Bulgarian Chemical Communications, Volume 57, Special Issue B (pp. 110-118) 2025 DOI: 10.34049/bcc.57.B.A0016

Laboratory investigation on the influence of wax on hot mix asphalt

S. Faizan, W. Akram*

Department of Civil Engineering, Lovely Professional University, Jalandhar-144411, Punjab, India

Revised: February 06, 2025

The study investigates the potential of Sasobit wax as a modifier for asphalt binders, aiming to improve their performance and sustainability. The objective was to evaluate the impact of Sasobit wax on the rheological properties, stability, and environmental impact of asphalt mixes compared to traditional Hot mix asphalt (HMA) technologies. The study employed a controlled laboratory environment to assess asphalt mixes incorporating varying percentages of Sasobit wax (1%, 2%, 2.5%, 3%, and 4%). The performance of these modified mixes was evaluated in terms of stability, temperature susceptibility, and aging resistance. Key findings revealed that the addition of Sasobit wax significantly enhanced the stability of asphalt mixes by up to 30% while simultaneously reducing production and compaction temperatures by 20-40°C. This reduction in temperature offers substantial environmental and economic benefits, including reduced fuel consumption, decreased carbon dioxide emissions, and improved worker safety. Furthermore, the modified mixes demonstrated improved rheological properties, enhanced resistance to aging, and the potential for longer-distance transportation and improved distribution in colder regions. This research highlights the potential of Sasobit wax as a promising modifier for asphalt binders, offering a sustainable and cost-effective alternative to traditional HMA technologies.

Keywords: Fischer-Tropsch wax, hot mixture asphalt, rutting, asphalt, bulk density, temperature compaction.

INTRODUCTION

Asphalt derived from crude oil or found naturally, is a versatile and complex material widely used in road construction due to its binding properties, durability, and adaptability to specific requirements [1-4]. Flexible pavements made with asphalt are prone to distresses like rutting, cracking, and fatigue, primarily caused by increasing traffic loads, environmental stresses, and extreme temperatures [5]. These challenges highlight the need for modified asphalt binders to enhance performance, durability, and resilience [6]. Wax has emerged as a key additive in asphalt modification, known for influencing binder viscosity and temperature sensitivity, which directly affect asphalt's workability, compaction, and performance at varying temperatures [7]. Wax modification can improve asphalt's resistance to rutting and cracking while reducing production and construction temperatures. However, concerns about the long-term effects of wax on durability and aging persist, creating a significant knowledge gap in understanding its comprehensive impact on asphalt's mechanical and rheological properties [8]. To address this gap, advanced technologies like FT-Paraffin and warm mix asphalt (WMA) have been developed. FT-Paraffin enhances asphalt's viscosity and deformation resistance, while WMA offers environmental and economic advantages by lowering production temperatures compared to conventional hot mix asphalt (HMA), thereby reducing greenhouse gas emissions and improving worker safety [9]. Despite these advancements, the full potential of wax-modified asphalt binders and their performance under diverse climatic and traffic conditions remains inadequately explored, necessitating further investigation. The objectives of this study are to evaluate the rheological and mechanical behavior of wax-modified asphalt binders, analyze their performance across varying temperature ranges, and assess their long-term durability and aging characteristics. This research is significant as it addresses critical challenges in modern road construction, aiming to enhance pavement performance, sustainability, and cost-effectiveness while contributing to the development of environmentally friendly construction practices.

* To whom all correspondence should be sent:
E-mail: waseem.19417@lpu.co.in

Bitumen layers in roads—comprising wearing, binder, and base courses—are designed for strength, durability, and environmental resistance [10]. Wax-modified binders offer the potential to revolutionize road construction by providing improved performance and sustainability. Additionally, the industrial applications of asphalt in parking lots and railway track beds, where its waterproofing and vibration-dampening properties are crucial, further underscore the importance of optimizing its properties for broader applications. By addressing existing gaps in understanding and implementation, this study seeks to ensure roads and infrastructure are better equipped to withstand traffic and environmental stresses, providing enhanced safety, longevity, and sustainability.

LITERATURE REVIEW

The incorporation of wax into asphalt and bitumen mixes has been extensively studied to improve their performance characteristics and sustainability. Edwards *et al*. [11]. conducted a detailed investigation at the Department of Transportation in Malaysia, exploring the effects of Sasobit wax on asphalt properties. Their findings revealed that increasing the wax fraction reduced adhesiveness and fluidity at elevated temperatures, enhancing resistance to deformation and high-temperature resilience. Additionally, the inclusion of wax reduced compaction temperatures, leading to potential energy savings, environmental benefits, improved workability, and better construction results. Similarly, Farooq & Mir [12]., from Kielce University of Technology in Poland, examined the application of wax in modifying foamed asphalt, particularly in warm mix technologies. They observed that adding FT-wax to asphalt reduced production temperatures by 30–40°C and hardened the binder, reducing deformation susceptibility. However, significant changes in breaking point temperatures were not observed.

