SCIENCE LETTERS

Available online at https://scilett-fsg.uitm.edu.my/

ISSN: 1675-7785
eISSN: 2682-8626

Science Letters 18(4) 2024, 12-20.

A Comprehensive Review: Assessing Crumb Rubber Integration in Bitumen for Road Construction

Nurul Najihah Mad Rosni[1*], Noor Syafiqah Mohd Sabri[2]

[1]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
[2] Quantity Surveying Studies, School of Construction Management and Quantity Surveying, College of Built Environment, Universiti Teknologi MARA Shah Alam, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 30 April 2024
Revised 31 August 2024
Accepted 30 September 2024
Online first
Published 28 October 2024

Keywords:
crumb rubber
modified bitumen
penetration test
road construction
softening point test

DOI:
10.24191/sl.v18i4.9666

ABSTRACT

This review paper investigates the effectiveness of Crumb Rubber Modified Bitumen (CRMB) in the construction of roads, with an emphasis on its potential to enhance pavement quality and contribute to environmental sustainability. The primary goal of this study is to evaluate the effects of integrating crumb rubber, obtained from used tires, into bitumen. This addresses the rising issue of tyre waste and improves the structural integrity and durability of road surfaces. The research undertaken by numerous experts emphasizes the importance of high-quality pavements in ensuring stable, smooth, and safe pavement surfaces. Conventional pavements frequently deteriorate rapidly due to traffic loads and temperature fluctuations. However, adding CR to bitumen has been demonstrated to greatly reduce these concerns by increasing pavement durability and serviceability, prolonging its lifespan, and lowering maintenance requirements. The review summarizes results from multiple studies, emphasizing that CRMB consistently exhibits a higher softening point and lower penetration values compared to conventional bitumen. The wet mixing process for CRMB preparation involves heating bitumen and integrating CR at high temperatures to produce a homogeneous mixture. When combined with penetration and softening point testing, this procedure illustrates the increased stiffness and temperature resistance provided by CR. Based on the results gathered, CRMB substantially improves the properties of bitumen, thereby establishing the substance as a feasible alternative for upgrading the longevity and effectiveness of road infrastructure. The paper emphasizes the need for additional research to balance rigidity and flexibility in CRMB to accommodate diverse climatic challenges.

INTRODUCTION

Bitumen is a durable, adhesive, long-lasting substance derived from natural asphalt or crude oil. During refining, the lighter fractions from crude oil, such as gasoline, diesel, and liquid petroleum gas, are removed to produce bitumen [1]. It is distinguished by its viscous consistency at room temperature and its solubility. The type of crude oil used, and the distillation techniques utilized significantly impact the quality

[1*] Corresponding author. *E-mail address*: najihah558@uitm.edu.my
https://doi.org/10.24191/jeeir.v10i1.9666

and properties of bitumen; bitumen with higher viscosity is generally produced from heavier crude oils [1]. It is used in construction because of its ability to withstand various weather conditions and high traffic volumes. Bitumen must possess certain rheological qualities for paving and industrial applications [2]. It must be flexible at low temperatures to prevent thermal cracking, stiff at high temperatures to prevent rutting, and fluid at high temperatures for efficient mixing.

On the other hand, conventional bitumens sometimes fail to satisfy these demands, which results in poor performance in extremely hot or cold temperatures and decreased durability in situations with heavy traffic. Modifiers and additives that improve bitumen performance include polymers, chemical modifiers, extenders, hydrocarbons, and anti-stripping additives. This review paper is dedicated mostly to discussing crumb rubber-modified bitumen utilized in recent decades of study, providing an overview of the science and technology of bitumen modifiers.

Crumb rubber-modified bitumen (CRMB) has been developed as an important breakthrough in road construction, addressing both environmental concerns and the goal of higher-quality pavements. This eco-friendly method has been widely studied in the pavement industry to modify asphalt mixture properties [3,4]. Incorporating crumb rubber (CR) obtained from scrap tyres for modified bitumen manufacturing provides an efficient method of recycling a significant waste product. It improves the structural integrity and lifespan of road surfaces. Jalal Kashesh et al. [5] points out that high-quality pavement is critical for providing a stable, smooth, safe riding surface. However, standard pavements frequently deteriorate due to traffic and temperature fluctuations. Adding crumb rubber to bitumen minimizes these concerns, considerably improving the pavement's durability and serviceability [6]. Besides, this strategy saves road construction resources and reduces landfill area, lowering environmental effects [7,8]. The use of crumb rubber in bitumen has two environmental benefits. For example, it addresses growing concern over the accumulation of waste tires [1,3].

