure 2. They were all obtained from the Bekelah Quarry, Pahang, Malaysia.

EXPERIMENTAL

The experimental procedure (Figure 3) for this study was designed to evaluate the performance of coconut fiber-modified bitumen mixtures through

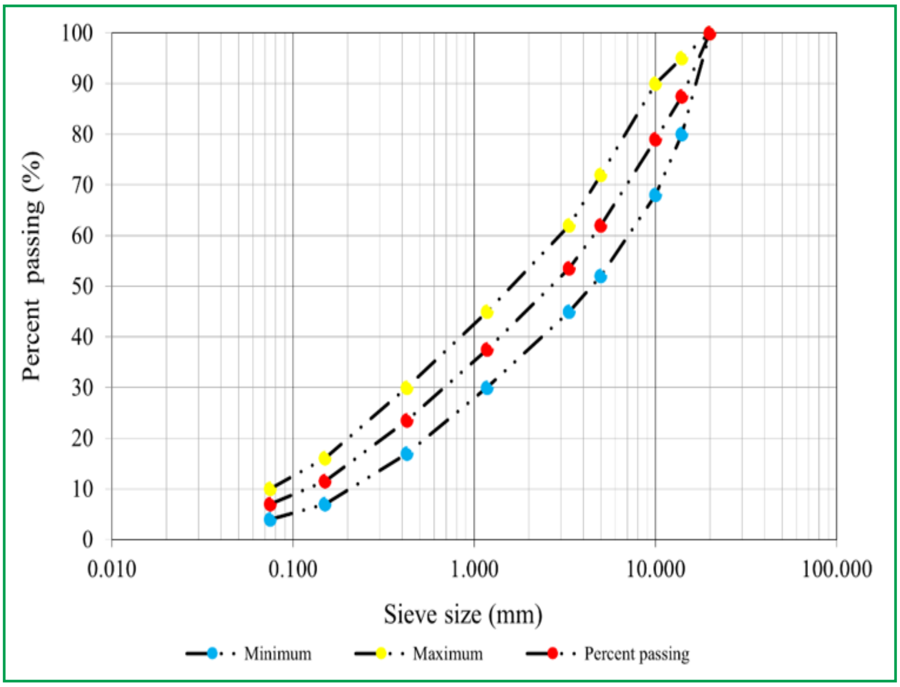

Figure 2. Gradation of ACW 14

a series of systematic tests. Initially, aggregate testing was conducted to ensure the suitability of the aggregates for use in bitumen mixtures. Sieve analysis was performed to determine the particle size distribution, followed by aggregate impact value (AIV) and aggregate crushing value (ACV) tests to assess the mechanical properties of the aggregates, such as resistance to impact and crushing. The bitumen used in this study was a 60/70 penetration grade, and its consistency and thermal properties were evaluated using penetration and softening point tests as per ASTM standards. Coconut fiber was incorporated into the mixture at varying proportions of 0%, 0.50%, 0.75%, and 1.0%.

To ensure even dispersion of coconut fibers within the bitumen mixture, specific steps were implemented during the mixing process. The fibers were gradually introduced into mechanical mixing at a constant speed of 1500 rpm for 60 min for a predetermined duration to promote uniform integration of fibers into the binder matrix. While these steps were designed to facilitate even dispersion, it is acknowledged that achieving perfect uniformity. The prepared mixtures underwent comprehensive mixture testing to assess their physical and mechanical properties. The Marshall stability test was conducted to determine the load-bearing capacity and flow of the mixtures, while the Indirect Tensile Strength (ITS) test evaluated the tensile properties and cracking resistance. The abrasion loss test, performed using a Los Angeles abrasion machine, assessed the durability and resistance to wear of the mixtures. All test results were analyzed to validate the performance of the coconut fiber-modified bitumen mixtures. Finally, the findings were compiled and critically analyzed to draw conclusions about the effectiveness of coconut fiber as a sustainable and performance-enhancing additive in bitumen modification.

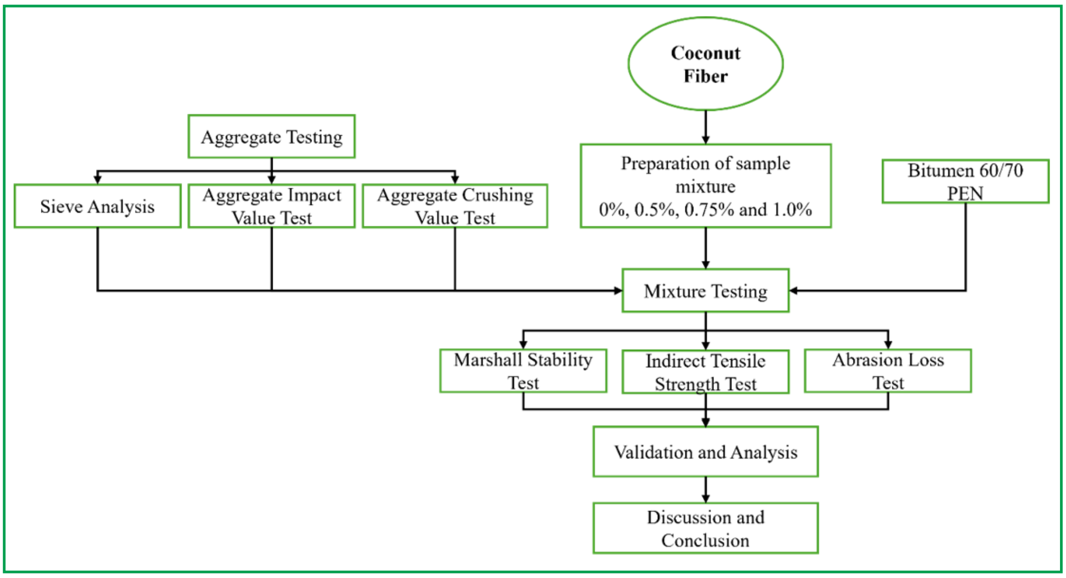

Figure 3. Flowchart of experimental procedures

Test on Bitumen

The penetration and softening point tests were conducted to evaluate the physical properties of coconut fiber-modified bitumen. The penetration test was performed following ASTM D5 [24] to measure the consistency of the bitumen by determining the depth (in tenths of a millimeter) to which a standard needle penetrated the bitumen sample under a load of 100 g for 5 seconds at 25°C. The softening point test was carried out in accordance with ASTM D36 [25] using the ring-and-ball method, which determines the temperature at which the bitumen reaches a specified level of softness. These tests assessed the effects of coconut fiber on the bitumen's workability and thermal performance.

