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Lignin-modified bitumen: Exploring characteristics and performance

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RESEARCH ARTICLE

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Abstract

The surge in crude oil prices has sparked interest in finding efficient and cost-effective alternatives to bitumen, a binder used in road pavement. Bitumen, derived from crude oil distillation or natural deposits, is primarily utilized in pavement grade bitumen, accounting for 83% of its usage. However, traditional hot mix asphalt, which relies heavily on bitumen, emits significant amounts of CO_2, CH_4, and N_2O, contributing to environmental concerns. To address these challenges, research efforts have focused on shifting from fossil-based to biobased resources in road construction. One promising approach involves incorporating biobased waste materials to enhance pavement properties and promote environmental sustainability. Lignin, a plant polymer found naturally in plants alongside cellulose and hemicellulose, is one such biobased waste material. With an estimated 300 billion tonnes in the biosphere and an annual growth rate of about 20 billion tonnes, lignin presents a vast, untapped resource. Its chemical composition and hydrocarbons closely resemble those found in bitumen, making it an ideal modifier for pavement construction. Due to its organic nature and similar chemical structure to bitumen, lignin presents a practical option as an extender or substitute for bitumen in road pavement. This report investigates the effects of waste lignin on the properties of bitumen binders, aiming to assess its feasibility and potential benefits in enhancing pavement performance while reducing environmental impact. Overall, this research represents a critical step towards developing sustainable road construction practices by leveraging biobased waste materials like lignin to mitigate the environmental impact of traditional asphalt pavement while improving performance and reducing costs.

Keywords: *Bitumen, Lignosulphonate, Industrial waste, Biopolymer, Bitumen extender*

1) INTRODUCTION

Bitumen, crafted from crude oil, stands as the most widely utilized material, constituting approximately 85% of global bitumen consumption. The price of crude oil is also rising over time. To tackle these challenges, we need to explore alternatives that prioritize sustainability, strength, and compliance with safety and cost-effectiveness standards for pavement construction. Substituting bitumen with alternative sustainable binders like lignin contributes to the reduction of CO_2 emissions. Lignin stands out as a predominant polymer naturally occurring in plant material. Lignin, a naturally occurring green bio resource, can serve as a modifier to substitute other industrial aromatic polymers. Lignin comprises chemical constituents and hydrocarbons similar to those present in bitumen. The cementitious properties of lignin make it well-suited for enduring road construction projects. Utilizing waste lignin effectively in bitumen pavement production not only diminishes pollution but also lessens dependence on petroleum bitumen while improving efficiency in the paper and wood sector.

This research aims to conduct a series of laboratory tests to enhance understanding of the lignin bitumen composite binder, ultimately driving improvements in performance, environmental impact, cost-effectiveness, innovation, and sustainability in road construction and maintenance.

1.1 Objectives

This study was commenced to examine the characteristics of both conventional and modified bitumen properties. The primary aims of the current project are:

- To find suitability of lignin modified bitumen by performing numerous tests onbitumen.
- To assess the influence of various lignin concentrations on the outcomes of multiple bitumen tests, providing a comprehensive understanding of how the addition of lignin impacts bitumen properties.
- To determine the ideal percentage of lignin for application of bitumen on the surface course.