Due to the rapid growth of the automotive and rubber industries, millions of tires are wasted each year, posing a severe environmental risk. The impact on landfills and the environment is significantly reduced by converting this waste into CRMB [9]. As the properties of CR are similar to the properties of bitumen, it is suitable to be used as a modifier to improve the properties of bitumen. Studies have shown that this modified bitumen works much better than conventional bitumen [10]. The previous results show that CR increases the properties of bitumen mixtures in addition to improving the physical qualities of rubberized bitumen binders, as proven by penetration and softening point tests [11-13]. It has been discovered that crumb rubber increases rut resistance and improves fatigue life with the increase in resilient modulus [8], [14]. The improvements include stronger resistance to cracking and aging, resulting in a longer road lifespan and fewer maintenance needs [15,16]. Therefore, CRMB offers a potential answer to road quality improvement and waste tire management, offering solutions to environmental sustainability and infrastructure growth.

METHODOLOGY

Material

Bitumen is a dark or black substance resulting from petroleum distillation. It is a viscous adhesive composed of high molecular weight hydrocarbons. Bitumen is solid at ambient temperature but becomes very viscous at 100 °C [17]. Tables 1 and 2 show the different bitumen grades researchers use in their

https://doi.org/10.24191/sl.v18i4.9666

studies. The various grades of bitumen indicate its appropriateness for different types of road construction and weather circumstances, mainly determined by its physical characteristics [1].

Mixing Process

Two main techniques blend Crumb rubber (CR) with bitumen. In this review article, all previous studies used the wet method to introduce CR in the bitumen. Research indicates that the wet method for modified bitumen-containing waste rubber performs better than the typical dry process in terms of fatigue resistance, rutting resistance, and resilience modulus [7,18,19]. The common wet mixing procedure requires heating the bitumen to a fluid condition that prohibits degradation, normally between 160 to 170°C. However, mixing duration and temperature depend on the type of crumb rubber and bitumen [20]. Fine sizes of CR are then slowly added to the heated bitumen, ranging from 5% to 25% by mass. The combination is blended at high temperatures to improve the interaction of CR and bitumen, resulting in a viscous fluid. This procedure frequently requires a high-shear mixer working at speeds ranging from 1000 to 3500 rpm to achieve thorough mixing and consistency. The mixing time is usually around 30 minutes, which allows the CR to be thoroughly incorporated into the bitumen [1,3].

Penetration Test

The bitumen penetration test is a method for determining the consistency of bitumen using ASTM D5 rules [21]. This test measures the depth of a standard needle that can penetrate a bitumen sample under certain conditions to determine its hardness. The test is carried out by driving a standard needle perpendicularly into a bitumen sample for 5 seconds at a temperature of 25°C and a load of 100 grams, as shown in Fig. 1. The penetration depth, measured in d-millimeters, reflects the bitumen's consistency. Higher penetration levels indicate a softer bitumen.

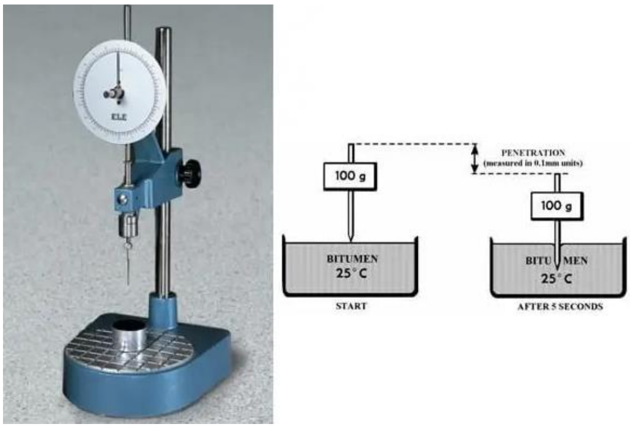

Fig. 1. Bitumen penetration test

Softening Point Test

According to ASTM D36/D36M−14 [22] requirements, the softening point test for bitumen is performed using the ring and ball apparatus, as shown in Fig. 2. The temperature at which the bitumen softens to the point that it can no longer hold the weight of a 3.5 g steel ball is determined by this test. Two horizontal discs of bitumen are cast in shouldered brass rings and heated at a controlled rate of 5°C per minute in a liquid bath, commonly distilled water. Each disc contains a steel ball. The bitumen softens and becomes less viscous as the temperature rises. The softening point is the mean temperature at which each ball, encased in bitumen, falls 25 mm. This test is critical for understanding the bitumen's temperature