Test on Aggregate

The aggregate tests were conducted to evaluate the suitability of aggregates for use in coconut fiber-modified bitumen mixtures. Sieve analysis was performed following ASTM standard to determine the particle size distribution, ensuring compliance with grading requirements. The aggregate impact value (AIV) test was carried out in accordance with BS EN 1097-2 [26] to assess the aggregate's resistance to impact, while the aggregate crushing value (ACV) test was conducted as per BS EN 1097-2 [26] to determine the aggregate's resistance to crushing under gradual compressive load. These tests ensured the selected aggregates met the mechanical and physical requirements for durable pavement construction.

Marshall Stability Test

The Marshall stability test was conducted to evaluate the load-bearing capacity of coconut fiber-modified bitumen mixtures, following ASTM D6927 [27]. Cylindrical specimens were prepared with varying percentages of coconut fiber (0%, 0.50%, 0.75%, and 1%) and compacted using a Marshall compactor to achieve the required density. The specimens were immersed in a water bath at 60°C for 30–40 minutes prior to testing. The stability and flow values were determined by applying a vertical load at a constant rate of 50 mm/min using a Marshall testing machine until failure. This test aimed to measure the maximum load the specimens could withstand and assess their deformation characteristics.

Indirect Tensile Strength Test

The Indirect Tensile Strength (ITS) test was performed to evaluate the tensile properties of coconut fiber-modified bitumen mixtures in accordance with ASTM D6931 [28]. Cylindrical specimens were prepared with varying coconut fiber contents (0%, 0.50%, 0.75%, and 1%) and compacted using a Marshall compactor. The specimens were conditioned at 25°C before testing. The ITS values were determined by applying a diametral load at a constant rate of 50 mm/min until failure. The maximum load was recorded, and ITS was calculated using the standard formula, considering specimen dimensions and the applied load. This test assessed the tensile resistance and cracking potential of the modified mixtures.

Abrasion Loss Test

The abrasion loss test was conducted to evaluate the durability of coconut fiber-modified bitumen mixtures using a Los Angeles abrasion machine. Bitumen specimens containing varying percentages of coconut fiber (0%, 0.50%, 0.75%, and 1%) were subjected to increasing numbers of revolutions (100, 200, 300, 400, and 500 cycles) to simulate wear and assess the material's resistance to abrasion. The mass loss of the specimens was recorded after each interval, and the abrasion rate was calculated as a percentage of the initial weight. This test aimed to determine the influence of coconut fiber content on the durability of the modified bitumen mixtures.

Results

Characterization of Coconut Fiber

The characterization of coconut fiber revealed its potential as a sustainable additive for bitumen modification, particularly due to its unique chemical composition (X-ray fluorescence (XRF)) and structural properties. Potassium oxide (K_2O) was identified as the dominant component, accounting for 44.5% of the total composition, followed by silica (SiO_2) at 15.4% (Table 3). The high K_2O content can enhance the chemical interaction between the ash and the bitumen, potentially improving the binder's adhesion to aggregates by promoting alkaline reactions, which can mitigate stripping and moisture damage. The silica content contributes to the stiffness and strength of the bitumen mix, as silica-rich materials often enhance the particle-particle and particle-binder interactions. Scanning electron microscope (SEM) analysis further revealed a highly porous and irregular morphology, which improves the surface area and bonding potential between the ash particles, bitumen, and aggregates. This synergy between the chemical composition and the structural properties of coconut fiber suggests that its incorporation can improve the mechanical performance, durability, and moisture resistance of bitumen mixtures, making it a valuable eco-friendly additive. Figure 4 indicates the SEM images of coconut fiber at 20 µm [29].

Table 3. Coconut fiber's chemical composition

Component	Chemical Composition (%)
K_2O	44.5
SiO_2	15.4
Cl	12.2
MgO	8.3
Al_2O_3	6.6
CaO	4.2
LOI	8.8

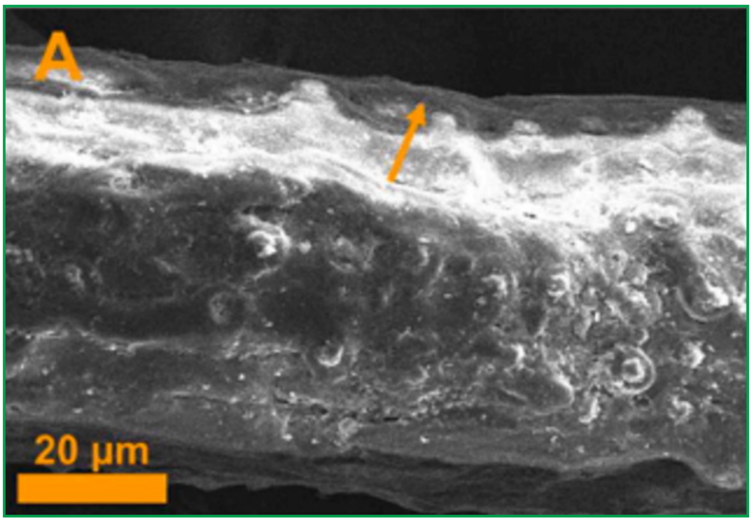

Figure 4. SEM images of coconut fiber [29]

Characterization of Coconut Fiber Modified Bitumen Binder

For the penetration results of coconut fiber-modified bitumen binder, there is a noticeable trend of varying penetration values as the fiber content increases (Figure 5). At 0% coconut fiber, the penetration value is 55.7 dmm. With the addition of 0.50% and 0.75% fiber, the penetration values decrease slightly to 55.4 dmm and 53.2 dmm, respectively, indicating a marginal increase in binder hardness or stiffness due to the fiber addition. However, at 1.00% fiber content, the penetration value rises significantly to 62.7 dmm, suggesting a reduction in stiffness. This shift may be due to the excessive fiber content causing a less homogeneous distribution within the binder, which may alter its resistance to deformation. This trend implies that moderate fiber content (0.50%-0.75%) may enhance the rigidity of the binder, while higher content (1.00%) may have a counterproductive softening effect.

