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# Performance Evaluation of Grated Coconut Waste as a Bitumen Modifier

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## Abstract

Coconut is extensively utilized in everyday existence, with around 3.18 million tonnes of waste, including grated coconut, being generated. Utilizing grated coconut waste as an ingredient in bitumen could alleviate the challenges encountered by environmental authorities. This study aimed to examine the impact of grated coconut waste on the characteristics of bitumen and evaluate its performance in the bitumen mixture. A mixture of bitumen 60/70 penetration grade and grated coconut waste was created, with varying percentages of 0%, 1%, 2%, and 3%. The mechanical qualities of grated coconut waste as a bitumen modifier were assessed using several tests, including the indirect tensile strength test and the Marshall stability test. The physical and mechanical characteristics of grated coconut waste as a modifier for bitumen were assessed utilizing tests for softening point test and penetration test. Based on this study, the findings for physical properties of penetration and softening point test, the used up until 3% grated coconut waste can give effect to the bitumen stiffness. One of the more significant findings to emerge from this study is that higher stability and tensile strength of 1% grated coconut waste at 10420 N and 271 kPa, respectively. In conclusion, the used of 1% grated coconut waste as a bitumen modifier resulted the positive effect to the physical properties and mechanical properties of the bitumen mixture.

**Keywords:** Grated Coconut Waste, Bitumen Modifier, Bitumen Mixtures, Physical Properties, Mechanical Properties

## Introduction

The use of agricultural waste in bitumen modification represents a significant advancement in sustainable road construction, addressing both environmental and performance challenges [1]. Agricultural byproducts such as coconut shells

[2], rice husk ash [3], and charcoal ash [4] are often disposed of as waste, leading to environmental pollution. However, when these materials are incorporated into bitumen, they can enhance the mechanical properties, durability, and overall performance of asphalt pavements. For example, rice husk ash, which is rich in silica, has been widely researched and utilized as a bitumen modifier [5]. Its pozzolanic properties improve the binder's resistance to moisture damage and increase the pavement's lifespan. This innovative approach not only reduces the environmental impact of agricultural waste but also provides a cost-effective solution for improving road infrastructure. Further research and development are essential to optimize the use of various agricultural wastes, ensuring consistent quality and performance in bitumen modification, ultimately contributing to a more sustainable and resilient transportation network.

Grated coconut waste is one of the byproduct of agricultural waste has been investigated as a possible additive in the modification of bitumen to enhance the characteristics of asphalt mixtures. Research indicates that coconut shell powder, obtained from coconut husks, can be employed for the alteration of asphalt binders, leading to enhanced physical and rheological attributes of the mixtures [6]. Moreover, the incorporation of waste polythene and coconut fiber in Stone Matrix Asphalt (SMA) mixtures has exhibited favorable impacts on the engineering properties of bituminous blends, thereby advocating sustainability and cost-effectiveness in the construction of pavements. Additionally, an innovative method utilizing natural rubber-ribbed smoked sheet and soda lignin derived from waste green coconut fiber has been devised for the modification of bitumen, resulting in improved pavement performance and increased stability, especially in tropical regions [7]. These discoveries collectively underscore the potential of utilizing grated coconut waste in bitumen modification to enhance the longevity and sustainability of flexible pavements.

Rana et al. [6] study the effects of coconut powder on asphalt binder performance under laboratory conditions. Their findings show that 7-8% replacement of coconut powder yielded best result as the modify asphalt binder. Meanwhile, Lorenz using charcoal from coconut shell waste as the bio bitumen for modifying bitumen. Addition of 2% of charcoal powder maximizes desires bitumen properties in the result of multiple stress creep recovery (MSCR) test. Furthermore, [8] found that finer coconut shell charcoal particles that been grounded for 3 hours resulted better result in tests.

Furthermore, the synthesis of nanomaterials derived from organic residues can contribute to the reduction of waste products and the fulfillment of the requirements for sustainable infrastructures [9, 10]. Within the spectrum of organic residues, coconut shells are identified as having the highest potential for nanomaterial production due to their robustness and superior characteristics in diverse composite configurations. Coconut shells represent a substantial portion of agricultural residues generated and discarded by multiple industrial sectors. Following palm oil, rubber, and paddy, coconut stands as the fourth most cultivated crop in Malaysia. Notably, coconut exhibits exceptional strength, rigidity, and lightness as a material. Moreover, its eco-friendliness is underscored

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by its biodegradability and the relatively low levels of carbon dioxide emitted during combustion [11].

These studies have offered important insights into the potential of grated coconut waste as a bitumen modifier. This research seeks to fill this gap by examining the impact of incorporating grated coconut waste on key bitumen properties, such as Marshall stability, indirect tensile strength, and their interrelationships.

## Materials and Methodology

### Aggregate

Figure 1 indicates that the particle sizes in the AC 14 gradation span widely, from 75 µm to 20.0 mm. The fine coarse aggregate particles cover the spaces between the coarse aggregate particles and aid in preventing water infiltration into the pavement, while the coarse aggregate particles are allowed to not interlock and provide the pavement strength thanks to the gap-graded distribution. A sample of 1200g was utilized after undergoing a seven-sized test. The units underwent screening and subsequent weighing to enhance flexibility and homogeneity, facilitating the incorporation of additional materials within a temperature range of 140 to 150 degrees Celsius.