2) METHODOLOGY AND DATA COLLECTION

The methodology adopted for the present study is depicted in the fig no 1

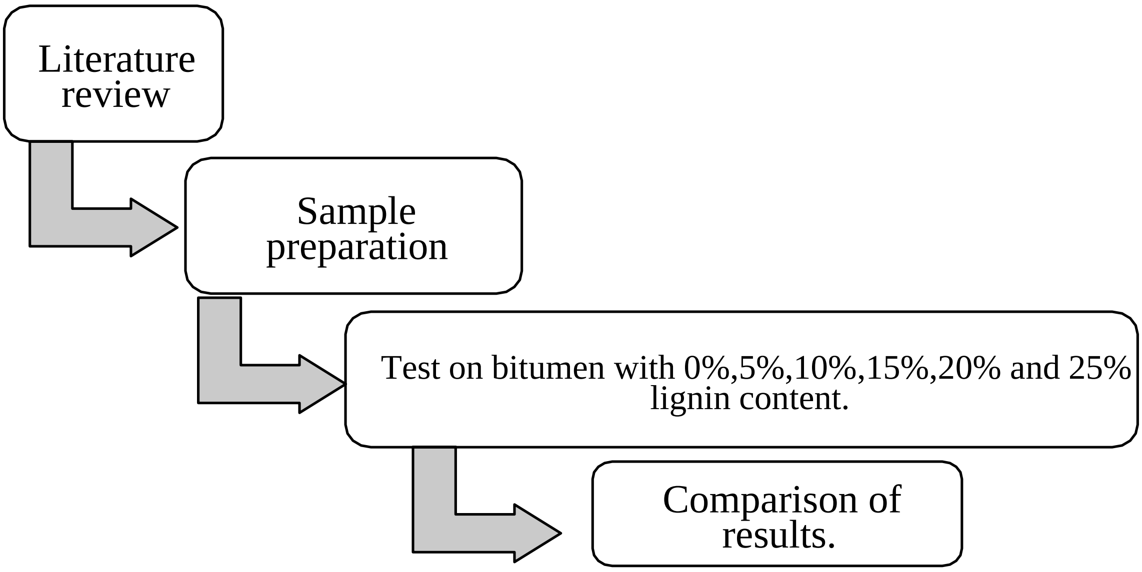

Figure 1: Methodology

2.1 Literature Review

Norgbey et al (2020) analyses the effects of waste lignin on the properties (characterization) of bitumen binders. The results show that increasing the lignin content, increased the cohesion and stiffening of the binder. Adding 10% lignin had a negligible influence on the workability and compaction characteristics of the asphalt mixture. The study provides baseline information that complements past studies and can be useful to all stakeholders in the asphalt industry.

Gaudenzi et al (2023) provides a compressive overview to understand the environmental and technical feasibility of the application of lignin in bituminous pavement applications, a multi-scale approach must be adopted. For this purpose, the paper aims at providing an overview of the use of lignin as renewable source in bituminous binders and mixtures, by investigating chemical, rheological and mechanical properties of lignin modified asphalt materials.

Jędrzejczak et al (2021) review focuses on the role of lignin and its derivatives in sustainable construction. Lignin's properties are defined in terms of their structure/property relationships and how structural differences arising from lignin extraction methods influence its application within the construction sector. Lignin and lignin composites allow the partial replacement of petroleum products, making the final materials and the entire construction sector more sustainable.

Wu et al (2021) provides a compressive overview on the feasibility of using lignin as an extender for bitumen was investigated. According to the literature review and preliminary tests, the ratio of bitumen to lignin was fixed at 4:1 by mass. The problem of lignin segregation was reasonably serious but was solved by adding additives. In general, the lignin could be a decent extender for bitumen with the appropriate procedure in practice.

Bajwa et al (2019) provides an overview on the ongoing progress in lignin production, utilization, and innovation highlights its promise as an eco-friendly substitute for conventional resources, necessitating additional investigation to refine manufacturing methods, improve product efficacy, and reduce environmental impact across the supply chain.[1]

2.2 Materials used

2.2.1 Bitumen

Bitumen derived from the distillation of crude oil is recognized for its waterproofing and adhesive attributes, serving as a fundamental material in the construction sector, especially for the creation of roads and highways. Here, we are using bitumen of velocity grade 30. Penetration grade bitumen stands out as an exceptional choice for road construction, capable of adapting to a wide range of environmental conditions. These grades, distinguished by their varying hardness and consistency levels, result in bitumen classification spanning from 30 to 120. In India, viscosity grade bitumen, offered in VG10, VG20, VG30, and VG40 varieties, has taken precedence over bitumen penetration grade as per the Indian Standard (IS:73). Its inherent advantages and properties make it a more dependable choice compared to other types of bitumen. The penetration grade classification relies on the penetration value at 25°C, whereas the VG system is determined by viscosity values at both 60°C and 135°C, indicating its suitability for various temperature ranges. This enables accurate prediction of bitumen behavior across different thermal conditions. For this research we are using VG30 bitumen.[2]

2.2.2 Lignin

Most commonly available lignin in the market can be categorized based on its sulfur content, with varying levels depending on the source and processing methods. The most prevalent type of lignin found in the market is sulfite lignin, which undergoes processing involving sulfur dioxide and a base such as calcium, sodium, magnesium, or ammonium. Approximately 800,000 tons of lignosulfonates and 15,000 tons of sulfonated lignin are estimated to be produced annually. Lignosulfonate holds a prominent position in the global lignin market, driven by increasing demand, particularly from the building and construction sectors.