For Figure 6, the softening point results, the trend shows that the softening point decreases as the coconut fiber content increases up to 0.75%, with values dropping from 50°C (0%) to 48.5°C at 0.75% fiber content. This decrease indicates

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that adding coconut fiber at low to moderate levels may reduce the thermal stability of the bitumen, potentially due to the fiber disrupting the binder's molecular structure, making it soften at a lower temperature. However, at 1.00% fiber content, the softening point slightly rises again to 50.2°C, suggesting an improvement in thermal stability at higher fiber concentrations. This could be due to fiber network formation within the binder at higher content, which may contribute to resistance against thermal deformation. This result suggests that while coconut fiber influences the thermal response of the binder, the optimal balance between improved mechanical performance and thermal stability may require controlling the fiber content within a narrow range.

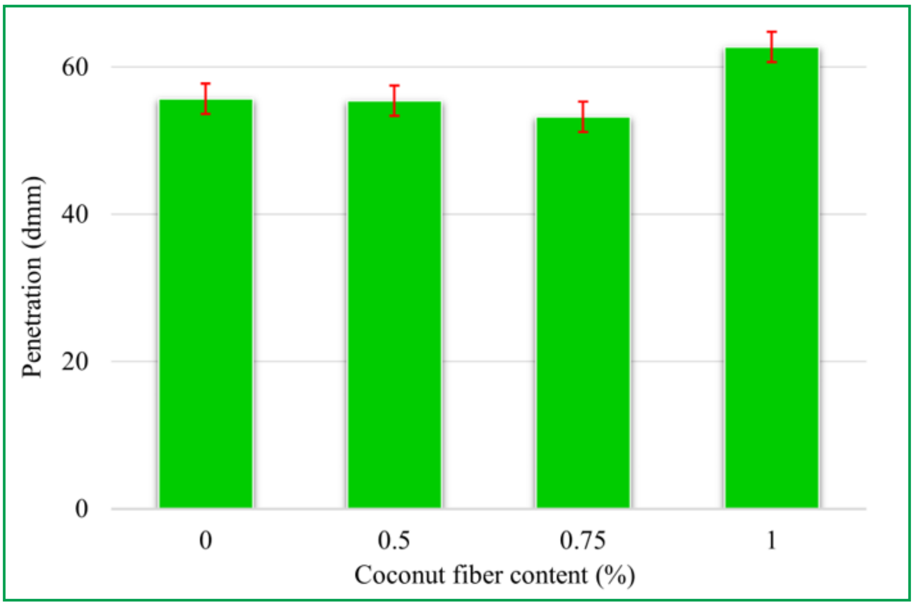

Figure 5. Penetration result of coconut fiber modified bitumen binder

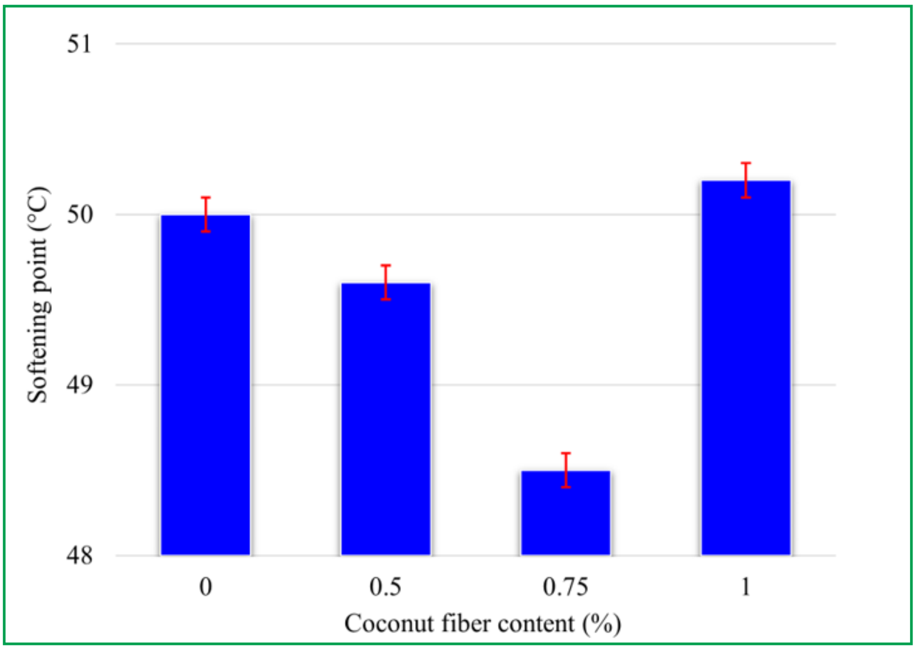

Figure 6. Softening point result of coconut fiber modified bitumen binder

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Characterization of Aggregate

The characterization of aggregate based on Table 4 shows that it meets the essential requirements for durability and mechanical performance, as indicated by the aggregate impact value (AIV) and aggregate crushing value (ACV). The AIV, which measures the aggregate's resistance to sudden impact or shock, is 24.82%, falling within the recommended range of 20-30%. This result suggests that the aggregate possesses sufficient toughness, making it suitable for applications where moderate impact resistance is required, such as in bitumen mixtures subjected to traffic loads. The ACV, representing the aggregate's resistance to gradual compressive loading, is 9.38%, well below the maximum allowable limit of 25%. This low ACV value implies that the aggregate has high compressive strength, a desirable property for maintaining structural integrity and stability under load. Overall, these values indicate that the aggregate is suitable for use in bituminous pavements, as it fulfills the necessary standards for impact and crushing resistance, contributing to the durability and performance of the bitumen mixture.