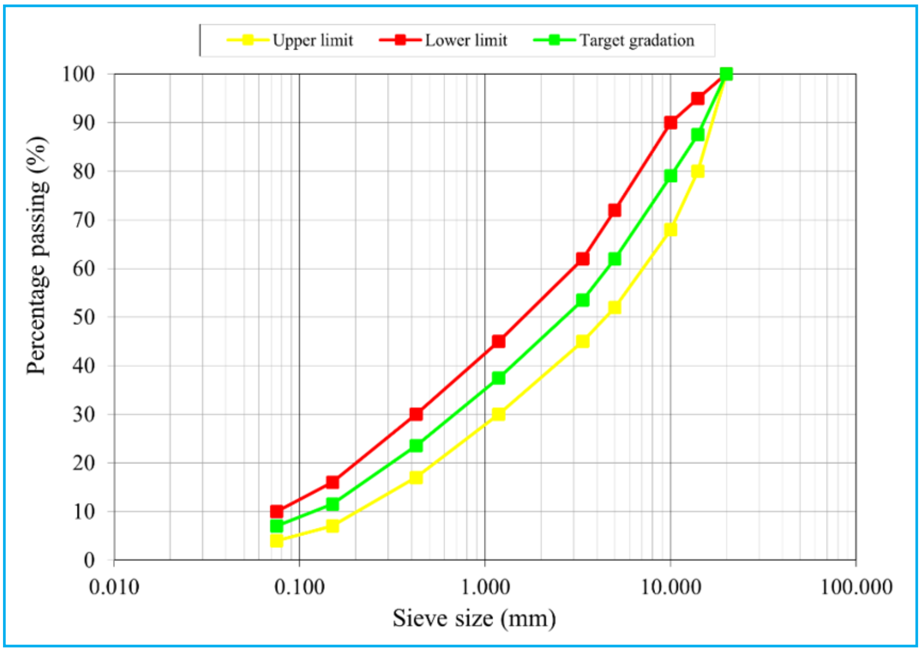


**Figure 1.** AC 14 aggregate gradation

### Bitumen

This study used bitumen 60/70 grade penetration (PEN) and the properties were evaluated through a series of standardized tests, yielding results that meet industry requirements. The penetration at 25°C, measured using ASTM D5 [12], falls within the specified range of 60 - 70 dmm, with an outcome of 67 dmm, indicating suitable consistency. The softening point, determined by ASTM D36

[13], was found to be 53°C, within the acceptable range of 49 - 56°C, demonstrating adequate thermal resistance. The specific gravity, tested according to ASTM D2726 [14] , was 1.03, aligning well with the required range of 1.01–1.06, which confirms the material's density is appropriate for bitumen applications. Lastly, the viscosity at 135°C, assessed using ASTM D4402 [15], showed a value of 0.45 Pa.s, significantly lower than the maximum allowable 3 Pa.s, indicating excellent flow properties at high temperatures. These outcomes collectively verify the bitumen's suitability for use in road construction, ensuring both compliance with standards and optimal performance. All the mixtures included a conventional mix (0%) and three modified bitumen mixtures with varying amounts of grated coconut waste at 1%, 2%, and 3%. The waste materials were incorporated into the bitumen before combining with the aggregate using a process called wet mixing.

### *Grated coconut waste*

Coconut waste sourced from local coconut milk processing industries represents a valuable yet underutilized resource with significant potential for sustainable applications. The coconut production is prevalent, the processing of coconuts generates substantial amounts of grated coconut waste. Typically discarded or used in low-value applications, these byproducts pose environmental disposal challenges. However, the fibrous and lignocellulosic nature of grated coconut waste makes it an ideal candidate for this study as bitumen modifier for asphalt pavements [16]. Figure 2 show the grated coconut waste is off-white to light brown depending on the production and drying processing. The particle size of grated coconut waste used were less than 75 µm after a series of processing using household grinder for about 3 – 5 minutes.

**Figure 2.** Grated coconut waste

## Methodology

### Preparation of Grated Coconut Waste - Modified Asphalt

The modified binder was formulated through the application of heat to bitumen 60/70 until it reached a temperature of 160°C within a steel receptacle, leading to its liquefaction. Following this, grated coconut waste were incorporated into the bitumen at varying ratios of 0%, 1%, 2%, and 3% based on the initial bitumen weight. Utilizing a high-velocity shear mixer running at 1500 rpm for a duration of 60 minutes facilitated the homogenization of the components. The chosen parameters align with commonly used mixing practices in similar materials, which ensures consistency and comparability with [17]. This rotational speed was specifically selected to ensure the effective dispersion of the residual components within the bitumen. The amalgamation process was executed at 160°C to prevent premature aging of the bitumen at elevated temperatures. Each experimental scenario and sample category involved the development of three specimens. It was concluded that the optimal quantity of bitumen was 5%. A visual depiction of the methodology steps undertaken in this investigation for both physical and mechanical assessments is presented in Figure 3.

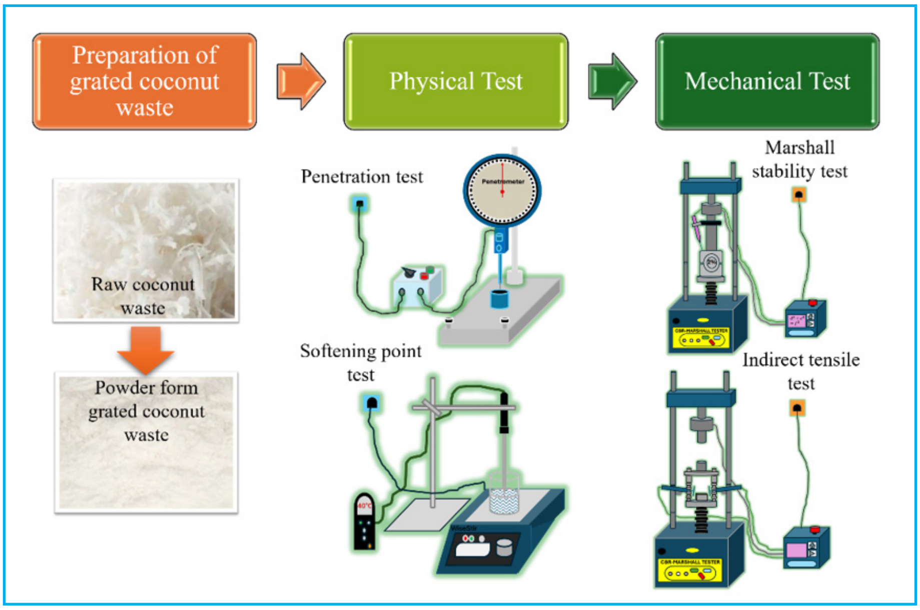


**Figure 3.** Visual depiction of methodology

## Aggregate test

### Aggregate impact value test

The aggregate impact value (AIV) test measures the resistance of aggregate to sudden shock or impact, which simulates the stresses and loading conditions the material would experience in real-world applications such as road construction. The test is conducted by placing a sample of aggregates, typically passing through a 14 mm sieve and retained on a 10 mm sieve, in a cylindrical mold. The sample is then subjected to a standard number of blows from a standardized weight dropped from a set height. After the test, the crushed aggregate is sieved, and the percentage of fines passing through a 2.36 mm sieve is calculated as the AIV. A lower AIV indicates higher resistance to impact, making the aggregate more suitable for use in high-traffic areas. The results are then compared against standard specifications [18] to determine the aggregate's suitability for use in road construction.