Lignosulfonates exhibit remarkable strength and serve as effective binders or additives in cement, acting as a coupling agent or binder in pellet or compacted materials. For this research, we are using lignosulfonate, which is in a powdered form.[3]

2.3 Blending

Lignin in various proportions is weighed and mixed appropriately via hand blending. Lignin before mixing was sieved to avoid curdling. Bitumen was melted at a temperature above its melting point. Lignin was then added to it at small proportions and hand mixed at the same time while maintaining the constant temperature. This helps in the even distribution of lignin all over the bitumen surface. [4]

2.4 Tests on Lignin Bitumen Composite Binder

2.4.1 Ductility Test

The characteristic of bitumen that enables it to undergo deformation or elongation is referred to as its ductility. A standard specimen will stretch before breaking when subjected to specified speed and temperature conditions.

The ductility of a bitumen specimen primarily provides information on both its tensile strength and ductility grade. Inadequate ductility can lead to cracking. Increased ductility indicates improved flexibility and resistance to deformation, thereby enhancing the longevity and structural integrity of the road surface. The table 1 and fig 2 shows the variations in ductilityvalue for different percentage of lignin. [5]

Table 1: Ductility Value for Various Percentage of Lignin

% of lignin	Set 1(cm)	Set 2(cm)	Set 3(cm)	Average
0	65.50	65.50	66	65.66
5	40	43	53	45.33
10	42	39	44	41.66
15	32	38.50	50.20	40.23
20	33	34	39	35.33
25	37.50	39	41	39.16

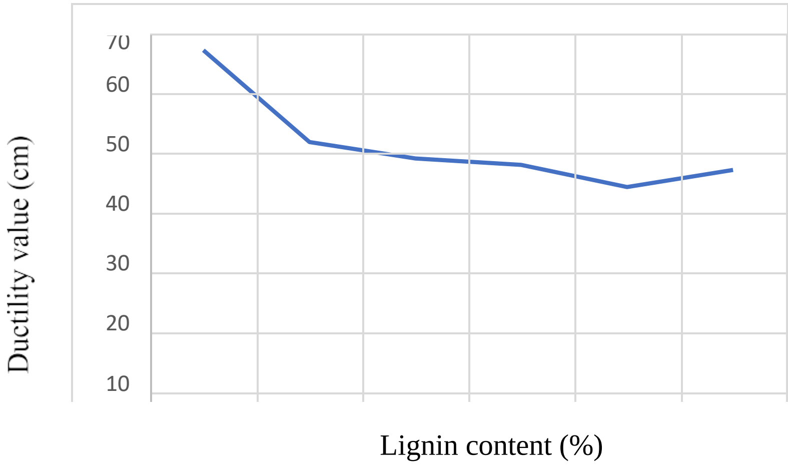

***Fig 2**: Graph showing variation in ductility values*

As per IS 73-2006, the minimum value for ductility of VG-30 bitumen is 40 cm. The results show gradual drop of values while increasing percentage of lignin up to 20% and a slight increase in 25%. It is also observed that up to 15% addition of lignin satisfies the minimum value. Based on the outcomes of the test, it can be concluded that addition of 15% lignin content is optimal for surface course application.

2.4.2 Penetration Test

The penetration test is conducted to determine the hardness or softness of bitumen utilized in road construction.

The penetration test for bitumen is essential as it assesses the hardness or consistency of the bitumen under specific temperature and load conditions. A higher penetration value suggests softer bitumen, making it potentially more suitable for regions with higher temperatures, while a lower penetration value indicates harder bitumen, which may be better suited for regions with lower temperatures.[7] table 2

Table 2: Penetration Value for Various Percentage of Lignin

% of lignin	Trial 1 (cm)	Trial 2 (cm)	Trial 3 (cm)	Average
0	58	57	57	57.3
5	60	61	60.8	60.6
10	63	63.4	63	63.13
15	53	52.7	53.2	52.96
20	45	45.3	44	44.76
25	39	38	38.5	38.5