Table 4. Aggregate properties results

Properties	Result Values (%)	Requirement Values (%)
AIV	24.82	20-30
ACV	9.38	< 25

Characterization of Bituminous Coconut Fiber

Marshall stability

Figure 7 presents the Marshall stability results for coconut fiber-modified bitumen mixtures show a distinct trend in stability values as the fiber content increases. At 0% coconut fiber, the mixture exhibits a stability value of 8.464 kN, which represents the baseline performance. With the addition of 0.50% and 0.75% fiber, the stability values decrease to 7.303 kN and 6.169 kN, respectively, indicating a reduction in load-bearing capacity as the fiber content increases at these moderate levels. This reduction may be attributed to inadequate bonding between the coconut fiber and the bitumen matrix, potentially leading to weaker internal structure. However, at a 1% fiber content, the stability value dramatically increases to 11.978 kN, surpassing the initial stability at 0% fiber content. This improvement suggests that, at higher concentrations, coconut fiber may form a reinforcing network within the bitumen matrix, enhancing its structural integrity and resistance to deformation. According to standard Marshall stability requirements for heavy traffic (above 8 kN), only the 0% and 1% fiber content mixtures meet the standard limit, with 1% showing significant improvement. This trend suggests that while low to moderate fiber content may reduce stability, a well-optimized higher fiber content can enhance the performance of bitumen mixtures, potentially due to improved fiber-matrix interactions at higher concentrations.

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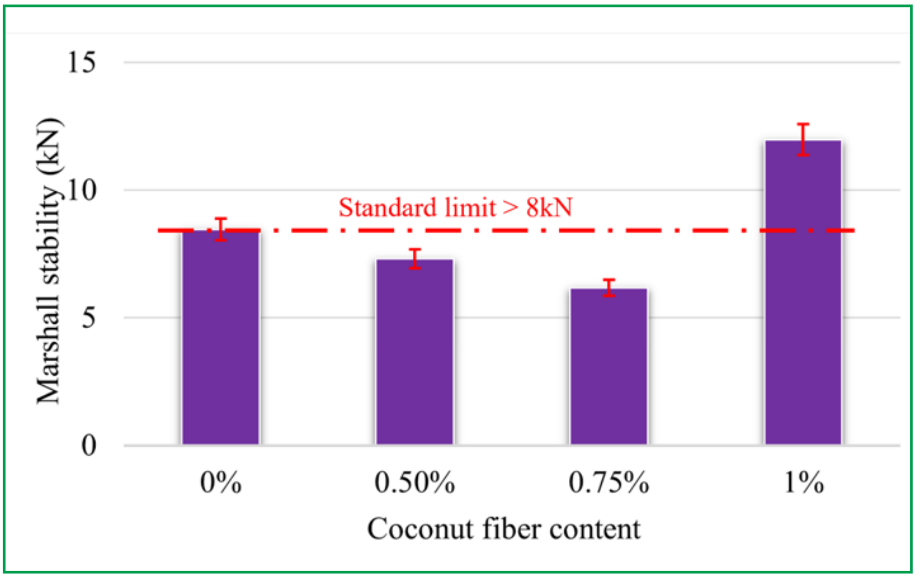

Figure 7. Marshall stability against various % of coconut fiber modified bitumen mixture

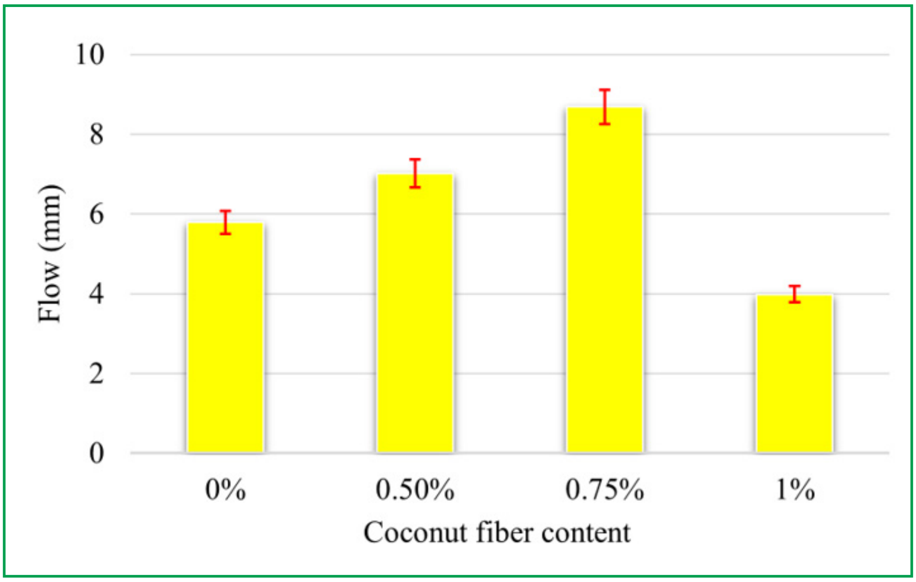

Figure 8. Flow against various % of coconut fiber modified bitumen mixture

Flow

The flow results for coconut fiber-modified bitumen mixtures exhibit a varied trend as the fiber content increases. At 0% fiber content, the mixture has a flow value of 5.789 mm, establishing the baseline deformation capacity under load (Figure 8). When 0.50% and 0.75% of coconut fiber is added, the flow values increase to 7.023 mm and 8.682 mm, respectively. This increase in flow suggests that, at these moderate fiber concentrations, the bitumen mixture becomes more flexible, potentially due to insufficient fiber-matrix bonding, which might allow more movement or deformation within the mix. However, at 1% fiber content, the flow value sharply decreases to 3.987 mm, indicating reduced deformation and an increase in mixture stiffness. This suggests that a higher fiber content may improve structural reinforcement within the matrix, thus restricting movement under load. According to standard limitations for Marshall flow (between 2-4 mm for optimal stability), only the 1% fiber content meets this standard, showing an ideal balance between flexibility and stiffness. This trend implies that lower fiber concentrations may compromise structural stability, while higher concentrations, particularly at 1%, enhance the mixture's resilience, possibly due to improved interlocking and distribution of fibers within the binder, which mitigates excessive deformation.