#### *Aggregate crushing value test*

The objective of the test is to assess the mechanical strength of aggregate. The aggregate, sized to pass through 14 mm and retained on 10 mm, is utilized for this purpose. Subsequently, the sample were positioned between the platens of the testing machine and subjected to a uniform rate until the required force of 400 kN is achieved within 10 minutes. The specimen were then sieved using a 2.36 mm sieve size, and the result is considered the aggregate crushing value (ACV). This test is conducted following the guidelines of BS EN 1097-2 [18].

### *Physical Test*

#### *Penetration test*

A penetration test was performed according to the ASTM D5 standard [12] to determine the consistency and hardness of bitumen. A lower penetration value indicated a harder bitumen. The penetration value depended on the grade of bitumen used in the sample testing. For this test, Bitumen 60/70 was utilized, with penetration values ranging from 60 to 70 under standard test conditions. The bitumen was thoroughly mixed until it reached a pourable consistency, then placed into test containers. These containers were maintained at 25°C in a temperature-controlled water bath for 1 hour. Afterward, the sample was removed, and the needle was positioned to touch the surface of the bitumen sample. The dial reading was set to zero at the point of contact. The needle was then released to penetrate the bitumen for 5 seconds, after which the final reading was recorded. Factors influencing the test's accuracy included pouring temperature, needle size, applied weight, and test temperature. The test was carried out using penetration equipment with a total load of 100 g applied for 5 seconds at a temperature of 25°C.

#### *Softening point test*

The softening point test was conducted according to ASTM D36 guidelines [13], which determine the temperature at which bitumen reaches a specified level of softness. Since bitumen lacks a distinct melting point, this test is crucial for comparing results. The bitumen was first melted and poured into two rings, which were placed on a plate for 30 minutes. A thermometer was aligned with the bottom of the ring at the center of the ring holder. Each sample was then weighted with 3.5 g steel balls, stirred, and heated. The temperature was recorded when the ball passed through the sample and dropped onto the base plate.

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### Penetration Index (PI)

Utilizing Eq. (1), which incorporates penetration and temperature data obtained from the softening point test, the penetration index (PI) was determined. It should be noted that, as per [20], PI values ranging from -3 to +7 indicate asphalt that is highly resistant to low temperatures and highly susceptible to high temperatures, respectively.

$$PI = \frac{1952 - 500 \log pen - 20\, softening\ point}{50 \log pen - softening\ point - 120} \quad (1)$$

## Mechanical Test

### Marshall stability test

The Marshall stability test was carried out according to ASTM D6927 [21] specifications. The samples were heated in a water bath at 60°C for 20 minutes. After heating, they were removed from the bath and placed in the lower part of the breaking head. The upper segment was then positioned, and the entire assembly was set up in the testing machine. A flow meter was placed on one of the posts and adjusted to zero. The load was applied at a rate of 50 mm/min until the maximum load was reached. The peak load was recorded in Newtons, and the flow measured by the flow meter was noted in millimeters.

### Indirect tensile strength

The indirect tensile strength test measures the stiffness of a bituminous mixture. This test was conducted in accordance with ASTM D6931 [22]. Cylindrical samples were loaded diametrically along the cylinder axis at a constant displacement speed until they fractured in the compression testing machine between the loading strips. The indirect tensile strength was determined by calculating the maximum tensile stress from the peak load at failure and the sample dimensions using Eq. (2). Where the St present the indirect tensile strength (kPa), P present the maximum load (N) and t  present the specimen height immediatey before test (mm) and D present the specimen diameter (mm).

$$S_t = \frac{2000 \text{ x P}}{\pi \text{ x } t \text{ x } D} \quad (2)$$

## Results and Discussions

## Physical Properties

### Aggregate analysis

Table 1 presents the findings of two key aggregate tests in comparison to their required values. The AIV was found to be 24.82%, which falls within the acceptable range of 20-30%, indicating the aggregate's adequate resistance to sudden impact. The ACV was recorded at 9.38%, well below the maximum permissible limit of 25%, suggesting that the aggregate has a high resistance

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to crushing under gradually applied compressive loads. These results indicate that the aggregate materials meet the standard requirements [19] for used in construction.

**Table 1.** Aggregate properties result

| Test | Standard | Results |
|---|---|---|
| Aggregate impact value | 24.82% | 20 - 30% |
| Aggregate crushing value | 9.38% | < 25% |

### *Penetration analysis*

Figure 4 shows the penetration values of the bitumen mix with grated coconut waste with different percentage of 1%, 2% and 3%. Figure 4 demonstrates that the penetration value of conventional bitumen surpasses that of all the modified bitumen. The rise in gross combination weight of grated coconut waste has a substantial impact on the penetration reading of modified bitumen binder. This demonstrates that the modifier has the ability to influence the stiffness of the bitumen itself. The penetration values of modified bitumen are as low as 2%, with a measurement of 46.2 mm, which is significantly lower than those of regular bitumen. Modified bitumen binders with a high penetration number are characterized by a soft texture, whereas those with a low penetration number have a hard texture [23].