https://doi.org/10.24191/sl.v18i4.9666

resistance and behavior at high temperatures. The softening point indicates the degree of softness and is essential in estimating the temperature at which bitumen must be heated for mixing.

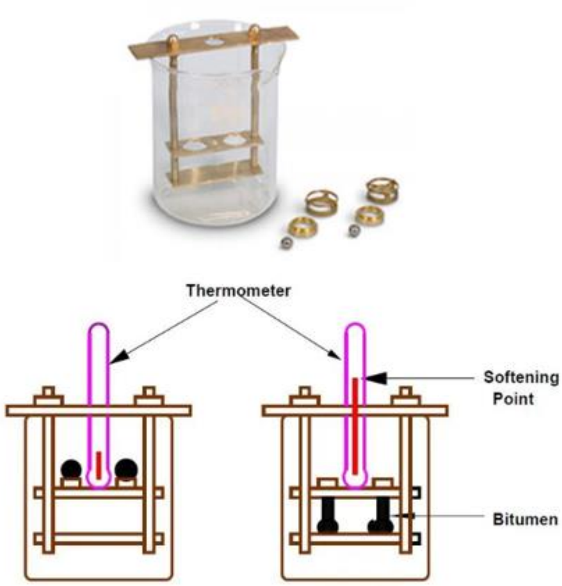

Fig. 2. Softening point test

RESULT AND DISCUSSION

This section reviews the previous findings about CRMB. Table 1 and Table 2 present the data from multiple previous studies that investigated the effects of different percentages of crumb rubber on bitumen properties. This comparison can help understand the effect of crumb rubber modification on the properties of bitumen.

Impact on Penetration Value

In terms of penetration value, all authors indicated a reduction in penetration values with the addition of crumb rubber, showing improved stiffness independent of the bitumen grade utilized [23-25]. Poovaneshvaran et al. [25] and Jalal Kashesh et al. [5], for example, reported decreases to 42 mm and 37 mm, respectively, when incorporated with 15% of CR. The same pattern was observed in the research of Humagain & Homagai [24] and A. However, Aziz et al. [7] found a less noticeable drop at lower CR concentrations. Li et al. [26] also found that the penetration degree results gradually decrease when CR content increases to 20%. However, when the percentage of CR increases from 20% to 25%, the penetration value gradually increases. Low susceptibility to high temperature increases stiffness [27,28]. In addition, the study by Wulandari and Tjandra [13] demonstrates that bigger crumb rubber sizes resulted in higher penetration values than smaller ones, implying a nuanced influence of crumb size on bitumen flexibility. The use of small-size CR not only speeds up the mixing process but also leads to a high CR surface area per unit mass of bitumen, resulting in fast dissolution [5]. The decrease in penetration values across these tests shows an increase in rigidity, which improves the load-bearing capability of the pavement but may reduce its flexibility, especially in colder areas.

Table 1. Comparative analysis of crumb rubber modified bitumen: result of penetration test.

Author (Year)	Grade of Bitumen	Unmodified Bitumen Penetration (DMM)	Modified Bitumen Penetration (DMM)
Poovaneshvaran et al., (2020) [25]	60/70	65	42 (15% CR)
Jalal Kashesh et al. (2023) [5]	40/50	43.5	37 (15% CR)
Li, et al., (2020) [26]	SK90 (90/100)	91.1	55.2(15% CR) 51.56 (17.5% CR) 51.23 (20% CR) 63.77 (22.5% CR) 70.27(25% CR)
Wulandari & Tjandra, (2017) [13]	60/70	64.3	41.33 (Size 40, 1% CR) 44 (Size 40, 2% CR) 43.8 (Size 80, 1% CR) 41.5 (Size 80, 2% CR)
Humagain & Homagai (2017) [24]	80/100	82	72.2 (6% CR) 64.5 (8% CR) 60 (10% CR) 51.8 (12% CR) 45 (14% CR)
A.Aziz et al., (2016) [7]	80/100	90	58 (5% CR) 54 (10% CR) 53 (15% CR)