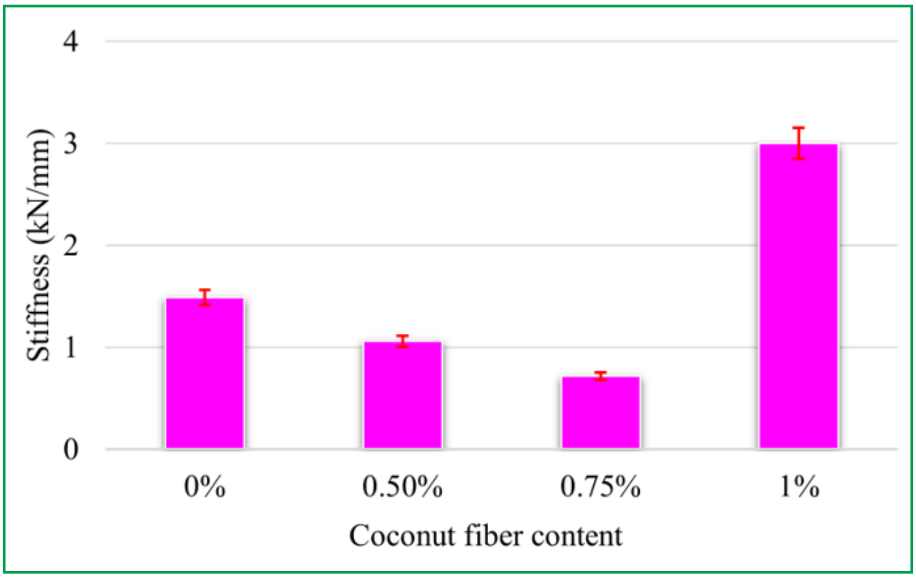

Figure 9. Stiffness against various % of coconut fiber modified bitumen mixture

Stiffness

Figure 9 shows the stiffness results for coconut fiber-modified bitumen mixtures reveal a clear trend of increasing and then decreasing stiffness with varying fiber content. At 0% fiber content, the mixture's stiffness is 1.491 kN/mm, which serves as the reference for unmodified bitumen. With the addition of 0.50% and 0.75% coconut fiber, stiffness values decrease to 1.061 kN/mm and 0.719 kN/mm, respectively. This reduction suggests that moderate fiber additions may lower the mixture's rigidity, possibly due to insufficient bonding or distribution of the fibers within the bitumen matrix, leading to a more flexible but less structurally cohesive mix. However, at 1% fiber content, stiffness dramatically increases to 3.002 kN/mm, more than doubling the baseline stiffness. This indicates that higher fiber content likely forms a reinforcing network within the matrix, enhancing rigidity and load resistance. According to standard limitations, bitumen mixtures for high-stress conditions generally benefit from higher stiffness to resist rutting and deformation. Thus, the 1% fiber content is optimal, suggesting a well-balanced mix with improved stiffness that may enhance pavement durability under heavy traffic loads. This trend implies that, while low to moderate fiber content may compromise structural stiffness, a higher concentration, specifically at 1%, can significantly improve the mix's ability to withstand deformation, likely due to stronger fiber-matrix interfacial bonding and effective fiber distribution.

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Indirect Tensile Strength

The indirect tensile strength (ITS) results for coconut fiber-modified bitumen mixtures display a distinct trend, with strength initially decreasing at moderate fiber contents before increasing at higher content levels. At 0% coconut fiber, the ITS of the mixture is 375.7 kPa, representing the baseline for unmodified bitumen. When 0.50% and 0.75% coconut fiber is added, the ITS decreases to 354 kPa and 289.7 kPa, respectively, indicating a reduction in tensile strength. This decline may suggest that at lower fiber contents, the coconut fiber does not sufficiently bond within the bitumen matrix, possibly leading to weak points and reduced cohesion under tensile stress. However, at 1% fiber content, the ITS significantly rises to 423 kPa, surpassing the baseline value and indicating enhanced tensile strength (Figure 10). This improvement at higher fiber content likely results from the formation of a reinforcing network within the bitumen matrix, allowing it to better withstand tensile forces. According to standard requirements for bitumen mixtures under high-stress conditions, a higher ITS is desirable to resist cracking and fatigue. Therefore, the result suggests that 1% coconut fiber content may be optimal for applications requiring enhanced tensile performance, likely due to better fiber dispersion and increased interaction within the matrix, which strengthens the overall cohesion and load-bearing capacity of the mixture.

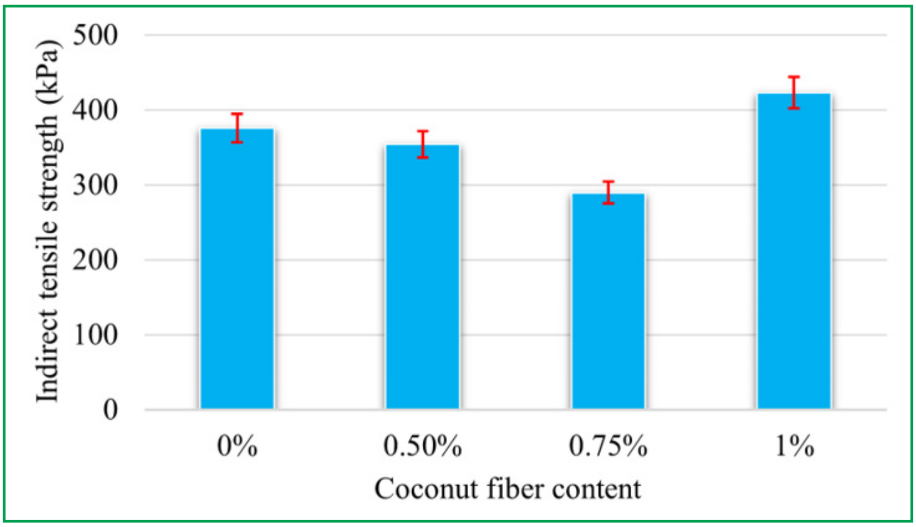

Figure 10. Indirect tensile strength against various % of coconut fiber modified bitumen mixture

