Journal of Engineering and Technological Sciences

Research Paper

The Effect of Coconut Powder on Asphalt Binder Performance under Laboratory Conditions

Rana A. Yousif[1], Sady A. Tayh[1] & Abbas F. Jasim[1]

Highways and Transportation Engineering Department, College of Engineering, Mustansiriyah University, Bab Al Muadham, Baghdad, Iraq, 10047

Corresponding author: abbas.jasim@uomustansiriyah.edu.iq

Abstract

Bituminous concrete mixture is the most widely used structural layer in flexible pavements. The surface layer of the paving is exposed to repeated loads in addition to changes in temperature, especially during the summer, when the temperature approaches the softness point of the asphalt binder, and therefore, it is subject to multiple types of failure, especially rutting. The properties of asphalt binder and asphalt mixtures can be improved by using various additives. Coconut shell powder, made from the dried husk of coconut fruit, is a popular addition in many industries. As a result of its high strength and stability, this waste material can be recycled into functional structural components such as composite material reinforcement. This study was conducted to evaluate the performance of coconut husk as very fine particles passing through sieve number 200 (0.075 mm) to modify the asphalt binder. The modifier was added at rates of (0, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10) by the weight of asphalt binder. Two asphalt binder types, 80/100 and 40/50 penetration grade, were used in this study. All asphalt samples were tested for penetration, softening point, rotational viscosity, and dynamic shear rheology. The results showed that the modified samples had better physical and rheological properties compared to the base asphalt binders. However, (7-8%) replacement of coconut husk powder, regardless of the base asphalt binder, yielded the best performance among the modified binders. In conclusion, coconut powder has significant potential as a road-building material due to its impact on the viability of the road construction sector.

Keywords: *coconut husk powder; modified asphalt; modifier; rheological properties; rotational viscosity.*

Introduction

Many countries are facing severe issues when it comes to maintaining their road networks due to increases in traffic loading density (in terms of axles) and high tire pressure (due to heavy cars) [1]. In combination with a wide range of solid components that serve as reinforcements, fillers, and additives, asphalt, a highly viscous compound, created by distilling petroleum leftovers, is utilized in construction [2]. These solid materials can be used as reinforcements, for example, fiber waste [3-5] and additives [6, 7], or they can be used as partial replacements of diverse aggregates [8]. As a result, asphalt binders and mixtures provide great test materials for new applications. Due to its well-known binding and waterproofing qualities, asphalt is frequently utilized in road pavement construction at a rate of about 70% by weight [9]. However, as supplied, this material is extremely vulnerable to high temperatures and drain-down [10, 11]. Therefore, before being used in applications for road construction, the asphalt binder needs to be modified [12-15].

A surface layer of pavement with thermal stability is essential [16]. Studies aimed at enhancing asphalt's performance have been undertaken to combat this issue [17]. One strategy involves incorporating fiber additions into the asphalt [18]. Fiber-added materials can be made from either synthetic or natural fibers [19]. Many tropical countries, which provide most of the world's demand for coconuts, have an abundance of coconut husk powder [20]. It is widely believed that coconuts originated in South and Southeast Asia. Coconut shell is a readily available agricultural waste product of the coconut industry that causes significant disposal issues. Even though coconut shells are rarely used in construction, they have proved to be an excellent replacement for standard coarse aggregate in the making of concrete because of their low cost and high lightness [21]. There is no need to do anything special before using coconut shell.

ISSN: 2337-5779
J. Eng. Technol. Sci. Vol. 55, No. 5, 2023, 577-586
DOI: 10.5614/j.eng.technol.sci.2023.55.5.7

Polyester, asbestos, glass, polypropylene, carbon, cellulose, and solid wastes like bamboo, coconut, date palm, and oil palm are just a few examples of the many virgin or recycled materials that can be used to create fibers. Coir fiber is a natural product processed from the husk of coconuts [22]. According to Subramani [23], including coir fiber in asphaltic mixes can improve their mechanical qualities. These include increased strength, stability, durability, resistance to permanent deformation, ductility, and compressibility [24-28]. Coconut powder may have less pozzolanic characteristics than quarry dust when used as a filler in the mix, as observed by Ramadhansyah *et al.* [21]. A novel waste used in the highway industry is coconut shell (CS). This is because coconut shell is a weather-resistant material that works well for building materials. Furthermore, it has little economic value and dumping it costs money and hurts the environment [30]. Coconut shell is considered one of the main causes of pollution, especially in countries producing this crop [29]. Chemically, CS is made up of 29.27 percent pentosans, 36.51 percent lignin, 33.61 percent cellulose, and 0.61 percent ash [31, 32].