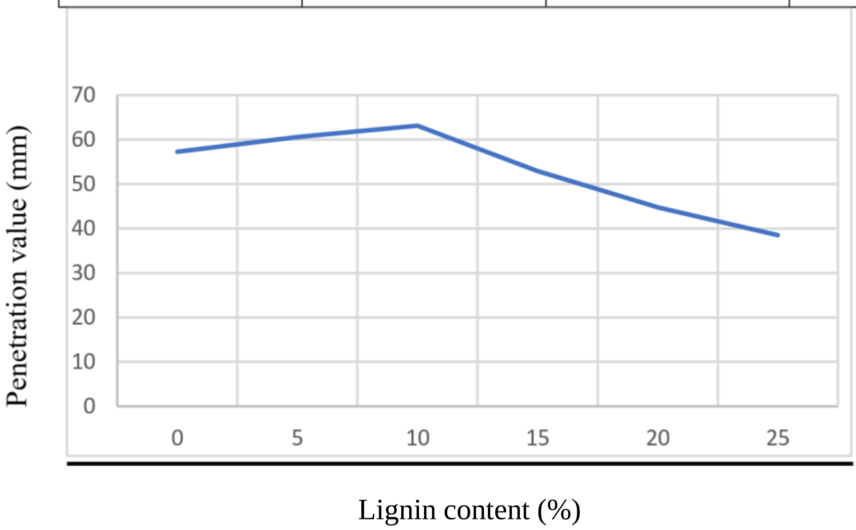

Fig 3*: Graph showing variation in penetration values*

As per IS 73-2006, the value of Penetration Test of VG-30 bitumen ranges between 50-70 mm. The results show a gradual rise in penetration value up to 10% addition of lignin and gradual drop in values up to 25%. It is also noted that adding lignin up to 15% falls within the allowable range. The specific test results suggest that incorporating up to 15% of lignin is optimal for surface course application. Fig 3

[8]

2.4.3 Softening point Test

The softening point test determines the temperature at which the substance reaches a specific degree of softening under predefined test conditions. This test utilizes a ring and ball assembly apparatus.

The softening point of bitumen establishes the heating temperature required for road applications, playing a critical role in selecting the appropriate grade for diverse uses and ensuring performance resilience against temperature fluctuations, thus averting premature failures.[9] table 3

Table 3: Softening Point Value for Various Percentage of Lignin

% Of lignin	Set 1(^{O}C)	Set 2(^{O}C)	Average (^{O}C)
0	48	48	48
5	44	45	44.5
10	49	51	50
15	54	55	54.5
20	60	58	59
25	68	67	67.5

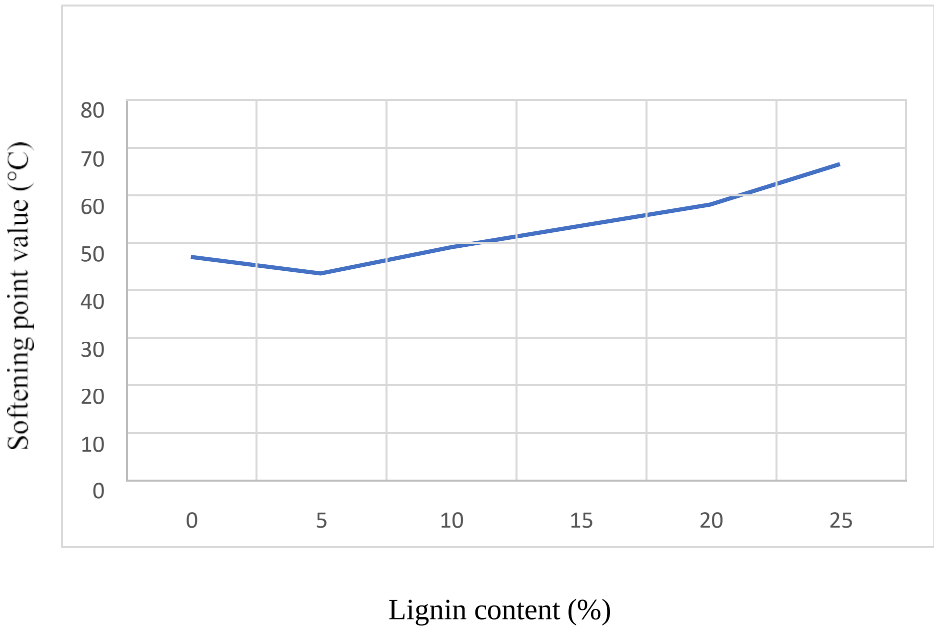

Fig 4: *Graph showing variation in softening point values*

As per IS 73-2006, the minimum value of Softening point of VG-30 bitumen is 47ºC. The results indicate a decrease in value with up to 5% addition of lignin, followed by a gradual increase in values up to 25%. The results from incorporating 10% to 25% lignin meet the minimum value criteria. Therefore, it can be concluded that adding 25% lignin is optimal for surface course application. Fig 4

[10]

On comparing the results of various tests conducted on lignin modified bitumen, we can conclude that the addition of 15% of lignin to bitumen is the most suitable percentage as it satisfies the specified values.