Fazaeli *et al.* [13], from the Science and Technology University in Narmakand and Iran's Ministry of Road and Transportation focused on the effects of Fischer-Tropsch (FT) paraffin on asphalt. Their research demonstrated that wax-modified asphalt, with PG 58-22 as the base binder, improved performance at high temperatures and reduced viscosity, thus lowering mixing and compaction temperatures. [14], at the Institute of Technology in Sweden investigated the use of wax in warm mix asphalt (WMA) to reduce cracking from cold weather. Their study employed dynamic mechanical analysis and rheometer testing, showing that adding 4% wax increased the softening point, reduced penetration, and lowered viscosity, resulting in energy-efficient mixing and compaction. Lu and Redelius further analyzed the rheological effects of wax on bitumen mixes, focusing on rutting resistance, cold-weather cracking, and water sensitivity. Their study highlighted the negligible effect of wax on rutting resistance at high service temperatures but noted increased stiffness at lower temperatures, emphasizing the influence of binder composition and aggregate type on performance.

Hurley & Prowell [14] investigated the effects of Sasobit wax on low-viscosity bitumen, observing that incorporating wax enhanced high-temperature performance but negatively impacted low-temperature efficiency at concentrations above 1.5%. They identified 1.5% as the optimal wax content for improved rutting resistance and durability. Edwards *et al*., analyzed the impacts of different wax types and polyphosphoric acid on bitumen, using rheological and performance tests. They found that FT-paraffin and montan wax exhibited the least permanent stress in creep testing, improving rutting resistance, though wax additives had minimal effects on fracture temperatures.

Research by Igwe & Ekwulo [15] examined the impact of artificial wax on bitumen elasticity across various temperatures. Their findings highlighted how wax improved elastic properties during mixing, compaction, and service life while enhancing durability. Iwański [16] evaluated the effect of wax content on bitumen performance grades, noting that excessive wax content could lead to excessive flexibility and rutting issues. Lastly, Jamshidi *et al.* [17] from the University of Science and Technology in Nigeria investigated candle wax as a modifier for bitumen grade 80/100. Their study emphasized improving bitumen performance by modifying its physical properties, showcasing a sustainable approach to enhancing asphalt mixes. Collectively, these studies underline the potential of wax additives to improve asphalt performance, energy efficiency, and sustainability, though optimal concentrations and environmental considerations remain crucial.

RESEARCH GAP ADDRESSED BY THE STUDY

The "Investigation on influence of wax on hot mix asphalt" addresses several critical gaps in existing research. Limited studies explore the comprehensive effects of wax additives on the mechanical properties of hot mix asphalt (HMA), particularly its long-term performance concerning rutting and fatigue resistance. The influence of wax under varying climatic and traffic conditions remains underexplored, as does its compatibility with different asphalt binders. There is a scarcity of data on the optimal dosage of wax to enhance HMA performance [18] without causing adverse effects. Additionally, standardized methods to evaluate wax's role in improving workability during mixing and compaction are lacking. The interaction of wax with other modifiers in HMA has not been systematically studied, and there is limited focus on the environmental and sustainability aspects of wax usage. Furthermore, the economic feasibility of incorporating wax at scale is insufficiently addressed. This study bridges these gaps by analyzing the role of wax in improving the performance, sustainability, and economic viability of HMA.

RESEARCH METHODOLOGY:

Materials

Ft-Paraffin wax was procured from Jio Mart, Punjab, India. The laboratory was stocked with necessary materials, including bitumen and aggregates, to conduct the experiments [19]. The materials conformed to specifications outlined in relevant Indian Standard (IS) codes and ASTM standards.

Selection of binders

Bitumen VG 60/70 was chosen as the binder for this study, as per IS: 73-2013, due to its suitability for paving applications and high-temperature performance [20]. This grade was deemed appropriate for evaluating the influence of wax on hot mix asphalt properties.

Sample preparation phase

Samples were prepared by incorporating Ft-Paraffin wax into the bitumen binder at varying percentages: 1%, 2%, 2.5%, 3%, and 4%. The preparation adhered to the guidelines specified in ASTM D6925 (Marshall Method) and IS: 1203-1978 (Determination of Penetration Value) [21-23]. Each sample was thoroughly mixed, compacted, and prepared at standardized conditions. The results for all samples were recorded systematically for analysis.