According to previous studies, the rheological and mechanical characteristics of coir-modified asphalt have improved, including the resilient modulus [33], fatigue life [34, 35], stiffness [36, 37], and stability [38, 39]. Mongkol *et al.* [40] used coconut peat and bagasse of sugarcane as a substitute for part of the fillers in asphalt mixtures to determine their effect on the viscosity of asphalt mastic and resistance to failure performance. Results showed that at 20 percent filler content, the viscosities of asphalt mastic made with coconut peat and bagasse were comparable to those for asphalt mastic made with limestone filler at all temperatures. Soenen *et al.* [41] conducted research to ascertain whether coconut shell peat fiber may be utilized as a bitumen modifier. After being dried, crushed, and divided into a granular and a fiber fraction, coconut shell peat fibers were analyzed. The granular fraction serves as a filler, largely stiffening the bituminous binders, while the fiber fraction principally improves the elastic behavior, which becomes more visible at higher service temperatures according to rheological data on peat-modified binders. According to the research, peat fibers may replace the cellulose fibers currently in use by significantly lowering drainage.

This study's primary objectives were to improve the mechanical qualities of asphalt materials with potential for use in the pavement sector and to reduce pollution brought on by waste products such as coconut shell powder. In this investigation, two conventional asphalt binders (80-100 and 40-50 penetration grade binders) had waste coconut shell powder added to them. Testing was done on the modified asphalts to ascertain their qualities, including penetration, softening point, penetration index, rotational viscosity, and dynamic shear rheology. Asphalts treated with coconut shell powder were compared to standard asphalt binders in terms of their characteristics.

Materials and Methods

Asphalt Cement

The bitumen binders used were 80/100 and 40/50 penetration grade. The physical properties of the materials used are shown in Table 1.

Table 1 Physical properties of asphalt binders used.

Properties	Unit	Specification	Test results (specification limit)	
			80-100	**40-50**
Softening point (R&B) °C	°C	ASTM D36	45.5 (---)	49.5 (---)
Penetration (25 °C) (0.1mm)	0.1mm	ASTM D5	87 (80-100)	47.4 (40-50)
Ductility at (25 °C) (cm)	cm	ASTM D113	103 (>100)	127 (>100)
Flash point (°C)	°C	ASTM D92	285 (>232)	253 (>232)
Fire point (°C)	°C	ASTM D92	312 (---)	274 (---)
Relative density	---	ASTM D70	1.02 (---)	1.03 (---)

Coconut Shell Powder

Coconut shell powder can be extracted from the outer shell of a coconut. The scientific name of coconut fiber is Cocos Nucifera. Coconut fiber comes in two varieties: brown fiber from mature coconuts and white fiber from

DOI: 10.5614/j.eng.technol.sci.2023.55.5.6

young coconuts. White fibers are smoother and finer but weaker than brown fibers, which are thick, strong and have great resistance to abrasion [27].

The fiber and coconut meat were still inside the husks even after they have been shattered between 50 and 100 millimeters. After 24 hours in the sun, the fiber was cut away. A cutter was used to split the fibers. The shells were crushed by hand using a pestle and mortar. After that, an aggregate crushing machine was used to crush the remaining shells [21]. To make a fine powder combined with a fiber fraction, the coir shell powder was processed in a household grinder for 3 to 5 minutes. Before being combined with asphalt binder, the peat fibers were dried in an oven at 110 ℃ for at least 2 hours [33]. The resultant coir shell powder is shown in Figure 1, while the properties of the coir shell powder are listed in Table 2.

(a) (b)

Figure 1 Coconut (a) shell fiber (b) shell powder.

Table 2 Properties of coconut shell powder.

Properties	Test result
Density (g/cm^3)	0.10
Total organic carbon (%)	20.20
Ash content (%)	2.7
Humidity (%)	0.35
pH value	5.6

Coconut Shell Powder-Asphalt Formulation

In order to ensure that the waste material was distributed evenly throughout the asphalt binder, the bitumen was heated to 160 ℃. Then, different percentages of dried coconut shell powder were added to the hot bitumen (0, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, and 10%) by weight of asphalt binder, and the fiber was blended with the base asphalt binders for 30 minutes at a rate of 200 rpm.

Results and Discussion

Penetration Test

Since asphalt hardness is measured indirectly with a penetration test, asphalt with a lower penetration value is tougher than asphalt with a higher value [42, 43]. At 25 °C, a control penetrometer was used to conduct penetration tests in accordance with the ASTM D5 standard. Figure 2 shows the penetration values of the modified asphalt binders as a function of the coconut shell powder content. The coconut shell powder affected the penetration value of the asphalts, especially at 8% and 7% of coconut powder, for the 80-100 and 40-50 asphalt binders, respectively, which yielded the lowest penetration values. Lower values of penetration mean a significant increase in stiffness, that is, an improvement in the ability to withstand traffic loads at normal temperatures.