3) ECONOMIC ANALYSIS

The approximate amount of bitumen that is needed for construction of 1km road is Rs.21,00,000. While replacing 15% of bitumen by lignin, we can able to reduce the amount by Rs.18,00,000. Hence for each km we will be able to save a cost of 3,00,000. [11]

4) CONCLUSION AND RECOMMENDATION

Lignin is a renewable and abundant natural polymer, making it an eco-friendly alternative to traditional bitumen modifiers derived from fossil fuels. Lignin plays a crucial role in bitumen by acting as a natural adhesive, enhancing the binding properties of asphalt mixtures. It can be obtained from various sources, including wood and agricultural residues, potentially reducing the cost of bitumen modification compared to synthetic additives. Blending bitumen with lignin improves the durability and strength of road surfaces, making them more resistant to wear and deformation caused by traffic and environmental factors.

Incorporating lignin into bitumen reduces the dependency on petroleum-based additives, lowering greenhouse gas emissions and environmental footprint associated with road construction and leads to reduction in cost of construction. From the study it can be observed that the addition of 15% of lignin to the bitumen is the most suitable percentage as it satisfies the bitumen properties within the specified values.

5) ACKNOWLEDGEMENTS

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6) REFERENCES

Journal Articles

1. Jiantao W, Quan L, Chonghui W, et al. “Investigation of lignin as a alternative extender of bitumen for asphalt pavements”. *Journal of cleaner production* , 10 October 2020, 10p. doi.org/10.1016/j.conbuildmat.2022.129773.
2. Elena G , Fabrizio C, Xiaohu L, et al. “The use of lignin for sustainable asphalt pavements” *Constrction building materials*, 2023, 362 (2023) 129773:16p. doi.org/10.1016/j.conbuildmat.2022.129773.
3. Bajwa DS, Pourhashem G, Ullah AH, et al. “A concise review of current lignin production, applications, products and their environment impact”.*Industrial Crops*

& Products, 2019,139(2019)111526:11p. doi.org/10.1016/j.indcrop.2019.111526.

4. Patryk J, Maurice NC, Teofil J, et al. "The role of lignin and lignin based materials in sustainable construction". *International journal of biological macromolecules*, 2021, 187(2021)624-650: 27p. doi.org/10.1016/j.ijbiomac.2021.07.125.
5. Yanru R, Hui C, Haijun X, et al. "Improved aging properties of bio-bitumen coating sheets by using modified lignin" *Journal of Environmental Management*, 2020, 274(2020)111178:5p. doi.org/10.1016/j.jenvman.2020.111178.
6. Ana MR, Jorge CP, Ignacio PP, et al. "Use of lignin biopolymer from industrial waste as bitumen extender for asphalt mixtures" *Journal of Cleaner Production*, 2019, 220(2019)87-98: 12p. doi.org/10.1016/j.jclepro.2019.02.082.
7. Stavros K ,Marianna P, Danai MK, et al. "Investigation of the Characteristic Properties of Lignin Modified Bitumen", *Article*, 2022, 3,734-748: 14p. doi.org/10.3390.
8. Xuancang W, Guanyu J, Zhenyang F, et al. "Mechanical Performance Characterization of Lignin-Modified Asphalt Mixture", *Article*, 2020, 10(9),3324: 12p doi.org/10.3390/app10093324
9. Yuliestyan ,Gabet T, Marsac P, et al. "Sustainable asphalt mixes manufactured with reclaimed asphalt and modified-lignin-stabilized bitumen emulsions". *Construction and Building Materials*, 2018, 662-671.72
10. Xueyan L, Panos A, Sandra E, et al. "Chemical and Rheological Evaluation of Aged Lignin-Modified Bitumen", *Article*, 2019, 12(24)4176: 19p. doi.org/10.3390/ma12244176.
11. Mansour F and Mohammad AN, "Rheological and ageing properties of asphalt bio-binders containing lignin and waste engine oil" *Construction and Building Materials*, 28 February 2022, 126364:doi.org/10.1016/j.conbuildmat.2022.126364.