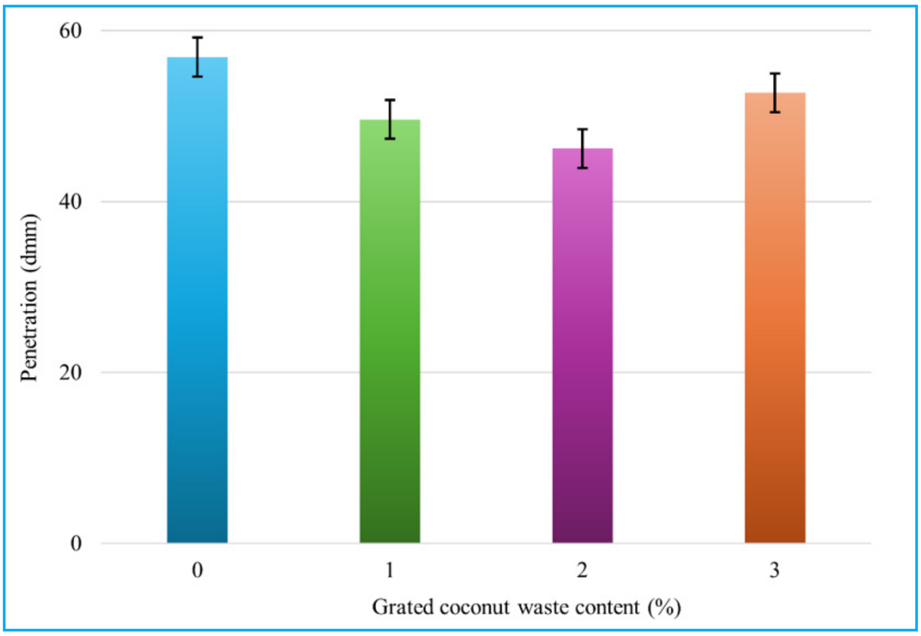


**Figure 4.** The penetration value of grated coconut waste modified bitumen binders

### *Softening point analysis*

Figure 5 shows the softening point result for conventional and modified with 60/70 penetration grade. Based on the results shown in Figure 5, it can be seen that modified bitumen with 3% of grated cococnut waste has higher softening point compared with conventional bitumen. Meanwhile, the lowest softening point is the modified bitumen with 1% grated coconut waste. A high softening point indicated that the binder was less susceptible to temperature [24].