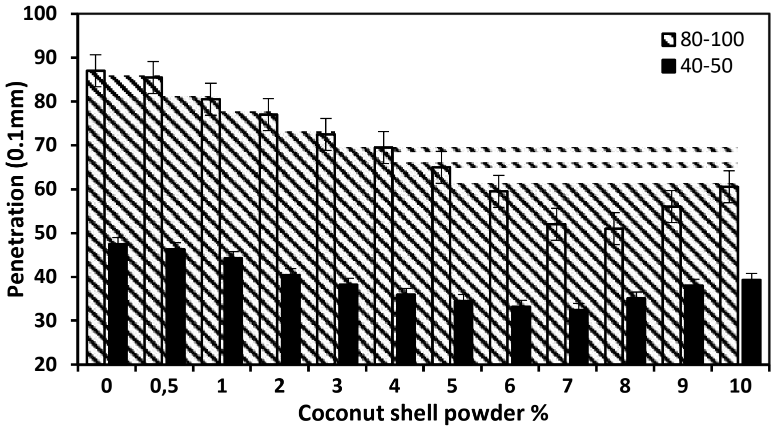

Figure 2 Penetration values for samples with different contents of coconut shell powder.

Softening Point

Softening point tests were made following the ASTM D36 standard in a ring and ball apparatus. As shown in Figure 3, the softening point of the virgin asphalts were 45.5 and 49.5 ℃ for the 80-100 and 40-50 binders, respectively. The softening point values increased until a certain percentage of coconut powder (7%) and then decreased for both base binders, which indicates the improvement of the sensitivity of the asphalt material to the change in temperature.

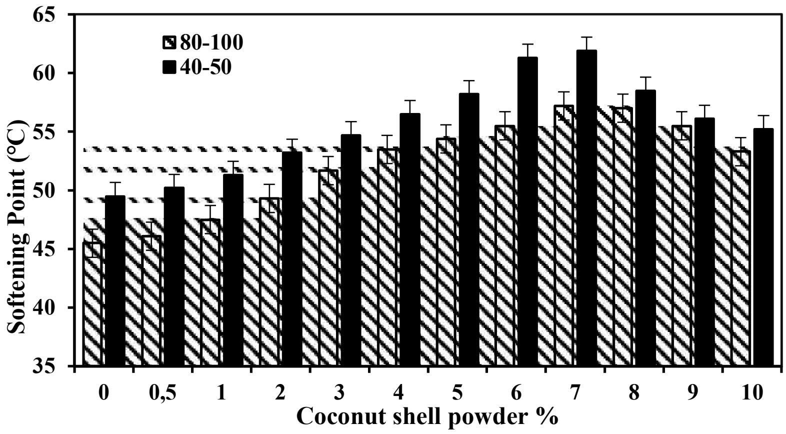

Figure 3 Softening point for samples with different contents of coconut shell powder.

Temperature Susceptibility

Bitumen's temperature sensitivity, or the rate at which its consistency varies with a change in temperature, is a crucial feature [44]. Bitumen's temperature susceptibility was evaluated using the penetration index in this study (PI). Based on the bitumen's softening point (ring and ball test), bitumen's penetration at 25 °C, and the assumption that bitumen's penetration at its softening point temperature is 800, the PI was calculated [45] with Eq. (1) . The relevant findings are displayed in Figure 4.

$$PI = \frac{1952-500\times log(P.25)-20\times T_{SP}}{50\times log(P.25)-SP-120} \tag{1}$$

The penetration index (PI) gives an idea of the temperature susceptibility of the fabricated mixtures: if PI is in the range of (-2 to +2), the binder is tolerably sensitive to changes in temperature. The results showed that the penetration index had the same behavior as the softening point, where it had changed significantly for both

DOI: 10.5614/j.eng.technol.sci.2023.55.5.6

base binders to reach the maximum difference at 7 wt% coir shell powder. All the mixtures fabricated in the present investigation showed a PI within the acceptable range. However, all the changes were positive, as the sensitivity to temperature change was significantly reduced to reach its maximum at 7 wt% for both types of asphalt used.

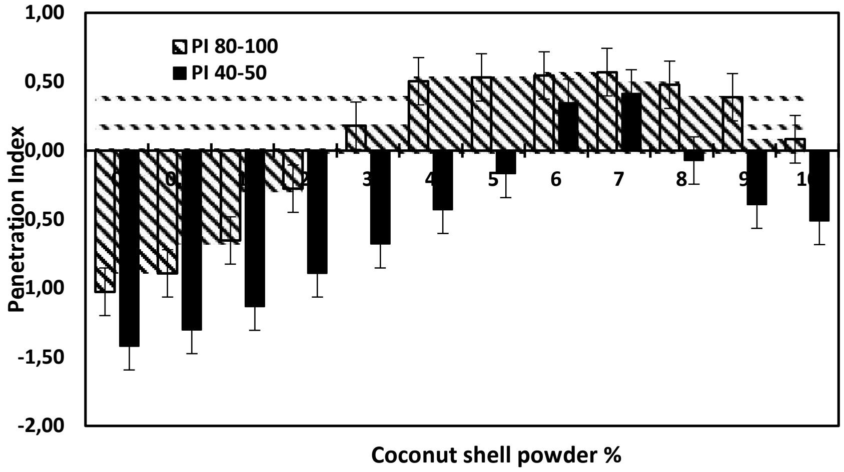

Figure 4 Penetration index for samples with different contents of coconut shell powder.