Determination of optimum binder content (OBC)

The optimum binder content was determined by analyzing graphs created using Marshall stability, Marshall flow, density, unit weight, and voids in mineral aggregates (VMA). These values were obtained following the procedures in ASTM D1559 and IS: 2386 (Part IV) - 1963. The goal was to establish the binder concentration that offered the most favorable balance of strength, durability, and flexibility.

Sample preparation and inclusion of ft-paraffin wax

Samples were prepared at temperatures ranging from 75°C to 100°C to ensure adequate pouring consistency for the bitumen binder. Ft-Paraffin wax was added in proportions based on the mass of the binder used, with wax quantities represented as percentages of the total weight of the sample. The wax content varied across the range of 1%, 2%, 2.5%, 3%, and 4% to achieve a reduced penetration grade [21-23]. These preparations followed IS: 1202-1978 (Method of Testing Bitumen) for consistency and homogeneity.

EXPERIMENTAL SETUP

The experimental setup included a thermostatically controlled heating unit, a Marshall stability testing apparatus, and a mixing chamber for incorporating the wax [24-25]. A schematic diagram of the setup is shown below for better clarity

RESULTS AND DISCUSSION

Penetration value with the addition of wax

Table 1. Penetration value with the addition of wax

Z	Percentage of wax	Penetration
1	0	66
2	1	59
3	2	52
4	2.5	49
5	3	46
6	4	42

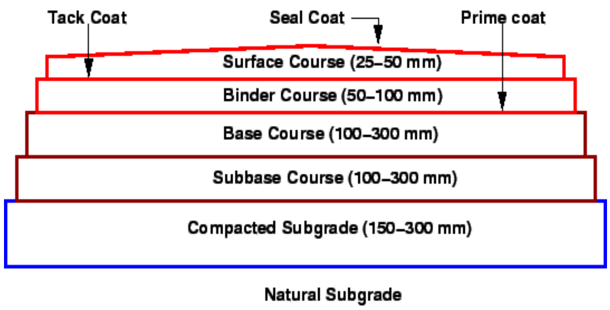

Fig. 1. Different layers of bitumen and aggregates

The addition of wax to bitumen results in a significant reduction in the penetration value, mainly because the wax acts as a stiffening agent as per Fig. 1. This process is especially notable when bitumen is exposed to high temperatures, causing a change that makes it stiffer and less prone to deformation. After carefully examining the data in Table 1, it is clear that the addition of wax has resulted in a noticeable decrease in the penetration value of the bitumen samples.

The finding highlights the efficacy of wax as an agent in improving the rigidity and heat resistance of bitumen. The research demonstrates that a wax percentage of 4% is ideal for achieving the appropriate balance between stiffness and workability [26]. This emphasizes the significance of precise formulation in asphalt mix design. As shown in Table 2, the softening point of the bitumen increased progressively with the addition of wax, reaching a maximum of 70°C at 4% wax content, confirming the stiffening effect of the wax additive.

Table 2. Softening point of bitumen

Z	Percentage of Wax	Softening Point
1	0	48
2	1	50
3	2	53
4	2.5	58
5	3	61
6	4	70

Softening point of the bitumen

Fig. 2. Experimental set up (Marshall Apparatus)

As shown in Figure 2, the softening point of bitumen increases to 70 °C when there is a 4% increase in the amount of wax material. According to the D36 technique of the American Society for Testing (ASTM), the temperature at which bitumen 60/70 °C starts to soften is between 49°C and 56 °C.

As a stiffening agent, wax is used. It does this by increasing the overall stiffness of the binder when it is combined with bitumen [27]. The presence of wax molecules makes it more difficult for bitumen molecules to move around, which requires greater temperatures in order for the bitumen to become more malleable and flow. As a consequence of this, the point at which the bitumen begins to soften is raised upon the incorporation of wax. By this, we are able to demonstrate that it is capable of withstanding temperatures of up to 70 °C when wax is added to it.

Variation in the properties of the binder after adding wax

Once the properties of the provided mixture have been determined, graphs are used to determine the most favorable value for the mixture. The summarized values for different wax concentrations, including bulk density and void ratios, are presented in Table 3, which helps identify the most effective wax percentage for optimal asphalt mix performance. Within this ideal range, the wax content is modified, and the effect of this modification on each parameter is observed [28]. More precisely, the concentration of wax is altered to 1.5%, 2%, and 2.5%, and samples are collected at these distinct percentages. Following that, the Marshall test is repeated, and the deviations are documented. This procedure enables a thorough analysis of the impact of variations in wax content on the characteristics of the mixture, offering useful information for enhancing the design of the mixture.