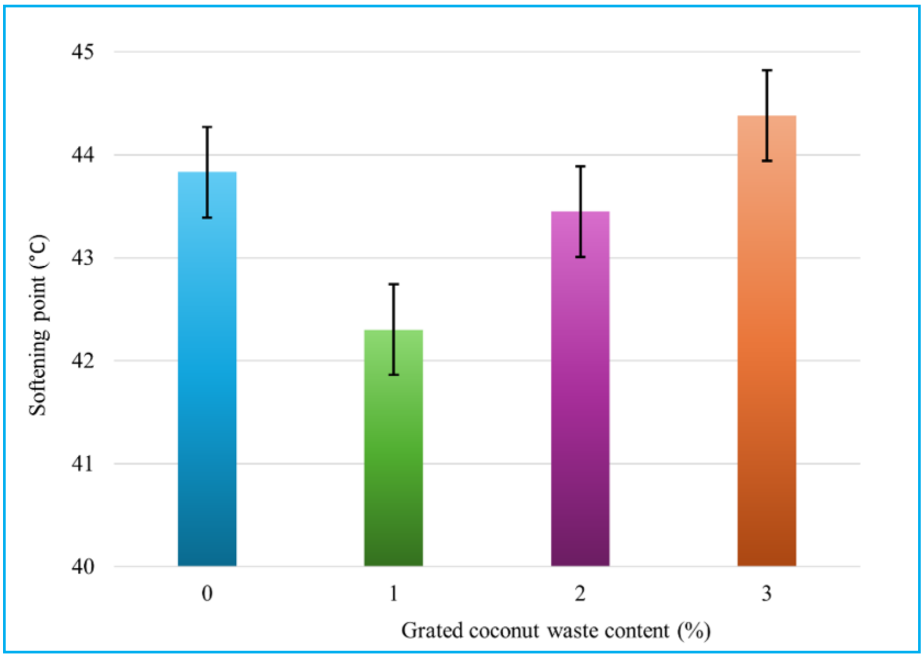


**Figure 5.** The softening point value of grated coconut waste modified bitumen binders

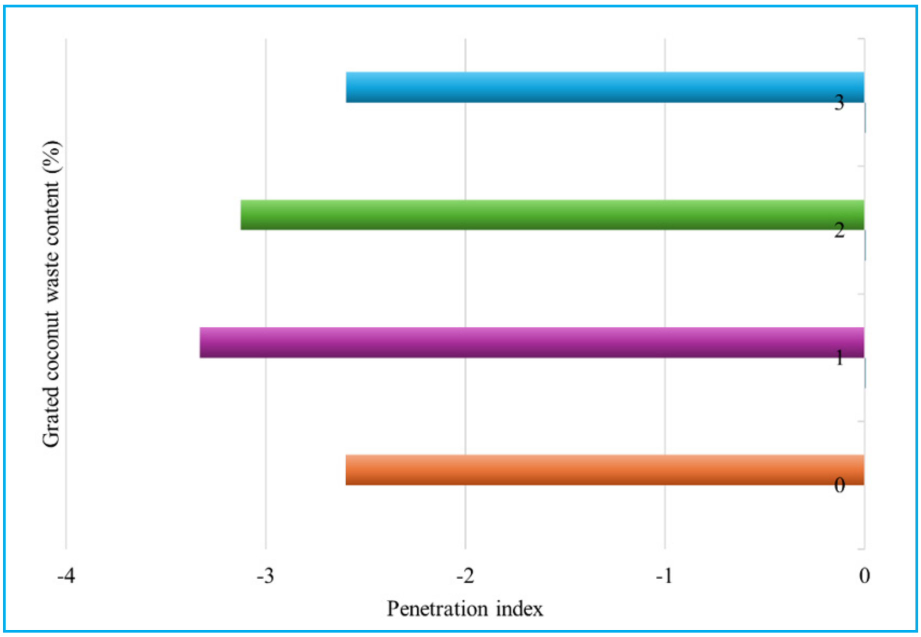


**Figure 6.** The penetration index value of grated coconut waste modified bitumen binders

### *Penetration index analysis*

The penetration index is a method used to assess the temperature sensitivity of grated coconut waste when incorporated into modified bitumen. Figure 6 displays the penetration index values corresponding to various percentages of grated coconut waste. The PI values for the samples declined from -2.601 to -3.125 and then increased up to -2.599. These results indicate that the modified bitumen had a significantly greater sensitivity to temperature in comparison to the conventional bitumen. The modified bitumen containing 3% by weight of grated coconut waste has the lowest penetration index PI value of -2.599. The modified bitumen with 1% and 2% concentrations exhibits the highest PI, measuring -3.331 and -3.125 respectively. The modified bitumen were susceptible to temperature fluctuations because its PI value were lower than that of conventional bitumen, which was caused by the softening point effect. Therefore, it can be inferred that conventional bitumen and modified bitumen with a 3% grated coconut waste content can be used in road construction for tropical regions.

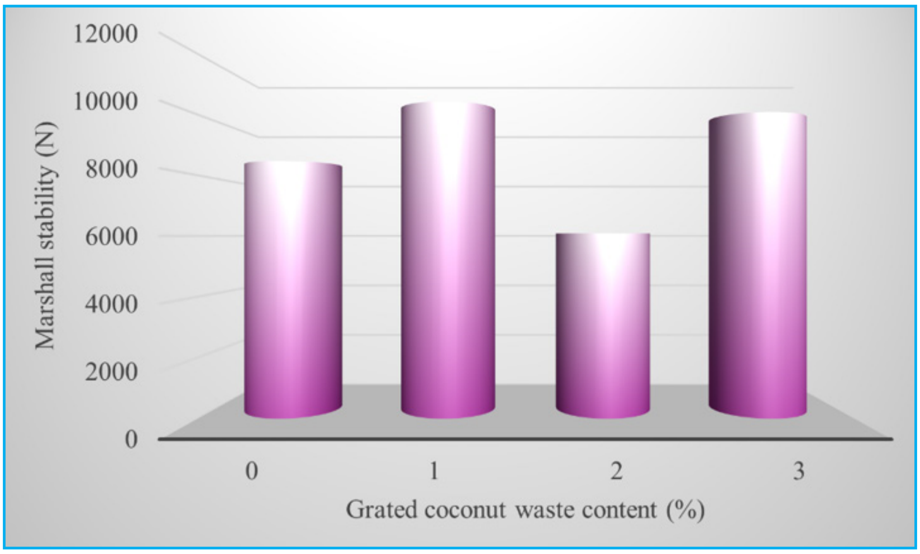


**Figure 7.** Marshall stability of grated coconut waste modified bitumen mixtures

## *Mechanical Properties*

### *Marshall stability*

Figure 7 presents the relationship between stability and percentage of grated coconut waste in modified bitumen mixture. The Marshall Stability values represent the load-bearing capacity of the bitumen mixture and are influenced by both the binder and modifier content. The variation in stability values at different modification levels can be explained by the interaction between the grated coconut waste and the bitumen matrix. At lower modification levels, such as 1%, the coconut waste may have enhanced the stiffness of the bitumen without significantly disrupting its cohesion, leading to improved stability values. However, at higher modification levels, such as 2% and 3%, the excess grated coconut waste could have resulted in uneven distribution or agglomeration within the bitumen, negatively impacting its ability to bind effectively with aggregates. This could lead to lower stability values as the structure becomes less cohesive. The lack of a clear trend in the Marshall Stability values might be due to the non-linear effect of the modifier on the bitumen. While small amounts of grated coconut waste may improve stability by reinforcing the binder, higher percentages could lead to diminishing returns or even reductions in stability as the bitumen's homogeneity is compromised. Additionally, the complex interaction between the waste material and the bitumen matrix may introduce variability in the test results, making it difficult to see a straightforward benefit. In summary, the Marshall stability values at different modification contents reflect a balance between the stiffening effect of the grated coconut waste and its potential to disrupt the bitumen's cohesion at higher concentrations.

### *Flow*

Figure 8 shows the flow against the percentage of grated coconut waste. According to the figure, the modified bitumen mixture exhibited a higher flow value compared to the standard bitumen mixture. The maximum flow was observed at 3% of grated coconut waste in the modified bitumen mixture, resulting in a flow of 8.09 mm, whereas the conventional bitumen mixture had a flow of just 5.79 mm. The flow value increased with the addition of grated coconut waste in the bitumen mixture. A low flow value is undesirable as it may indicate insufficient bitumen binder, potentially leading to durability issues. Conversely, a high flow value suggests that the mixture could be prone to permanent deformation. The Malaysian Standard Specification for Road Works specifies that the flow result shall be within the range of 2.0 – 4.0 mm. Nevertheless, all of the mixture met the specific criteria. Findings from Figure 8 indicated that 3% grated coconut waste had a high flow indicated that the high tendency in pavement mixture easily exposed the deformation.