Rotational Viscosity Test

The asphalt binder's viscosity is used as an indicator of its flow properties, guaranteeing smooth pumping and handling of the binder at the hot mixing plant. Figure 5 displays the results of measurements made at 135 °C with a rotational Brookfield viscometer on unaged binders, including coir shell powder. The viscosity values were measured at one shear rate of 20 rpm, as recommended by the Asphalt Institute, using spindle 27. It can be seen that the addition of coconut shell powder increased the viscosity of the binders until they reached the highest viscosity at 7% and 8% by weight of the 40-50 and 80-100 binders, respectively, and then decreased again. This suggests that including coir shell powder into the pavement mix increases the mixture's resilience to permanent deformation by making the binders stiffer at high pavement service temperatures.

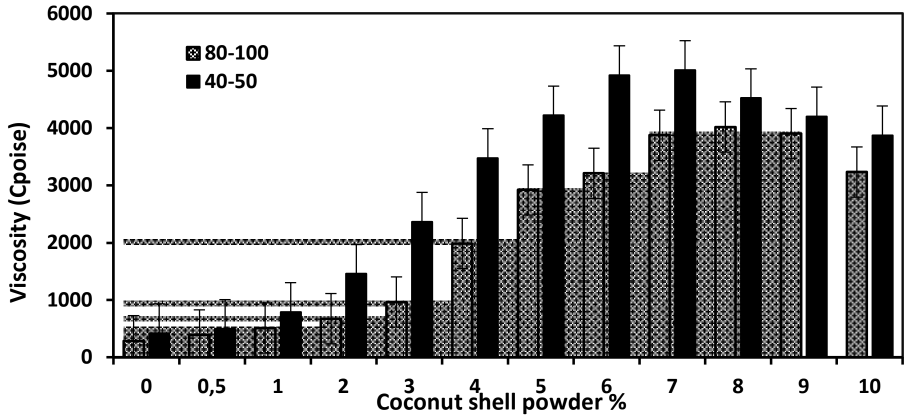

Figure 5 Rotational viscosity for samples with different contents of coconut shell powder.

Rheological Testing

A dynamic shear rheometer was used to characterize the viscosity and elastic behavior of unaged asphalt binders to study their rheological characteristics. The Strategic Highway Research Program's asphalt binder standards (SHRP) were used in this study, which uses a plate that is 1 mm thick and 25 mm in diameter at a frequency of

10 rad/sec and a controlled stress mode of 0.12 kPa for unaged asphalt binders. In order to describe the initial stiffness and resistance of the asphalt binders to permanent deformation, the rutting parameter (G*/sinδ) in DSR was calculated. For the original asphalt binder, 1000 Pa is the lowest permitted value for G*/sinδ (AASHTO T315, 2010). To ascertain the change in binder performance as a function of temperature, a DSR oscillation temperature sweep test was conducted at moderate and high service temperatures ranging from 40 to 82 °C with 6-degree steps. Figures 6 and 7, respectively, depict the temperature dependence of the rutting parameter (G*/sinδ) related to the base asphalt binders (80-100 and 40-50).

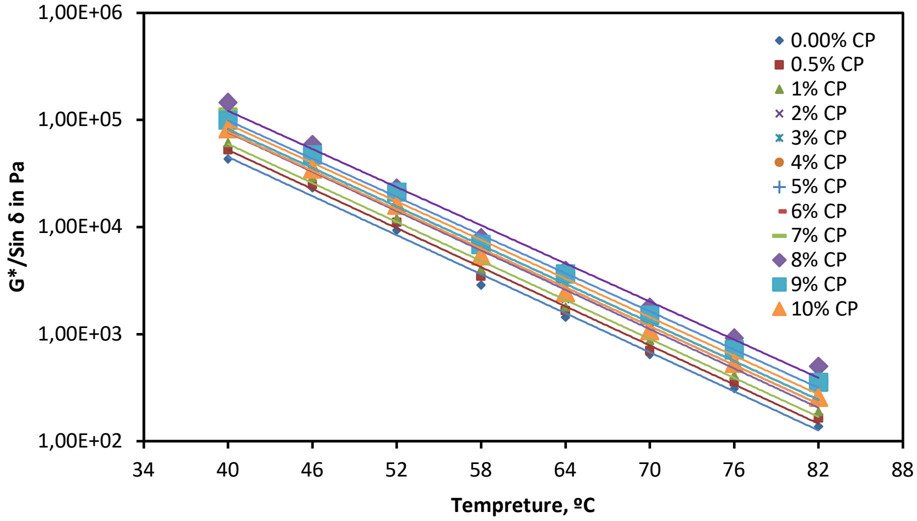

Figure 6 Rutting parameter values (G*/sinδ) for the modified 80-100 asphaltic binder as a function of temperature.