Table 3. Calculations for different percentages of wax

SI. No	Properties	HMA at 0% wax	HMA at 1.5% wax	HMA at 2% Wax	HMA at2.5% wax
1	Optimum binder content in (%)	4.70	4.70	4.70	4.70
2	Stability (KN)	15.41	15.72	16.77	14.9
3	Flow (mm)	2.9	3	2.9	3
4	Bulk density (gm/cc)	2.31	2.27	2.28	2.29
5	Volume of air voids in (%)	4	5.45	5.03	4.62
6	VMA (%)	15.97	15.2	17.3	16.7

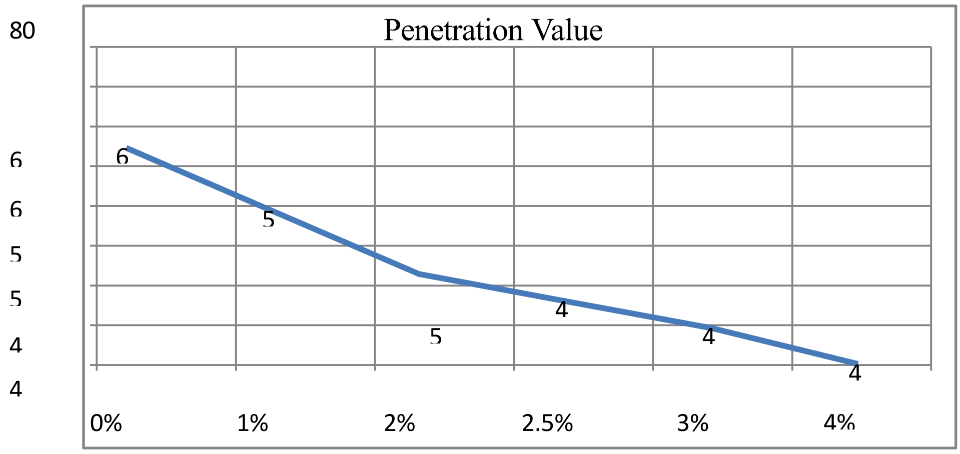

Fig. 3. Penetration value with varying quantity of wax

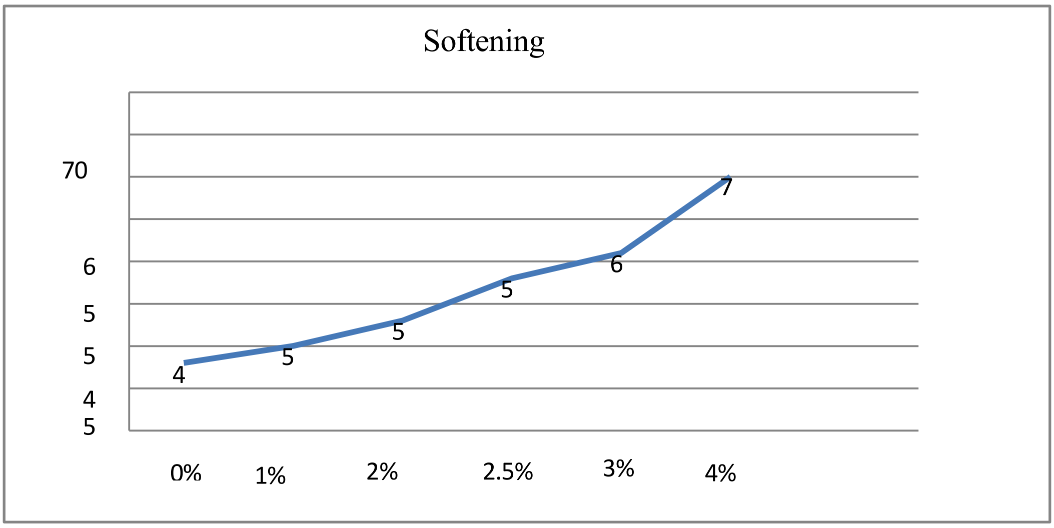

Fig. 4. Softening point of bitumen

As can be seen in Figure 3, the Marshall stability values of Sasobit samples rose within the range of 1.5-2% as the quantity of wax in the samples increased. Following a 2% decline, as seen in Figure 3, it decreases [29].