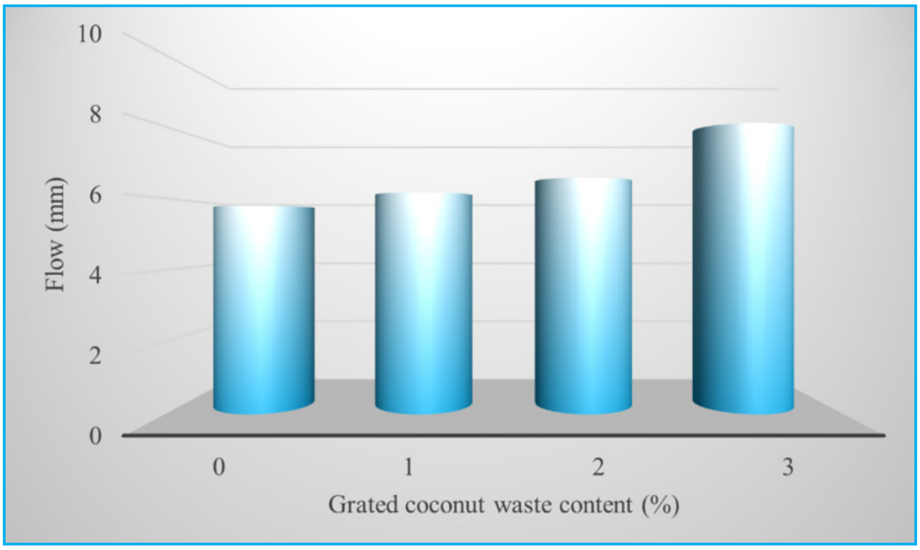


**Figure 8.** Flow of grated coconut waste modified bitumen mixtures

### *Stiffness*

Figure 9 displays the stiffness outcomes for various percentages of grated coconut waste. The stiffness value of the modified bitumen mixture at 1% was greater than that of the conventional bitumen mixture. The stiffness of the modified bitumen mixture was measured to be 1701.65 N/mm (1%), while the conventional bitumen mixture had a stiffness of 1490.89 N/mm (0%). A higher stiffness value indicates that the pavement is stiffer which is can help to resist permanent deformation [25]. The modified asphalt mixture with 2% of grated coconut waste was the lowest value of stiffness which 926.76 N/mm. The lower stiffness value observed in the 2% modified bituminous mixture could be due to an imbalance in the distribution and interaction of the grated coconut waste within the bitumen matrix. At 2%, the modifier may have introduced a certain level of heterogeneity in the mixture, disrupting the uniformity of the bitumen and aggregate bonding. This uneven distribution could reduce the overall stiffness by creating weak zones or pockets where the coconut waste particles prevent the bitumen from fully binding to the aggregates.

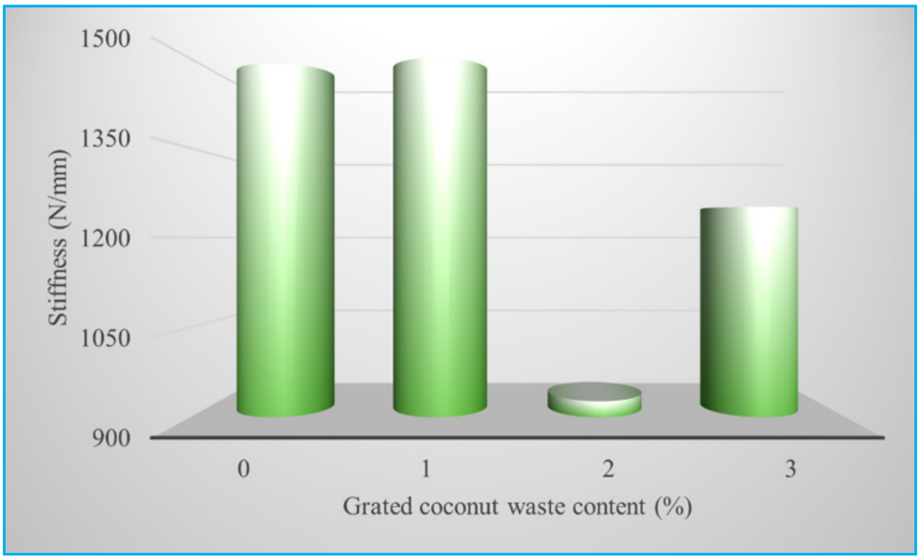


**Figure 9.** Stiffness of grated coconut waste modified bitumen mixtures

## *Correlation Analysis of Grated Coconut Waste Modified Bitumen Mixtures*

The study found a significant correlation between stability, flow, and stiffness in bitumen mixtures modified with grated coconut waste, with a high average Coefficient of Determination ($R^2$) of 0.967 across all testing parameters. These findings suggest that incorporating grated coconut waste may enhance the performance and engineering properties of sustainable modified bitumen.

**Table 2.** Grated coconut waste modified bitumen mxitures's equations

| Parameters | Equation |
|---|---|
| Stability (N) | $y = 508.75x^2 - 1476.2x + 9194.8$ |
| Flow (mm) | $y = 0.2875x^2 - 0.1315x + 5.8435$ |
| Stiffness (N/mm) | $y = 28.530x^2 - 234.85x + 1595.2$ |

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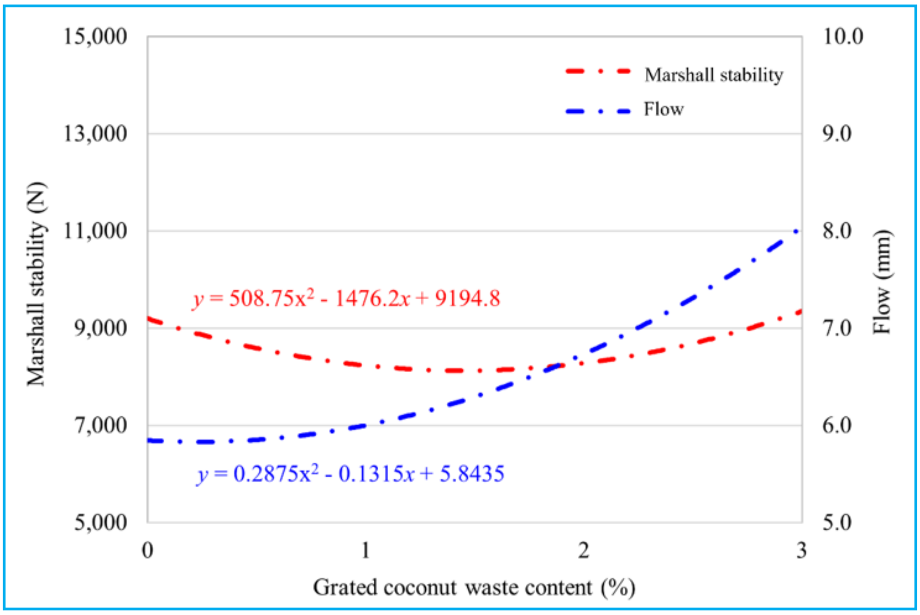