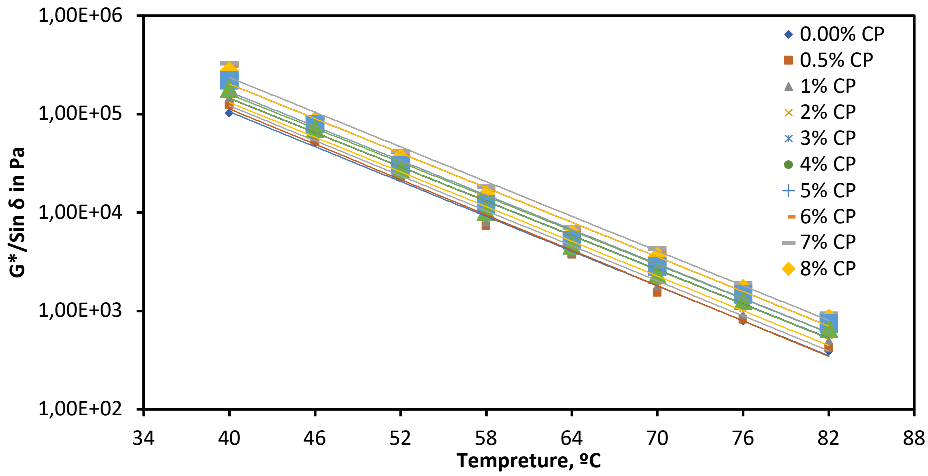

Figure 7 Rutting parameter values (G*/sinδ) for the modified 40-50 asphaltic binder as a function of temperature.

The trends observed in Figures 6 and 7 clearly show that generally higher values of (G*/sinδ) (stiffer asphalts) were obtained by increasing the content of coir powder in the base asphalts, until reaching maximum values corresponding to 7 and 8 wt% coir powder for the 40-50 and 80-100 binders, respectively. This indicates that these two ratios gave the highest resistance to permanent deformation (rutting) for both types of asphalt binders.

DOI: 10.5614/j.eng.technol.sci.2023.55.5.6

The varying effects of coir fiber on the rheological properties of the 80-100 and 40-50 asphalt binders provide credence to the claim that the influence of additives on asphaltic binders differs from binder to binder, depending on the original binder's source and chemical composition. Its effects are unique to the specific context in which they were observed.

As for the effect of using coconut powder on the failure temperature for both types of asphalt binder, it was as shown in Figures 8 and 9. Figure 8 shows the increase in the failure temperature of the 80-100 asphalt binder from 67 ℃ for the original asphalt to 75 ℃ at a coconut powder percentage of 8%. This indicates an increase in the performance grade of the asphalt binder by at least one grade from PG64 to PG70. Figure 9 shows the increase in the failure temperature of the 40-50 asphalt binder from 64 ℃ for the original asphalt to 81 ℃ at 7% of added coconut powder. This indicates an increase in the performance grade of the asphalt binder by at least one grade from PG70 to PG76.

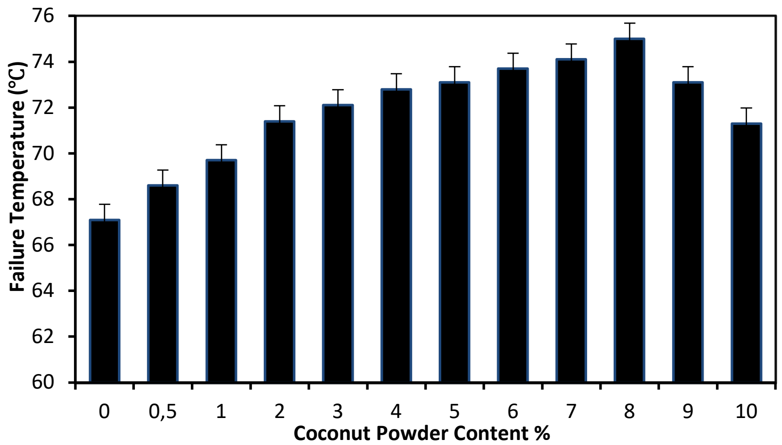

Figure 8 The failure temperature for the modified 80-100 asphaltic binder.

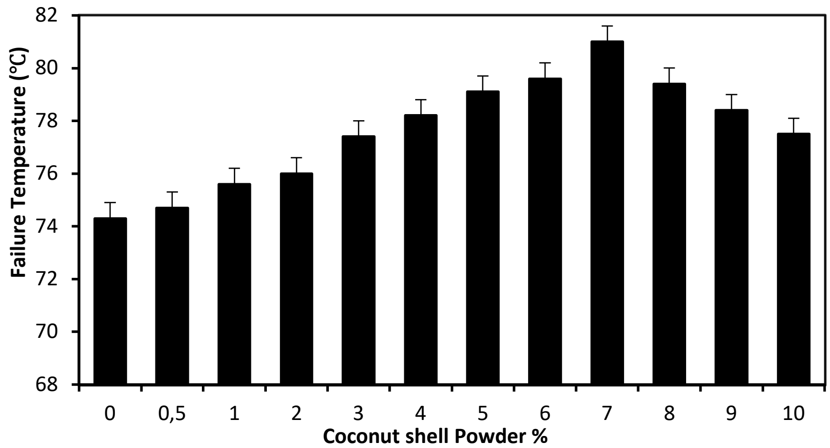

Figure 9 The failure temperature for the modified 40-50 asphaltic binder.