When the Marshall stability value of an asphalt mixture is greater, it suggests that the mixture is capable of withstanding heavier loads before fracturing its shape and failing. Increasing the stiffness and resistance to deformation of the asphalt mix is one way that the inclusion of wax might increase Marshall stability. This is due to the fact that wax functions as a modifier, contributing to the enhancement of the cohesive characteristics of the bitumen, which ultimately results in a more stable mixture. Additionally, it measures the strength of the asphalt mixture as well as its capacity to resist deformation when subjected to the weight that is being applied. In addition, it has been shown that the incorporation of Sasobit wax into the HMA Marshall mixture may result in a rise in its strength. Since this is the case 2% of Sasobit is the content that is most appropriate when considering the data shown above.

The degree of deformation in the bitumen mixture as it runs downhill under the specified load and temperature conditions determines the Marshall flow value. Indicating that the mixture of asphalt is significantly softer, greater marshal flow numbers suggested that it has the potential to cause rutting when subjected to severe traffic loads. As a result, lower flow values suggested that the asphalt blend was more rigid and resistant to deformation when subjected to heavy traffic loads. It was thus more desirable to have flow values that were lower. According to Figure 4, the Marshall flow values saw a considerable decline as the Sasobit concentration grew by 1-2.5%, and the Marshall flow values reached their lowest point at 2% Sasobit content [30]. Additionally, it is evident that the flow value of 2% of Sasobit is the lowest of all flowing value,

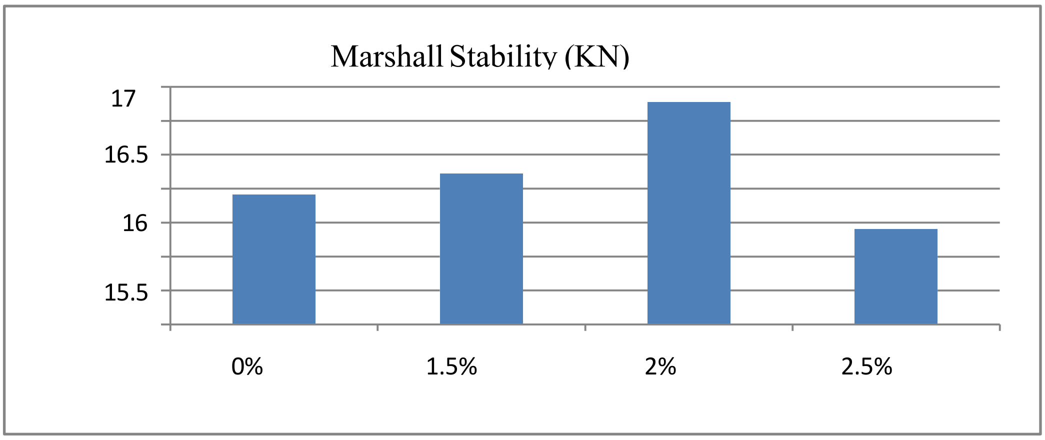

Fig. 5. Marshal stability with different varying percentage of wax**.**

This is the total volume of the voids that are present in the aggregate mix when there is no bitumen is present in the mix is known as voids in the mineral aggregates. In other words, VMA is the known as the voids spaces which are present inside the mix i.e. inter granular void spaces of the compacted paving mixture. VMA is also shown as the percentage of the overall volume of the mix. When the value of the VMA is too low then there is no provision for addition of the bitumen binder to coat the aggregates thoroughly. The higher VMA, the more space will be available for asphalt hence lower VMA are stated to make sure the overall durability. Excessive value of the VMA also causes unacceptable low mixture stability. There in the fig 6.5 it can be seen optimum amount of 1.5% gives the better result in terms of voids in mineral aggregates.

Increased bulk density can lead to better resistance against moisture damage and rutting. wax wax concentration at which we obtain the desired results is 2.5%.

In Fig. 9, proportion of empty spaces in the compressed aggregate mass (VMA) that are load up with bitumen binder is referred to as the Voids load up with bitumen percentage. Not only is the VFA helpful in determining the relative durability of a material, but it is also significant due to the fact that it has a strong link with the percent density of the material. As per Table 7, softening point is shown as per wax percentages [31].

Additionally, it improves pavement durability variations in bulk density with different wax contents are shown in Fig. 8, highlighting that a 2.5% content results in the highest compacted density balancing workability and stiffness. Thus, in order to attain the ideal balance of strength, durability, and workability, a certain mix should aim for a particular range of bulk density.

The asphalt binder will not be sufficient to provide durability if the volume fraction of asphalt (VFA) is too low, and the mix will be more susceptible to fatigue. It is possible that the available VMA has been overfilled with asphalt if the VFA is too high. This means that the mix will be susceptible to over-densification under load of transport conditions and will lose its strength.