**Figure 10.** Marshall stability vs flow of grated coconut waste modified bitumen mixtures

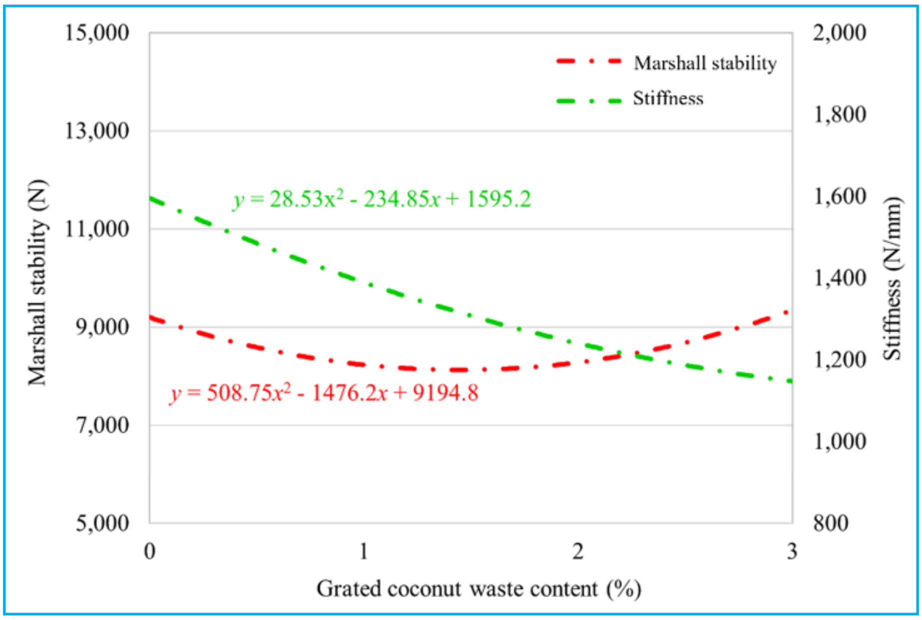


**Figure 11.** Marshall stability vs stiffness of grated coconut waste modified bitumen mixtures

## Indirect Tensile Strength

The result of indirect tensile strength conducted on grated coconut waste modified bitumen and the control samples were summarized in Figure 12. These results demonstrate that the control bitumen exhibited greater resistance to potential stripping compared to the grated coconut waste modified bitumen mixtures. The bitumen mixture containing 1% (271 kPa) of grated coconut waste exhibits superior performance compared to the other adjusted mixtures. Higher tensile strength leads to higher cracking resistance and strain prior to pavement failure [26]. According the Malaysian Standard Specification for Road Works, the minimum requirement for ITS is 200 kPa at temperature of 25 $^0$C. Only the conventional asphalt mixture and the modified asphalt mixture containing 1% of grated coconut waste pass the minimum requirement.

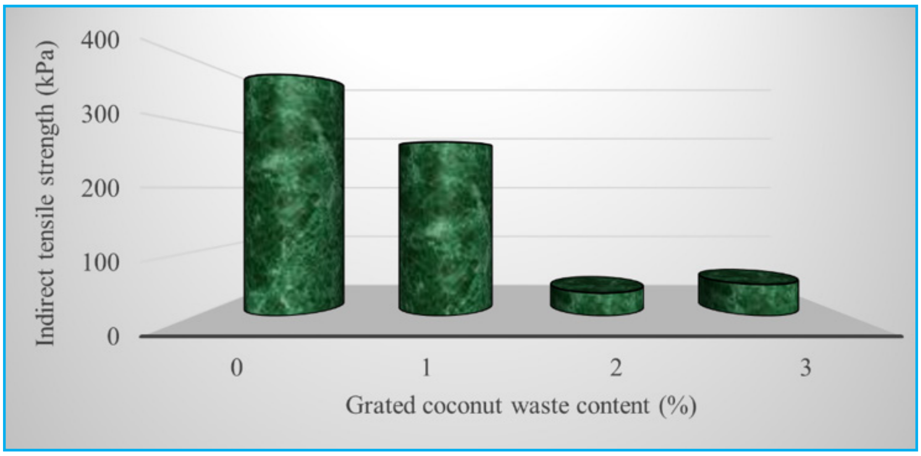


**Figure 12.** Indirect tensile strength of grated coconut waste modified bitumen mixtures

## *Conclusions*

Grated coconut waste was utilized as a bitumen modifier in the modified bitumen mixture. Mechanical properties were assessed through Marshall stability and indirect tensile strength tests, while physical properties were evaluated using the softening point and penetration tests. Incorporating grated coconut waste as a modifier enhanced Marshall stability and flow, particularly in terms of stability and flow. The addition of 1% grated coconut waste improved the stability of the bitumen mixture, and using up to 3% of grated coconut waste yielded optimal results in penetration and softening point tests compared to conventional bitumen. The findings indicate that grated coconut waste is effective in improving the mechanical properties of hot mix asphalt, showing its ability to resist deformation under applied loads. Additionally, the use of 1% grated coconut waste as a bitumen modifier enhanced the cracking resistance of the bitumen mixture, as demonstrated by the indirect tensile strength test results. Overall, the grated coconut waste-modified binder significantly improved the mechanical properties of the asphalt mixture compared to the unmodified mixture.

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## *Conflicts of Interest*

The authors declare no competing interest.

## Author Contributions

**Wan Noor Hin Mior Sani:** writing, original draft preparation. **Wan Mohamad Faizrul Hakimi Wan Ahmad Sofian:** writing, reviewing and editing. **Syarini Mohd Amin:** reviewing and editing. **Mohd Zul Hanif Mahmud:** reviewing and editing. **Kabiru Usman Rogo:** reviewing and editing. **Mohd Hazree Hashim:** funding and reviewing.