Discussion

The results of the penetration and softening point tests showed that when the percentage of coconut shell powder in the modified asphalt material was increased, the penetration value decreased while the softening point increased significantly, which indicates an increase in the viscosity of the modified asphalt material. As the results of the rotational viscosity test showed, adding coconut shell powder to the asphalt binder led to an increase in viscosity. Increases in viscosity often indicate stiffening of the blend, which in turn reduces its tendency to deform under loading. The viscosity became higher, probably due to the crosslinking effect caused by the coconut shell powder with the asphalt binder.

The results also showed that the sensitivity of the modified asphalt to temperature changes was significantly improved, through the penetration index, especially at 7-8% added coconut powder, regardless of the type of binder used. However, it was noted that the percentage of change in consistency or sensitivity to change in temperature for the 80-100 asphalt binder was relatively greater than for the 40-50 asphalt binder, as it was originally more liquid (less viscous); this was expected.

As a result of this change, the modified asphalt binders had better resistance to temperature change in the service temperatures and, accordingly, produced asphalt binders with upgraded service performance grades, especially at higher temperatures. These changes make the asphalt more resistant to deformation. The results of the rheological testing revealed the improvement of the failure temperature for both asphalt binders used by at least one performance grade, indicating an improvement in the resistance to rutting at high service temperatures and allowing to use the modified binders in hot regions.

Conclusions

In this study, using a mechanical stirring process, two types of asphalt binders (80-100 and 40-50) were modified with coir shell powder. Up to 10 wt% coir shell powder was added to the two control asphalts, so the blend's behavior could be studied. The following are the main conclusions drawn from the outcomes of this study:

1. There is a maximum or optimal value of coir shell powder content that delivers the best mechanical qualities, as determined by the results of fundamental tests (penetration, softening point, and viscosity). Properties change, and binders get weaker, if this amount is exceeded.
2. Coir shell powder increased the stiffness properties of the base asphalt binders. This is clear by the raise in the softening point and viscosity of the bitumen, and a decrease in penetration grade of the bitumen.
3. The results showed that the modified asphalt binders performed better than the base asphalt binders, while the content of 7-8 percent coconut shell powder offered the best performance of the variants studied. Enhancing their rheological properties makes the materials more resistant to heavy traffic loading by enhancing the performance grade for the base asphalt binders at least one grade up.
4. Using coir fiber to improve the rheology of asphaltic materials has the added bonus of being an eco-friendlier solution to the problems caused by discarded coconut husk. This can aid in the efficient utilization of raw materials and byproducts in the building of flexible pavements, a technique used all over the world.

Acknowledgement

The authors acknowledge the help they received from Mustansiriyah University/College of Engineering/ Highways and Transportation Engineering Department in Baghdad, Iraq.

References

[1] Safiuddin, M., Jumaat, M.Z., Salam, M., Islam, M. & Hashim, R., *Utilization of Solid Wastes in Construction Materials,* International Journal of Physical Sciences, **5**, pp. 1952-1963, 2010.

[2] Herráiz, T.R., Herráiz, J.I.R., Domingo, L.M. & Domingo, F.C., *Posidonia Oceanica Used as a New Natural Fibre to Enhance the Performance of Asphalt Mixtures*, Construction and Building Materials, **102**, pp. 601-612, 2016.

[3] Abtahi, S.M., Sheikhzadeh, M. & Hejazi, S.M., *Fiber-reinforced Asphalt-Concrete–A Review*, Construction and Building Materials, **24**, pp. 871-877, 2010.

[4] Huang, Y., Bird, R.N. & Heidrich, O., *A Review of the Use of Recycled Solid Waste Materials in Asphalt Pavements*, Resources, Conservation and Recycling, **52**, pp. 58-73, 2007.

DOI: 10.5614/j.eng.technol.sci.2023.55.5.6

[5] Dong, W., Li, W. & Tao, Z., *A Comprehensive Review on Performance of Cementitious and Geopolymeric Concretes with Recycled Waste Glass as Powder, Sand or Cullet*, Resources, Conservation and Recycling, **172**, pp. 105664, 2021.

[6] Abdullah, M.E., Zamhari, K.A., Shamshudin, M.K., Hainin, M.R. & Satar, M.K.I.M., *Rheological Properties of Asphalt Binder Modified with Chemical Warm Asphalt Additive,* Advanced Materials Research, **671**, pp. 1692-1699, 2013.

[7] Colorado, H.A., Nino, J.C. & Restrepo, O., *Applications and Opportunities of Nanomaterials in Construction and Infrastructure*, Characterization of Minerals, Metals, and Materials, **437**, 012014, 2018.

[8] Smith, M.R. & Collis, L., *Aggregates: Sand, Gravel and Crushed Rock Aggregates for Construction Purposes*, Geological Society of London, Geological Society of London, Springer, SPE 17, 2001.