Abrasion loss

The abrasion rate loss results for coconut fiber-modified bitumen mixtures, tested across different revolution counts, show varied resistance to abrasion with increasing fiber content. At 0% coconut fiber, the mixture exhibits a steady increase in abrasion loss with higher revolutions, reaching a maximum of 1.23% loss at 500 revolutions (Figure 11). For the 0.50% fiber content, abrasion loss remains consistently lower than the 0% mixture at all revolution stages, with only 1.55% loss at 500 revolutions, suggesting that adding a small amount of coconut fiber enhances the mix's abrasion resistance. However, at

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0.75% fiber content, the abrasion rate increases significantly, with the mixture experiencing a 3.76% loss at 500 revolutions, which indicates that excessive fiber content at this level may lead to weaker cohesion within the bitumen, reducing its resistance to abrasion. In contrast, the 1% fiber content mixture demonstrates improved performance, with a maximum abrasion loss of 2.61% at 500 revolutions, indicating a balance between fiber reinforcement and mixture integrity at this concentration. According to standard limitations for abrasion in durable pavement mixtures, lower abrasion loss is preferable to ensure long-term resistance to wear and tear under traffic loads. These results suggest that while moderate fiber content (0.50%) offers optimal abrasion resistance, the 1% fiber content also performs well and may provide additional structural benefits, while 0.75% fiber content appears to be less effective, possibly due to suboptimal fiber distribution or reduced bonding strength in the matrix at this level.

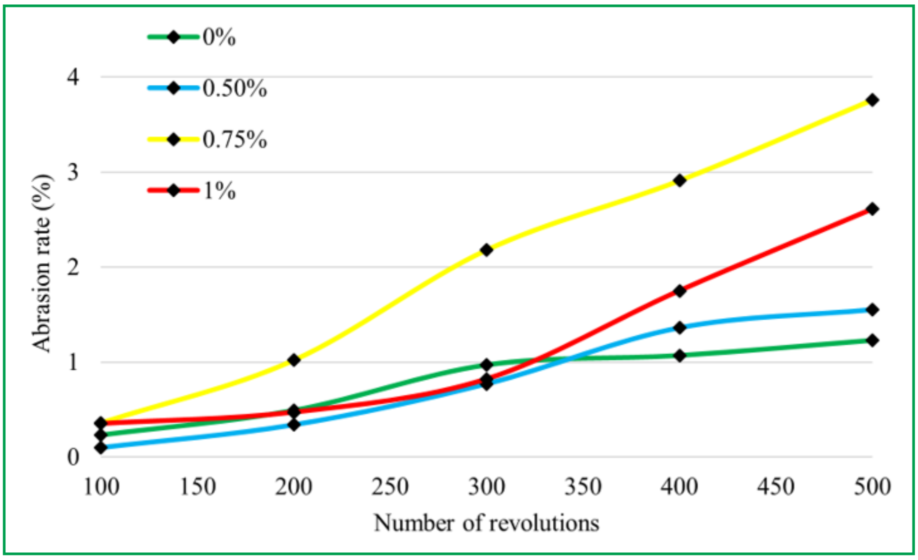

Figure 11. Abrasion rate loss vs number of revolutions of various % coconut fiber

Polynomial correlation between Marshall stability and ITS

The correlation between Marshall stability and indirect tensile strength (ITS) with varying coconut fiber content follows a second-order polynomial relationship, as represented by the equation (1):

$$\text{ITS (kPa)} = -4.6866x^2+107.17x-188.89 \quad (1)$$

where x is the coconut fiber content in percentage. The coefficient of determination, $R^2 = 0.9818$, indicates a very strong fit, meaning that 98.18% of the variation in ITS is explained by the changes in coconut fiber content (Figure 12). The polynomial trend suggests that ITS initially decreases with increasing fiber content, reaching a minimum, before improving significantly at higher fiber levels. This non-linear relationship highlights the complex interaction between fiber content and tensile performance, likely due to factors such as fiber dispersion, bonding efficiency within the bitumen matrix, and overall structural reinforcement. The high R^2 value confirms that this polynomial model is a reliable representation of the ITS behavior with varying coconut fiber percentages.

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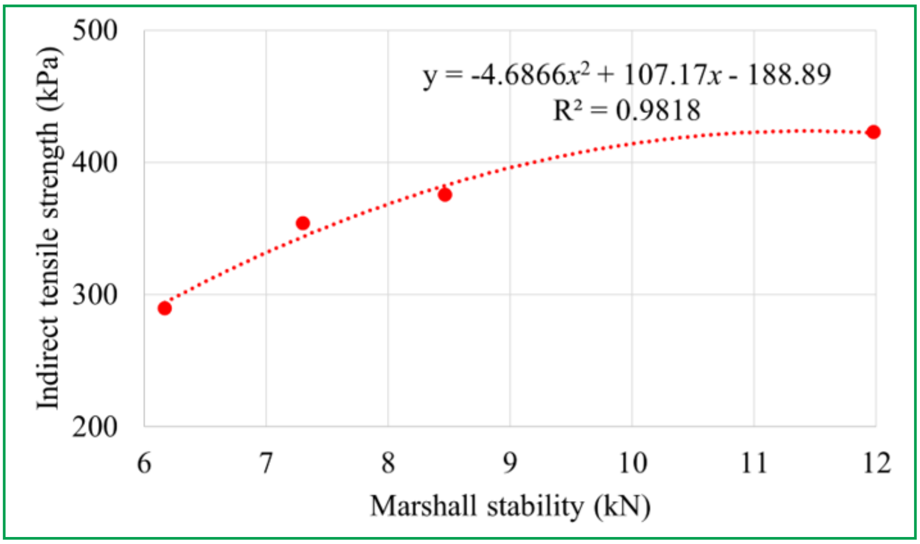