## Data Availability Statement

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

## References

[1] 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

[2] R.P. Jaya, M. R. Hainin, K. A. Masri, Y. Duraisamy, and E. Shaffie, "Performance of Charcoal Coconut Shell Ash in the Asphalt Mixture under Long Term Aging," International Journal of Recent Technology and Engineering, vol. 8, no. 3S3, pp. 383–387, 2019, doi: http://dx.doi.org/10.35940/ijrte.c1010.1183s319

[3] M. M. Nassef, Alaa R. Gabr, and Sherif M. El-Badawy, "Laboratory Evaluation of Rice Husk and Sawdust," Mansoura Engineering Journal, (MEJ), vol. 46, no. 4, 2021, doi: http://dx.doi.org/10.21608/bfemu.2021.204643

[4] 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, 1(1), pp. 13-32, 2024, doi: http://dx.doi.org/10.70028/sgm.v1i1.1

[5] R.P. Jaya, M.R. Hainin, N.A Hassan, H. Yaacob, M.K.I.M. Satar, M.N.M. Warid, A. Mohamed, M.E. Abdullah, and N.I. Ramli, "Marshall stability properties of asphalt mixture incorporating black rice husk ash" Materials Today: Proceeding, 5(10), pp. 22056–22062, 2018, doi: http://dx.doi.org/10.1016/j.matpr.2018.07.068

[6] 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, 2023, doi: http://dx.doi.org/10.5614/j.eng.technol.sci.2023.55.5.7

[7] 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.

[8] M.E. Abdullah, N.N.M. Rosni, R.P. Jaya, H. Yaacob, N.A. Hassan, and Agussabti, "Effect of charcoal ash coconut shell from waste material at different size on the physical properties of bitumen," in Key Engineering Materials, 2017, doi: http://dx.doi.org/10.4028/www.scientific.net/KEM.744.121

[9] S.N.A. Jeffry, R.P. Jaya, N.A. Hassan, H. Yaacob, J. Mirza, and S.H. Drahman, "Effects of nanocharcoal coconut-shell ash on the physical and rheological properties of bitumen," Constr Build Mater, vol. 158, pp. 1–10, 2018, doi: http://dx.doi.org/10.1016/j.conbuildmat.2017.10.019

[10] A. Fareed, S.B.A. Zaidi, N. Ahmad, I. Hafeez, A. Ali, and M.F. Ahmad, “Use of agricultural waste ashes in asphalt binder and mixture: A sustainable solution to waste management,” Constr Build Mater, vol. 259, p. 120575, 2020, doi: http://dx.doi.org/10.1016/j.conbuildmat.2020.120575

[11] K.S. Ukanwa, K. Patchigolla, R. Sakrabani, E. Anthony, and S. Mandavgane, “A review of chemicals to produce activated carbon from agricultural waste biomass,” Sustainability, 11(22), 6204. doi: http://dx.doi.org/10.3390/su11226204

[12] ASTM D5, “Standard test method for penetration of bituminous materials,” 2013.

[13] ASTM D36, “Standard test method for softening point of bitumen (ring-and-ball apparatus),” Manual on Hydrocarbon Analysis, 6th Edition, 2014, doi: 10.1520/mnl10830m

[14] ASTM D2726, “Standard test method for bulk specific gravity and density of non-absorptive compacted bituminous mixtures,” American Society for Testing and Materials, 2000.

[15] ASTM D4402, “Standard test method for viscosity determination of asphalt at elevated temperatures using a rotational viscometer,” Annual Book of ASTM Standards, vol. 94, no. C, 2006.

[16] R. Mamat, M.R. Hainin, N.A Hassan, M.N.M. Warid, M.K.I.M. Satar, and N.A.A. Rahman, “Chemical Properties of Modified Bitumen Incorporating Coconut Char,” Road and Airfield Pavement Technology: Proceedings of 12th International Conference on Road and Airfield Pavement Technology, vol. 193, 2022, doi: http://dx.doi.org/10.1007/978-3-030-87379-0_46

[17] S.N.A. Jeffry, “Performance of nanocarbon from coconut shell ash as bitumen modifier in asphalt mixture,” PhD Dissertation, Universiti Teknologi Malaysia, 2019.

[18] BS EN 1097-2, “Tests for mechanical and physical properties of aggregates. Part 2, Methods for the determination of resistance to fragmentation”. 2020.

[19] JKR Malaysia, “Standard specification for road works, section 4: flexible pavement,” pp. 1–187, 2008.

[20] J. Read and D. Whiteoak, “The Shell Bitumen Handbook”, Fifth. London, UK: Thomas Telford Publishing, 2003.

[21] ASTM D6927, “Standard test method for Marshall stability and flow of asphalt mixtures. designation” American Society for Testing Materials, vol. i, 2015.

[22] ASTM D6931, “Standard test method for indirect tensile (IDT) strength of bituminous mixtures 1,” 2012, doi: 10.1520/D6931-12

[23] S. Poovaneshvaran, M.R.M. Hasan, and R.P. Jaya, “Impacts of recycled crumb rubber powder and natural rubber latex on the modified asphalt rheological behaviour, bonding, and resistance to shear” Construction and Building Materials, 234, 2020, doi: http://dx.doi.org/10.1016/j.conbuildmat.2019.117357

[24] N.C. Ming, R.P. Jaya, H. Awang, N.L. Siaw Ing, M.R. Mohd Hasan, and Z.H. Al-Saffar, “Performance of glass powder as bitumen modifier in hot mix asphalt,” Physics and Chemistry of the Earth, vol. 128, 2022, doi: http://dx.doi.org/10.1016/j.pce.2022.103263

[25] H. Yaacob, R.P. Jaya, A.H. Madzaili, N.A. Hassan, M.E. Abdullah, and D.S. Jayanti, "Stiffness modulus and creep properties of the coconut shell in an asphalt mixture," Journal of Fundamental and Applied Sciences, vol. 9, no. 6S, p. 50, 2018, doi: http://dx.doi.org/10.4314/jfas.v9i6s.5

[26] W.N.H.M. Sani, R.P. Jaya, and K.A. Masri, "Performance of hybrid asphalt mixture through the stability and tensile strength," The Open Civil Engineering Journal, vol. 17, no. 1, 2023, doi: http://dx.doi.org/10.2174/0118741495271362231111102911