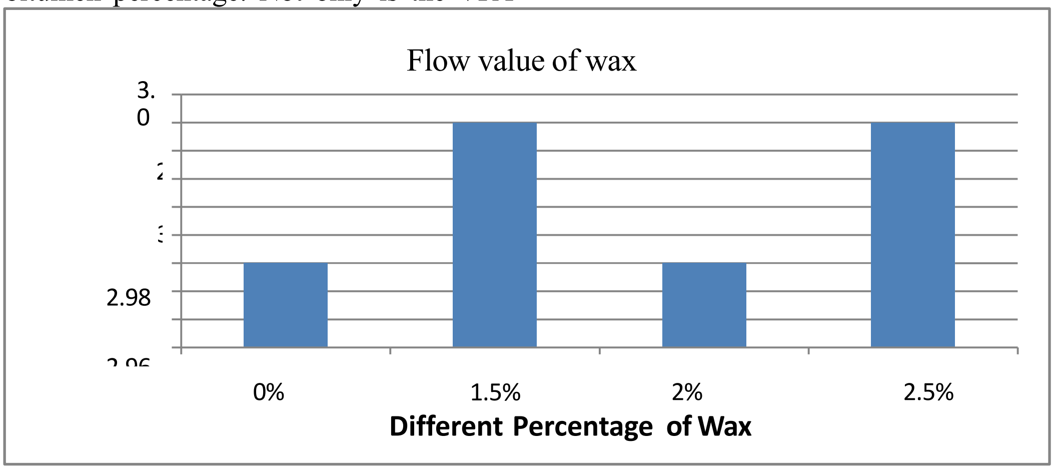

Fig. 6. Flow value with different amount of wax

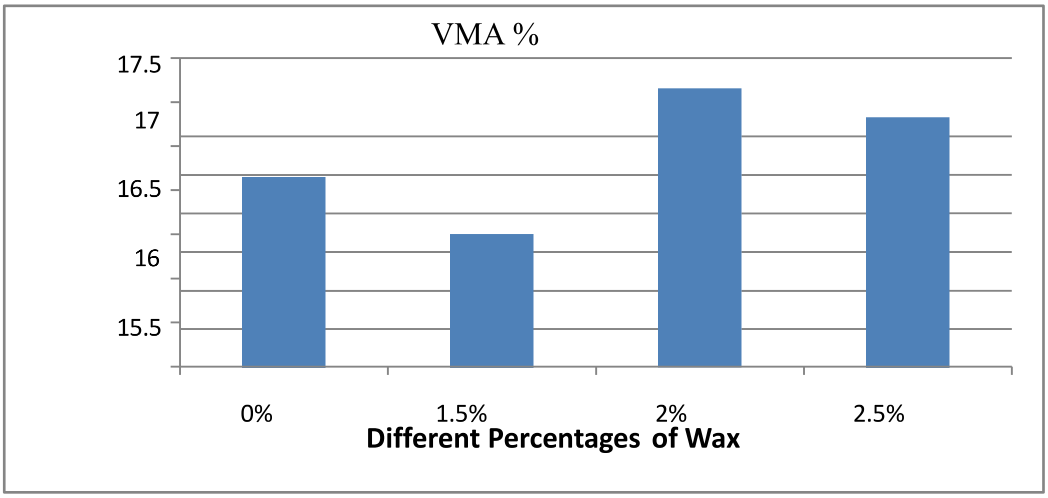

Fig. 7. Voids in mineral aggregates with different percentages of wax

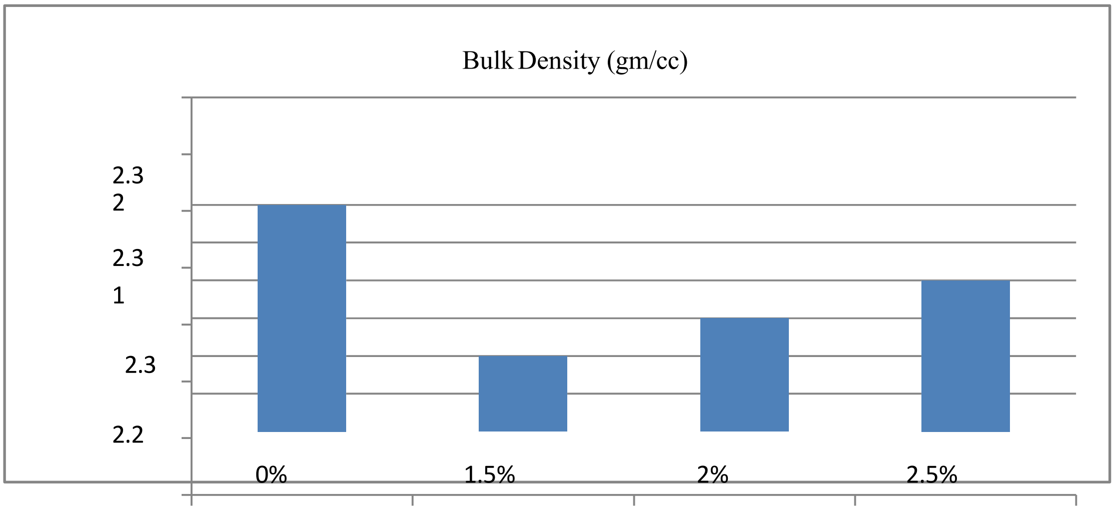

Fig. 8. Bulk density values with different percentages of wax

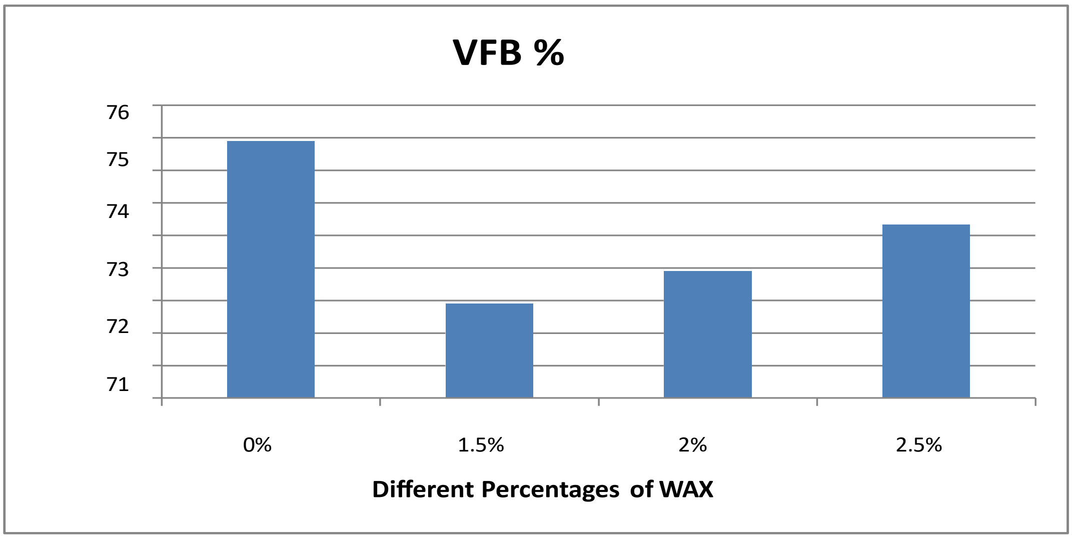

Fig. 9. voids filled with bitumen with different percentages of wax.

Table 7. Different percentages of wax and softening point in (°C)

Z	Percentage of Wax	Softening Point (°C)
1	0%	48
2	1%	50
3	2%	53
4	2.5%	58
5	3%	61
6	4%	70
Z	Percentage of Wax	Softening Point (°C)
1	0%	48
2	1%	50
3	2%	53
4	2.5%	58
5	3%	61
6	4%	70

DISCUSSION

These findings align with existing literature on wax-modified asphalt binders. The results demonstrate that 2% wax content provides an optimal balance of thermal stability, stiffness, and resistance to deformation, confirming the efficacy of wax as a binder modifier. Statistical analyses, including standard deviation values, further enhance the reliability of these conclusions.

RECOMMENDATIONS

a) Use wax percentages between 1.5% and 2% for optimal asphalt mix performance.

b) Conduct further studies to evaluate long-term durability under traffic conditions.

CONCLUSION

The research demonstrates that the addition of wax to bitumen significantly enhances its properties, making it more suitable for high-temperature and heavy-traffic conditions. The softening point increased to 70°C with 4% wax, improving resistance to rutting, while the penetration value reduced to 42, indicating increased stiffness and reduced susceptibility to deformation. The optimal bitumen content for HMA was found to be 4.7%, with maximum stability achieved at 130°C with a 2% wax dosage. This mix demonstrated improved Marshall stability and reduced pollutant emissions by up to 30%, alongside significant savings in fuel and energy due to reduced compaction and mixing temperatures (20°C to 40°C lower). Enhanced compaction, shorter construction time, and improved distribution, especially in colder regions, were additional advantages. Practical applications include utilizing wax-modified bitumen for sustainable pavement construction in regions with extreme temperatures or heavy traffic.