Figure 12. Polynomial correlation of coconut fiber bitumen modified mixtures

Conclusions

The incorporation of coconut fiber in bitumen mixtures presents a complex interaction between mechanical properties, fiber content, and the material's overall performance. The Marshall stability results indicate an inconsistent response to varying fiber percentages, with a notable increase at 1% fiber content, suggesting improved structural integrity at higher fiber concentrations. However, the indirect tensile strength (ITS) demonstrates a polynomial relationship, with ITS initially decreasing before peaking at 1% fiber content. This indicates that while lower fiber contents may lead to insufficient reinforcement or weaker bonding, higher contents enhance tensile performance due to increased fiber-matrix interaction. Despite the apparent benefits at higher fiber percentages, the intermediate values show suboptimal performance, likely due to uneven fiber distribution or reduced cohesion within the mixture. The abrasion loss and flow analysis further emphasize the balance required to optimize fiber content for durability and flexibility, as excessive fiber inclusion could lead to a trade-off between mechanical properties.

The results demonstrate that 1% coconut fiber content is the most effective in improving both Marshall stability and ITS, achieving values of 11.978 kN and 423 kPa, respectively. The strong polynomial correlation (R^2 = 0.9818) between ITS and fiber content highlights the importance of selecting an appropriate fiber percentage to maximize performance. This optimal level ensures enhanced structural integrity and while higher fiber content (1%) improves mechanical properties like stability and ITS, intermediate levels (0.50–0.75%) show reduced performance due to weaker bonding or insufficient reinforcement. Abrasion resistance trends suggest that lower fiber percentages provide better durability under wear conditions, while higher contents may compromise this due to rigidity. A careful balance is needed to optimize coconut fiber-modified mixtures for specific applications, ensuring durability without sacrificing mechanical performance.ensile strength due to improved fiber dispersion and bonding within the bitumen matrix.

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Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Wan Noor Hin Mior Sani: conceptualization, methodology. **Asnif Hakimi Azman:** data curation, writing - original draft preparation. **Jusma Jaafar:** visualization, investigation. **Indra Mawardi:** supervision. **Norhidayah Abdul Hassan:** validation. **Mohd Hazree Hashim:** writing-reviewing and editing.

Data Availability Statement

The data used to support the findings of this study are included within the article.

References

[1] S. Abdulrahman, M. R. Hainin, M. K. I. M. Satar, N. A. Hassan, and A. Usman, “Rutting and moisture damage evaluation of warm mix asphalt incorporating POFA modified bitumen,” International Journal of Engineering and Advanced Technology, vol. 9, no. 1, pp. 90–98, Oct. 2019, doi: http://dx.doi.org/10.35940/ijeat.A1052.109119

[2] Q. Zhang, J. Luo, Z. Yang, J. Wang, Y. Zhao, and Y. Zhang, “Creep and fatigue properties of asphalt mastic with steel slag powder filler,” Case Studies in Construction Materials, vol. 18, Jul. 2023, doi: http://dx.doi.org/10.1016/j.cscm.2022.e01743

[3] W. N. H. Mior Sani, N. S. Shahrom, R. Ab Rashid, N. Abdul Hassan, Z. H. Al-Saffar, M. H. Hashim, “Assessing the Viability of Wood Ash as a Filler in Asphalt Mixtures”, Disaster in Civil Engineering and Architecture, vol. 1, no. 1, pp. 1–21, Sep. 2024, doi: http://dx.doi.org/10.70028/dcea.v1i1.9

[4] O. Fadele and M. Otieno, “Utilisation of supplementary cementitious materials from agricultural wastes: a review,” Proceedings of Institution of Civil Engineers: Construction Materials, vol. 175, no. 2, 2022, doi: http://dx.doi.org/10.1680/jcoma.19.00098

[5] A. H. Jagaba, S. R. M. Kutty, G. Hayder, L. Baloo, A. Noor, N. S. A. Yaro and A. K. Usman, “A systematic literature review on waste-to-resource potential of palm oil clinker for sustainable engineering and environmental applications,” Materials, vol. 14, no. 16, Aug. 2021, doi: http://dx.doi.org/10.3390/ma14164456

[6] S. M. Rhasbudin Shah, Y. Hooi Min, S. N. Awang, and L.S. Tey, “Waste materials as extender of bituminous binder: A review,” Jurnal Kejuruteraan, vol. 35, no. 6, pp. 1467–1474, Nov. 2023, doi: http://dx.doi.org/10.17576/jkukm-2023-35(6)-19

[7] N. S. A. Yaro, M. Bin Napiah, M. H. Sutanto, A. Usman, and S. M. Saeed, “Performance evaluation of waste palm oil fiber reinforced stone matrix asphalt mixtures using traditional and sequential mixing processes,” Case Studies in Construction Materials, vol. 15, Dec. 2021, doi: http://dx.doi.org/10.1016/j.cscm.2021.e00783

[8] W. N. H. Mior Sani, N. F. Allias, H. Yaacob, Z. H. Al-Saffar and M. H. Hashim, "Utilisation of Sawdust and Charcoal Ash as Sustainable Modified Bitumen," Smart and Green Materials, vol. 1, no. 1, pp. 13-32, June 2024, doi: http://dx.doi.org/10.70028/sgm.v1i1.1

[9] H. Xu, S. Wu, A. Chen, Z. Li, Y. Zou, and P. Cui, "Influence of hybrid fibers on rheological properties of asphalt binders and its prediction with computing techniques," Construction and Building Materials, vol. 401, Oct. 2023, doi: http://dx.doi.org/10.1016/j.conbuildmat.2023.132904