Impact on Softening Point Value

The softening point of bitumen determines its temperature sensitivity, with higher values indicating a lower temperature sensitivity [30]. Poovaneshvaran et al. [25] and Jalal Kashesh et al. [5] discovered that crumb rubber substantially enhances the bitumen's softening point. Poovaneshvaran et al. [25] noted a 15% CR rise from 49°C to 61°C, while Jalal Kashesh et al. [5] observed a 52.5°C to 58°C increase. Similarly, Humagain & Homagai [7], Aziz et al. [24] and Li et al. [26] support this trend; however, the degree of increase varies depending on the CR content. Khaleel et al. [31] noted that the increase in softening value is due to the increased stiffness of the bitumen caused by interactions between CR and bitumen.

In contrast, Wulandari & Tjandra [13] study stands out for testing different sizes of crumb rubber, demonstrating that not only the proportion of crumb rubber but also the size of crumb rubber plays an important impact in changing the softening point. Their findings showed that the size of the crumb rubber also plays an important role, with smaller sizes resulting in a greater increase in the softening point. Size 80 (2%) has the greatest rise, with a softening point of 65.35°C. Crumb rubber size influences the properties of modified bitumen [13,18]. Using the fine size of CR may reduce segregation during the preparation of the mixture and increase the complex modulus and phase angle of bitumen. The uniform increase in softening point across these experiments shows that modified bitumen has improved thermal resistance, which is useful in warmer locations where high-temperature rutting is a concern.

Table 2. Comparative analysis of crumb rubber modified bitumen: result of softening point test.

Author	Grade of Bitumen	Unmodified Bitumen Penetration (DMM)	Modified Bitumen Penetration (DMM)
Poovaneshvaran et al. [25]	60/70	49.0	61 (15% CR)
Jalal Kashesh et al. [5]	40/50	52.5	58 (15% CR)
Li et al. [26]	SK90 (90/100)	46.35	58.67 (15% CR) 59.55 (17.5% CR) 59.15 (20% CR) 60.55 (22.5% CR) 61.65 (25% CR)
Wulandari & Tjandra, [13]	60/70	52.2	54.06 (Size 40, 1% CR) 57.96 (Size 40, 2% CR) 57.35 (Size 80, 1% CR) 65.35 (Size 80, 2% CR)
Humagain & Homagai [24]	80/100	45	44.85 (6% CR) 45.4 (8% CR) 46.4 (10% CR) 48.2 (12% CR) 50.5(14% CR)
Aziz et al. [7]	80/100	45.5	54 (5% CR) 56.5 (10% CR) 58 (15% CR)

CONCLUSION

The complete analysis of CRMB across multiple research demonstrates the profound impact of crumb rubber on bitumen's physical properties. Incorporating CR results in a significant increase in softening point and a decrease in penetration values, indicating greater thermal resistance and increased bitumen stiffness. Furthermore, the study highlights that the significant limit for crumb rubber concentration improves stiffness and thermal resistance, which is most noticeable at concentrations of up to 20%. Beyond this point, the effectiveness of crumb rubber may decrease, indicating an appropriate concentration range for optimizing CRMB performance benefits. Furthermore, the effect of crumb rubber size on bitumen characteristics provides a fascinating path for future research, with certain size ranges being potentially adjusted to obtain desired results. The increase in the higher softening point is particularly crucial for applications in hotter regions where resistance to high-temperature deformation is critical. In contrast, the decrease in penetration values indicates increased load-bearing capacity, which also needs flexibility, particularly in colder environments.

The research suggests that using CR-modified bitumen to increase road durability and performance is a good idea. It also highlights the significance of future research into the appropriate CR content and size for balancing stiffness and flexibility under varied climatic circumstances. This comprehensive study of the features of CR-modified bitumen lays the door for a more durable and flexible road infrastructure. The author suggested an extensive use of CR-modified bitumen in the road pavement industry due to the inherent limitations of good bitumen and sturdy pavements in the existing transportation network.

https://doi.org/10.24191/sl.v18i4.9666

ACKNOWLEDGEMENTS/FUNDING

The authors would like to acknowledge the support of Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia, for providing the facilities to complete this review article.

CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted without any self-benefits or commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Najihah carried out the research, collected previous articles, and wrote and edited the review article. Syafiqah anchored the review, revised, edited, formatted the article, and approved its submission.

REFERENCES

[1] Here are your references formatted in APA 7th edition:
[2] Hunter, R. N., Self, A., Read, J., & Hobson, E. (2015). *The shell bitumen handbook* (Vol. 514). ICE Publishing.
[3] Olli-Ville, L. (2015). *Low-temperature rheology of bitumen and its relationships with chemical and thermal properties* (Vol. 15). School of Engineering – Aalto University.
[4] Sangiorgi, C., et al. (2017). A complete laboratory assessment of crumb rubber porous asphalt. *Construction and Building Materials, 132*, 500–507. https://doi.org/10.1016/j.conbuildmat.2016.12.016
[5] Ding, X., Ma, T., Zhang, W., & Zhang, D. (2017). Experimental study of stable crumb rubber asphalt and asphalt mixture. *Construction and Building Materials, 157*, 975–981. https://doi.org/10.1016/j.conbuildmat.2017.09.164
[6] Jalal Kashesh, G., Joni, H. H., Dulaimi, A., & Jalal Kaishesh, A. (2023). Laboratory investigation on the performance of asphalt bitumen using recycled tyre rubber produced in Iraq. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.03.725
[7] Mensahn, E. S. K., Lugeiyamu, L., & Kunlin, M. (2020, December). Flexible pavement: A review on the influence of waste rubber particles in asphalt and asphalt mixtures.
[8] Aziz, M. M. A., Altieb, Z. A., Bin Kassim, K. A., & Jibrin, H. B. (2016). A short review on using crumb rubber as modification of bitumen binder. *Jurnal Teknologi, 78*(7-3). https://doi.org/10.11113/jt.v78.9479
[9] Borinelli, J. B., Blom, J., Vuye, C., & Hernando, D. (2024). Does the wet addition of crumb rubber and emission reduction agents impair the rheological performance of bitumen? *Construction and Building Materials, 417*, Article 135351. https://doi.org/10.1016/j.conbuildmat.2024.135351
[10] Fiore, N., Caro, S., D'Andrea, A., & Scarsella, M. (2017). Evaluation of bitumen modification with crumb rubber obtained through a high-pressure water jet (HPWJ) process. *Construction and Building Materials, 151*, 682–691. https://doi.org/10.1016/j.conbuildmat.2017.06.100
[11] Pais, J. C., et al. (2023). Crumb rubber modified binders. In A. Cannone Falchetto, L. Poulikakos, E. Pasquini, & D. Wang (Eds.), *Valorisation of waste and secondary materials for roads: State-of-the-art report of the RILEM TC 279-WMR* (pp. 37–67). Springer International Publishing. https://doi.org/10.1007/978-3-031-33173-2_3
[12] Lastra-González, P., Calzada-Pérez, M. Á., Castro-Fresno, D., Vega-Zamanillo, Á., & Indacoechea-Vega, I. (2017). Porous asphalt mixture with alternative aggregates and crumb-rubber modified binder at reduced temperature. *Construction and Building Materials, 150*, 260–267. https://doi.org/10.1016/j.conbuildmat.2017.06.008