[9] Vale, A.C.D., Casagrande, M.D.T. & Sares, J.B*., Behaviour of Natural Fibre in Stone Matrix Asphalt Mixtures Using Two Design Methods*, Journal of Materials in Civil Engineering, **26**(3), pp. 457-465, 2014.

[10] Putman, B.J. & Amirkhanian, S.N., *Utilization of Waste Fibres in Stone Matrix Asphalt Mixtures, Resources, Conservation And Recycling*, **42**(3), pp. 265-274, 2004.

[11] Marasteanu, M.O., Clyne, T., McGraw, J., Li, X. & Velasquez, R., *High-temperature Rheological Properties of Asphalt Binders*, Transportation Research Record, **1901**(1), pp. 52-59, 2005.

[12] Limantara, A.D., Winarto, S., Gardjito, E., Subiyanto, B., Raharjo, D., Santoso, A., Sudarmanto, H.L. & Mudjanarko, S.W., *Optimization of Standard Mix Design of Porous Paving Coconut Fiber and Shell for the Parking Area*, in AIP Conference Proceedings, AIP Publishing, **2020**(1), 020029, 2018.

[13] Deng, Z., Li, W., Dong, W., Sun, Z., Kodikara, J. & Sheng, D., *Multifunctional Asphalt Concrete Pavement toward Smart Transport Infrastructure: Design, Performance and Perspective*, Composites Part B: Engineering, **265**, 110937, 2023.

[14] Khairuddin, F.H., Asri, S.Z.M., Misnon, N.A., Yusoff, N.I.M., Fadzil, A.D. & Ahmad, K.Z.K., *Physicothermal and Topography Analysis of Polyurethane Modified Bitumen with Rediset for WMA Application*, Journal of Engineering and Technological Sciences, **55**(1), pp. 30-39, 2023.

[15] Yaro, N.A., Napiah, M., Sutanto, M.H., Usman, A., Mizwar, I.K. & Umar, A.M., *Engineering Properties of Palm Oil Clinker Fine-Modified Asphaltic Concrete Mixtures*, Journal of Engineering and Technological Sciences, **54**(2), 220205, 2022.

[16] Lei, B., Xiong, Q., Zhao, H., Dong, W., Tam, V.W., Sun, Z. & Li, W., *Performance of Asphalt Mortar with Recycled Concrete Powder under Different Filler-to-asphalt Weight Ratios*, Case Studies in Construction Materials, 18, pp. e01834, 2023.

[17] Long, G., Li, L., Li, W., Ma, K., Dong, W., Bai, C. & Zhou, J.L., *Enhanced Mechanical Properties and Durability of Coal Gangue Reinforced Cement-Soil Mixture for Foundation Treatments*, Journal of Cleaner Production, **231**, pp. 468-482, 2019.

[18] Reddy, B.D., Jyothy, S.A. & Shaik, F., *Experimental Analysis of the Use of Coconut Shell as Coarse Aggregate*, J. Mech. Civil Eng, **10**(6), pp. 6-13, 2014.

[19] Sivaraja, M. & Kandasamy, S., *Characterisation of Natural Fibres as Concrete Composites for Structural Applications*, International Journal of Materials and Product Technology, **36**(1-4), pp. 385-395, 2009.

[20] Hadiwardoyo, S.P., *Evaluation of the Addition of Short Coconut Fibers on the Characteristics of Asphalt Mixtures*, Civil and Environmental Research, **3**(4), pp. 63-73, 2013.

[21] Ramadhansyah, P.J., Aqeela, M.N., Amiera, J.S.N., Norhafizah, M., Norhidayah, A.H. & Dewi, S.J., *Use of Coconut Shell from Agriculture Waste as Fine Aggregate in Asphaltic Concrete*, ARPN Journal of Engineering and Applied Sciences, **11**(12), pp. 7457-7462, 2016.

[22] Amiera Jeffry, S.N., Jaya, R.P., Manap, N., Miron, N.A. & Hassan, N.A., *The Influence of Coconut Shell as Coarse Aggregates in Asphalt Mixture*, Key Engineering Materials, **700**, pp. 227-237, 2016.

[23] Subramani, T., *Experimental Investigations on Coir Fibre Reinforced Bituminous Mixes*, Strain, **2**, pp. 4-5, 2012.

[24] Xiao, F., Amirkhanian, S.N., Shen, J. & Putman, B., *Influences of Crumb Rubber Size and Type on Reclaimed Asphalt Pavement (RAP) Mixtures*, Construction and Building Materials, **23**(2), pp. 1028-1034, 2009.

[25] Chiew, Y. L., Iwata, T. & Shimada, S., *System Analysis for Effective Use of Palm Oil Waste as Energy Resources*, Biomass and Bioenergy, **35**(7), pp. 2925-2935, 2011.

[26] Sahari, J., & Sapuan, S.M., *Natural Fibre Reinforced Biodegradable Polymer Composites*, Rev. Adv. Mater. Sci, **30**(2), pp. 166-174, 2011.