[10] S. Wu, "Nanomaterials in roadway asphalt materials," Handbook of Nanomaterials: Electronics, Information Technology, Energy, Transportation, and Consumer Products: Volume 1, vol. 1, pp. 649–662, Jan. 2024, doi: http://dx.doi.org/10.1016/B978-0-323-95511-9.00010-X

[11] P. J. Ramadhansyah, M. K. Azman, A. M. Idris, W. W. N. Aifa, S. Ekarizan, M. R. Hainin and Y. Haryati, "Voids characteristic of hot mix asphalt containing waste cooking oil," in IOP Conference Series: Earth and Environmental Science, vol. 244, no. 1, Institute of Physics Publishing, Mar. 2019, doi: http://dx.doi.org/10.1088/1755-1315/244/1/012049

[12] P. J. Ramadhansyah, K. A. Masri, W. W. Azahar, N. Mashros, A. H. Norhidayah, M. M. Warid and H. Yaacob, "Waste cooking oil as bio asphalt binder: a critical review," in IOP Conference Series: Materials Science and Engineering, vol. 712, no. 1, Institute of Physics Publishing, Jan. 2020, doi: http://dx.doi.org/10.1088/1757-899X/712/1/012040

[13] A. Usman, M. H. Sutanto, M. Napiah, S. E. Zoorob, S. Abdulrahman, and S. M. Saeed, "Irradiated polyethylene terephthalate fiber and binder contents optimization for fiber-reinforced asphalt mix using response surface methodology," Ain Shams Engineering Journal, vol. 12, no. 1, pp. 271–282, Mar. 2021, doi: http://dx.doi.org/10.1016/j.asej.2020.06.011

[14] O. J. Asebiomo, O. S. Aderinola, P. Ejigboye, and O. Titiloye, "Performance evaluation of coconut fiber ash as mineral filler in asphalt mixture," Innovative Infrastructure Solutions, vol. 9, no. 5, May 2024, doi: http://dx.doi.org/10.1007/s41062-024-01449-x

[15] C. N. Che Wan, T. L. Ting and R. P. Jaya, "Chemical and physical properties of coconut fiber in asphalt mixture: A rview," Journal of Engineering and Science Research, vol. 3, no. 1, pp. 11–16, Feb. 2019, doi: http://dx.doi.org/10.26666/rmp.jesr.2019.1.3

[16] I. A. Tan, W. H. Wu, R. A. Chan, and L. L. Lim, "Effect of mercerization and acetylation on properties of coconut fiber and its influence on modified bitumen." Journal of Civil Engineering, Science and Technology, vol. 5, no. 1, pp. 17–22, 2014

[17] A. Z. Zulkafli, K. N. M. Yunus, N. H. M. Kamaruddin, and H. F. Suhandri, "Performance of coconut fiber as bitumen modifier in asphalt mixture influence to fatigue resistance," in IOP Conference Series: Earth and Environmental Science, vol. 1205, no. 1, Institute of Physics, 2023, doi: http://dx.doi.org/10.1088/1755-1315/1205/1/012064

[18] C. Chin and N. Charoentham, "Laboratory investigation of stone mastic asphalt mixtures containing coconut fiber". Engineering & Applied Science Research, vol. 48, no. 2, pp. 131–136, March. 2021.

[19] T. L. Ting, R. P. Jaya, N. A. Hassan, H. Yaacob and D. S. Jayanti. "A review of utilization of coconut shell and coconut fiber in road construction." Jurnal Teknologi, vol. 76, no. 14, pp. 1–7, 2015, doi: http://dx.doi.org/10.11113/jt.v76.5851

[20] R. A. Yousif, S. A. Tayh, and A. F. Jasim, "The effect of coconut powder on asphalt binder performance under laboratory conditions," Journal of Engineering and Technological Sciences, vol. 55, no. 5, pp. 577–586, Dec. 2023, doi: http://dx.doi.org/10.5614/j.eng.technol.sci.2023.55.5.7

[21] M. Ashfaq and S. V George, "A comparative study on coconut fiber and PET for increasing the stability of stone matrix asphalt," International Journal of Scientific & Technology Research, vol. 8, no. 11, 2019.

[22] R. Maharaj, R. Ali, D. Ramlochan, and N. Mohamed, "Utilization of coir fibre as an asphalt modifier," Progress in Rubber, Plastics and Recycling Technology, vol. 35, no. 2, pp. 59–74, May 2019, doi: http://dx.doi.org/10.1177/1477760618795996

[23] R. Kumar and A. Sharma, "Experimental study of coir fiber & rice husk ash on geotechnical properties of expansive soil." International Journal of Research in Applied Science and Engineering Technology, vol. 7, no. 12, pp. 996–1005, Dec. 2019, doi: http://dx.doi.org/10.22214/ijraset.2019.12159

[24] ASTM D5, "Standard Test Method for Penetration of Bituminous Materials," ASTM International, West Conshohocken, PA, USA, 2013.

[25] ASTM D36, "Standard test method for softening point of bitumen (ring-and ball apparatus)," ASTM International, West Conshohocken, PA, USA, 2014.

[26] BS EN 1097-2:2020, "Tests for mechanical and physical properties of aggregates - Methods for the determination of resistance to fragmentation," British Standards Institution (BSI), London, UK, 2020.

[27] ASTM D6927, "Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures," ASTM International, West Conshohocken, PA, USA, 2015.

[28] ASTM D6931, "Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures," ASTM International, West Conshohocken, PA, USA, 2017.

[29] F. Mulana, M. P. Aulia, Azwar, and S. Aprilia, "Coconut fiber and fly ash polymer hybrid composite treated silane coupling agent: Study on morphology, physical, mechanical, and thermal properties," South African Journal of Chemical Engineering, vol. 50, pp. 10–19, Oct. 2024, doi: http://dx.doi.org/10.1016/j.sajce.2024.07.008