[13] Manoharan, M., Daniel, J. J., Premkumar, S., & Vedhanayaghi, V. J. (2020). Study on behaviour of crumb rubber modified bitumen. *International Journal of Advanced Science and Technology, 29*, 342–351.
[14] Wulandari, P. S., & Tjandra, D. (2017). Use of crumb rubber as an additive in asphalt concrete mixture. *Procedia Engineering, 171*, 1384–1389. https://doi.org/10.1016/j.proeng.2017.01.451
[15] Krishnapriya, M. G. (2015). Performance evaluation of natural rubber modified bituminous mixes. *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development, 5*, 121–134.
[16] Milad, A., Ahmeda, A. G. F., Taib, A. M., Rahmad, S., Solla, M., & Yusoff, N. I. M. (2020). A review of the feasibility of using crumb rubber derived from end-of-life tire as asphalt binder modifier. *Journal of Rubber Research, 23*(3), 203–216. https://doi.org/10.1007/s42464-020-00050-y
[17] Mushunje, K., Otieno, M., & Ballim, Y. (2018). A review of waste tyre rubber as an alternative concrete constituent material. *MATEC Web of Conferences, 199*. https://doi.org/10.1051/matecconf/201819911003
[18] Chattaraj, R. (2019). Bitumen—A very versatile construction. *Materials Related to Highway Engineering, 3*, 115–120.
[19] Ibrahim, M. R., Katman, H. Y., Karim, M. R., Koting, S., & Mashaan, N. S. (2013). A review on the effect of crumb rubber addition to the rheology of crumb rubber modified bitumen. *Advances in Materials Science and Engineering*, Article 415246. https://doi.org/10.1155/2013/415246
[20] Sienkiewicz, M., Borzędowska-Labuda, K., Wojtkiewicz, A., & Janik, H. (2017). Development of methods improving storage stability of bitumen modified with ground tire rubber: A review. *Fuel Processing Technology, 159*, 272–279. https://doi.org/10.1016/j.fuproc.2017.01.049
[21] Behnood, A., & Modiri Gharehveran, M. (2019). Morphology, rheology, and physical properties of polymer-modified asphalt binders. *European Polymer Journal, 112*, 766–791. https://doi.org/10.1016/j.eurpolymj.2018.10.049
[22] ASTM D5/D5M-13. (2013). *Standard test method for penetration of bituminous materials*. American Society of Testing Materials (ASTM) International.
[23] ASTM D36/D36M−14. (2014). *Standard test method for softening point of bitumen (Ring-and-Ball Apparatus)*. American Society of Testing Materials (ASTM) International. https://doi.org/10.1520/D0036
[24] Carpani, C., Bocci, E., Prosperi, E., & Bocci, M. (2022). Evaluation of the rheological and performance behaviour of bitumen modified with compounds including crumb rubber from waste tires. *Construction and Building Materials, 361*, Article 129679. https://doi.org/10.1016/j.conbuildmat.2022.129679
[25] Humagain, P., & Homagai, P. (2017). Properties study of crumb rubber modified bitumen. *Journal of Nepal Chemical Society, 37*. https://doi.org/10.3126/jncs.v37i0.32151
[26] Poovaneshvaran, S., Mohd Hasan, M. R., & Putra Jaya, R. (2020). 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*, Article 117357. https://doi.org/10.1016/j.conbuildmat.2019.117357
[27] Li, H., Li, W., Temitope, A. A., Zhao, D., Zhao, G., & Ma, Q. (2020). Analysis of the influence of production method, crumb rubber content and stabilizer on the performance of asphalt rubber. *Applied Sciences, 10*(16). https://doi.org/10.3390/app10165447
[28] Ganapathy, G. P., & Haupt, T. C. (2023). Engineering properties of SBS and crumb-rubber modified bitumen – A design of experiment approach. *Journal of Engineering, Design and Technology*, ahead-of-print. https://doi.org/10.1108/JEDT-01-2022-0037
[29] Qian, C., Fan, W., Yang, G., Han, L., Xing, B., & Lv, X. (2020). Influence of crumb rubber particle size and SBS structure on properties of CR/SBS composite modified asphalt. *Construction and Building Materials, 235*, Article 117517. https://doi.org/10.1016/j.conbuildmat.2019.117517

[30] Kashesh, G. J., Joni, H. H., Dulaimi, A., & Kaishesh, A. J. (2023). Laboratory investigation on the performance of asphalt bitumen using recycled tyre rubber produced in Iraq. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.03.725
[31] Suresh, B., & Rao, V. (2018). Determination of physical and rheological properties of bitumen mixed with waste plastic. *International Journal of Civil Engineering and Technology (IJCIET)*, *9*, 985–990.
[32] Khaleel, O. R., Al Gharbi, L. K. N., & Fayyadh, M. M. (2023). Enhancing bitumen properties through the utilization of waste polyethylene terephthalate and tyre rubber. *Sustainability, 15*(12). https://doi.org/10.3390/su15129298