[27] Ali, M., Liu, A., Sou, H. & Chouw, N., *Mechanical and Dynamic Properties of Coconut Fibre Reinforced Concrete*, Construction and Building Materials, **30**, pp. 814-825, 2012.

[28] Hainin, M.R., Matori, M.Y. & Akin, O.E., *Evaluation of Factors Influencing Strength of Foamed Bitumen Stabilised Mix*, Jurnal Teknologi, **70**(4), pp. 111-119, 2014.

[29] Gunasekaran, K., Annadurai, R. & Kumar, P.S., *Long Term Study on Compressive and Bond Strength of Coconut Shell Aggregate Concrete*. Construction and building materials, **28**(1), pp. 208-215, 2012.

[30] Nagarajan, V.K., Devi, S.A., Manohari, S.P. & Santha, M.M., *Experimental Study on Partial Replacement of Cement with Coconut Shell Ash in Concrete*, International Journal of science and research, 3(3), pp. 651-661, 2014.

[31] Shelke, A.S., Ninghot, K.R., Kunjekar, P.P. & Gaikwad, S.P., *Coconut Shell as Partial Replacement for Coarse Aggregate*. International Journal of Civil Engineering Research, **5**(3), pp. 211-214, 2014.

[32] Ting, T.L., Jaya, R.P., Hassan, N.A., Yaacob, H. & Jayanti, D.S., *A Review of Utilization of Coconut Shell and Coconut Fiber In Road Construction*. Jurnal Teknologi, **76**(14), pp. 121-125 2015.

[33] Oda, S., Fernandes Jr, J.L. & Ildefonso, J.S., *Analysis of Use of Natural Fibers and Asphalt Rubber Binder in Discontinuous Asphalt Mixtures*, Construction and Building Materials, **26**(1), pp. 13-20, 2012.

[34] Panda, N., *Laboratory Investigations on Stone Matrix Asphalt Using Sisal Fibre for Indian Roads,* Bachelor of Technology Project, National Institute of Technology, Rourkela, India, 2010.

[35] Al-Sabaeei, A.M., Agus Mustofa, B., Sutanto, M.H., Sunarjono, S. & Bala, N., Aging and Rheological Properties of Latex and Crumb Rubber Modified Bitumen Using Dynamic Shear Rheometer. Journal of Engineering & Technological Sciences, **52**(3), pp.385-398, 2020.

[36] Kara De Maeijer, P., Soenen, H., Van den bergh, W., Blom, J., Jacobs, G. & Stoop, J., *Peat Fibers and Finely Ground Peat Powder for Application in Asphalt*, Infrastructures, **4**(1), 3, pp. 1-14, 2019.

[37] Nataliasari, I.D., Pranolo, S.H., Pramesti, F.P. & Setyawan, A., *Stiffness and Creep Properties of HRS-BC Powered by Palm Shell Gasification in Dryer Unit,* Journal of Engineering & Technological Sciences, **54**(6), pp. 1160-1172, 2022.

[38] Thulasirajan, K. & Narasimha, V.L., *Studies on Coir Fibre Reinforced Bituminous Concrete*, Int J Earth Sci Eng, **4**(6), pp. 835-838, 2011.

[39] Maharaj, R., Ali, R., Ramlochan, D. & Mohamed, N., *Utilization of Coir Fibre as an Asphalt Modifier*, Progress in Rubber, Plastics and Recycling Technology, **35**(2), pp. 59-74, 2019.

[40] Mongkol, K., Chaturabong, P. & Suwannaplai, A., *Effect of Bagasse and Coconut Peat Fillers on Asphalt Mixture Workability*, Coatings, **10**(12), 1262, 2020.

[41] Soenen, H., Kara De Maeijer, P., Blom, J. & Van den Bergh, W., *Peat as an Example of a Natural Fiber in Bitumen*, in RILEM 252-CMB Symposium: Chemo-Mechanical Characterization of Bituminous Materials, Springer International Publishing, pp. 300-305, 2019..

[42] Alsheyab, M.A. & Khedaywi, T.S., *Effect of Electric Arc Furnace Dust (EAFD) on Properties of Asphalt Cement Mixture*, Resources, Conservation and Recycling, **70**, pp. 38-43, 2013.

[43] Loaiza, A., Cifuentes, S. & Colorado, H.A., *Asphalt Modified with Superfine Electric Arc Furnace Steel Dust (EAF Dust) with High Zinc Oxide Content*, Construction and Building Materials, **145**, pp. 538-547, 2017.

[44] Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D.Y. & Kennedy, T.W., *Hot Mix Asphalt Materials*, Mixture Design and Construction, National Asphalt Pavement Association, Lanham, Maryland, ed. 2, 1996.

[45] Rusbintardjo, G., Hainin, M.R. & Yusoff, N.I.M., *Fundamental and Rheological Properties of Oil Palm Fruit Ash Modified Bitumen*, Construction and Building Materials, **49**, pp. 702-711, 2013.

Manuscript Received: 1 May 2023
Revised Manuscript Received: 1 November 2023
Accepted Manuscript: 29 November 2023