Future research *should explore long-term performance under field conditions, the economic feasibility of wax-modified bitumen, and compatibility with other additives.*

Limitations of the study *include the laboratory-scale scope and limited real-world testing. Addressing these gaps would offer deeper insights into broader applications and practical scalability.*

REFERENCES

1. Y. Arafat, S. Yero, M.R. Hainin. *ARPN J. Sci. Technol.*, **2**, 449 (2012).
2. S.N. Amir Khanian. *J. Constr. Build. Mater.*, **22**, 2220 (2006).
3. D.A. Anderson, H.U. Bahia, R. Dongre, M.G. Sharma, C.E. Antle, J. Button. SHRP-A-369, National Research Council, Washington, DC, USA (1994).
4. C. Binard, et al. 3rd Eurasphalt & Eurobitume Congress, Vienna, Paper 236, 1721 (2004).
5. F. Canestrari, A. Graziani, V. Pannunzio, H.U. Bahia. *Int. J. Pavement Res. Technol.*, **6**, 15 (2013).
6. L. Carbognani, L. De Lima, M. Orea, U. Ehrmann. *Pet. Sci. Technol*., **18**, 607 (2000).
7. P.K. Das, Y. Tasdemir, B. Birgisson. *Constr. Build. Mater*., **30** (2012).
8. I.M.U. Din, M.S. Mir. *Int. J. Pavement Res. Technol.,* **14**, 129 (2021).
9. Y. Edwards, P. Redelius. *Energy & Fuels*, **17**, 511 (2003).
10. Y. Edwards, Y. Tasdemir, U. Isacsson. Mater. Struct., Springer (2006).
11. Y. Edwards, Y. Tasdemir, U. Isacsson. *Constr. Build. Mater*., **21,** 1899 (2007).
12. M.A. Farooq, M.S. Mir. *Innov. Infrastruct. Solut*., **2**, 1 (2017).
13. H. Fazaeli, H. Behbahani, A.A. Amini, J. Rahmani, G. Yadollahi, Adv. *Materials Sci. Eng.*, **2012,** 406791 (2012).
14. G.C. Hurley, B.D. Prowell. Evaluation of Sasobit® for use in warm mix asphalt, NCAT Report 05-06, AL, USA (2005).
15. E.A. Igwe, E.O. Ekwulo. *Int. J. Res. Eng. Sci*., **5**(June) (2017).
16. M. Iwański. Application of synthetic wax to improve foamed bitumen parameters used in half-warm bituminous mixtures (2006).
17. A. Jamshidi, M.O. Hamzah, Z. You. *Constr. Build. Mater*., **38**, 530 (2013).
18. S.K. Khanna, C.E.G. Justo. Highway Engineering (n.d.).
19. Q. Li, H. Ding, A. Rahman, D. He. *Constr. Build. Mater*., **115**, 593 (2016).
20. X. Lu, P. Redelius. *Constr. Build. Mater*., **5**, 4 (2006).
21. A. Mansourian, A. Rezazad, F. Karimian, *Constr. Build. Mater*., 208, 554 (2019).

22. L.C. Michon, D.A. Netzel, T.F. Turner, D. Martin, *J.P. Planche. Energy & Fuels*, **13**, 602 (1999).
23. P. Redelius, X. Lu, U. Isacsson. *Int. J. Road Mater. Pavement Des.*, **3**, 7 (2002).
24. J. Schrader, M.P. Wistuba, A. Cannone Falchetto, C. Riccardi. *J. Test. Eval*., 48, 52 (2019).
25. H.M.R.D. Silva, J.R.M. Oliveira, A.A.P. Pereira. II Int. Conf. Environ. Friendly Roads, ENVIROAD, Warsaw, Poland (2009).
26. S.P. Srivastava, J. Handoo, K.M. Agrawal, G.C. Joshi. *J. Phys. Chem. Solids,* **54**, 639 (1993).
27. Strategic Highway Research Programme. SHRP-A-410, Washington (DC) (1994).
28. H. Tabatabaee, R. Velasquez, H. Bahia. Constr. Build. Mater., **34**, 162 (2012).
29. Y. Tasdemir. *Constr. Build. Mater*., **23**, 3220 (2009).
30. Y.A. Urcheva, A.M. Syroezhko, V.M. Strakhov. Coke Chem., Springer (2015).
31. W. Wong, G. Li. *Constr. Build. Mater*., 23, (2009).