Partial Replacement of bitumen by Plant Polymer Lignin in Bituminous Pavement

Manjima M A, Nihal Nazar, Maria Jose
Department of Civil Engineering
Amal Jyothi College Of Engineering
Kottayam, India
manjimama2023@ce.ajce.in

Soumya Anand
Assistant Professor, Department of Civil Engineering
Amal Jyothi College of Engineering
Kottayam, India
soumyaanand@amaljyothi.ac.in

***Abstract*—Lignin is the second-largest plant polymer on Earth after cellulose. About 98% of lignin produced in the papermaking and pulping industry is used for combustion or power generation. Less than 2% of lignin is used in more valuable fields, mainly in the formulation of dispersants, adhesives, and surfactants. Asphalt is one of the most important materials in pavement engineering. It is a dark brown complex mixture composed of hydrocarbons with different molecular weights and their non-metallic derivatives which is extracted from crude oil. Because the chemical structure of lignin is similar to that of asphalt, it is a carbon-based hydrocarbon material. The high cost and the environmental impact associated with using petroleum bitumen in pavement construction is a problem facing the asphalt industry. In this study partial replacement of bitumen by lignin is done, and various physical properties like penetration, ductility and softening point are done to find its optimum replacement value. Later to measure the maximum load and flow rate of lignin modified asphalt specimen Marshall Test is done and to study about its rheological properties of the asphalt binder Dynamic Shear Rheometer Test (DSR) is performed. These tests are performed to confirm the properties and to provide a sustainable solution in the coming future.**

Keywords— lignin, alternative for bitumen, partial replacement, sustainable

I. INTRODUCTION

The most prominent application of lignin in pavement engineering was to add lignin as an asphalt modifier, which can significantly improve the aging resistance of asphalt and had different effects on the high-temperature rheological property, low-temperature crack resistance, and fatigue resistance of asphalt. Lignin can also be used as an asphalt filler. It can reduce the consumption of asphalt and achieve the effect of energy conservation, emission reduction, and cost reduction. In our project we are partially replacing bitumen by lignin in 0,5,10,15, 20,25 percentages to find the optimum value of replacement. This is estimated by comparing values of penetration, ductility and softening point. Later Marshall test is done to find the load and flow rate, and to roll to study about its rheological properties of the asphalt binder Dynamic Shear Rheometer Test (DSR) is performed. These tests are performed to confirm the properties and to provide a sustainable solution in the coming future. Lignin is nature's most abundant aromatic polymer. It is a type of wood waste, that is unwanted during the production of paper or ethanol and is frequently used as a source of fuel for power industrial plants through combustion. The efficient use of waste lignin in the production of bitumen pavements will not only reduce the environmental impact, but also reduce reliance on petroleum bitumen and also improve efficiency in the wood industry by utilising an unwanted waste by-product. The overall demand for the bitumen accounts for about 100 million tons per year i.e., about more than 700 million barrels are consumed annually. The majority of asphalt used commercially is obtained from petroleum. Nonetheless, large amounts of asphalt occurring are concentrated form in nature. Naturally occurring deposits of bitumen are formed from the remains of ancient, microscopic algae (diatoms) and other once living organisms.

II. MATERIALS USED

A. Bitumen

Bitumen is a black viscous mixture of hydrocarbons obtained naturally or as residue from petroleum distillation. Bitumen is commonly used to build highways and motorways. Bitumen is known for its waterproofing and adhesive properties and is commonly used in the construction industry, notably for roads and highways. Production occurs through distillation, which removes lighter crude oil components like gasoline and diesel, leaving the heavier bitumen behind. In this project viscosity grade 30(VG30) is used. This bitumen is primarily used for the construction of extra-heavy bitumen pavements that have to bear significant traffic loads. Bitumen VG30 is the most widely used type of bitumen in road construction, insulation, building construction industries, and also in the production of cutback bitumen. It's better to know that this VG30 bitumen can be used instead of 60/70 penetration bitumen grade.

B. Lignin

Lignin is nature's most abundant aromatic polymer. Lignin, a type of wood waste, is unwanted during the production of paper or ethanol and is frequently used as a source of fuel to power industrial plants through combustion. Carbon fibres, plastics with designable properties, polymer foams, fuels, and other valuable chemical compounds are examples of new lignin valorization routes. Lignin derivatives, such as lignosulphates, have also found widespread use as concrete admixtures and additives. The efficient use of waste lignin in the production of bitumen pavements will not only reduce the environmental impact, but will also reduce reliance on petroleum bitumen and improve efficiency in the wood industry by utilising an unwanted waste by-product. Lignin is a constituent of wood, together with cellulose and hemicellulose. Lignin as a material for processing may or may not contain sulphur. Sulphur content is an important parameter that impacts the final application of lignin. The group of sulphur-containing lignin includes kraft lignin (KL) and lignosulfonates (LS), produced primarily within industrial lignocellulose pulping processes. The second type includes, among others, soda and organosolv lignin. Kraft lignin is created in a process bearing the same name. The lignin obtained by such a process has a sulphur content of 1.5–3% by weight, is soluble at pH > 10, and exhibits high purity. (Maurice N. Collins et.al.2021)

Here we are using kraft lignin in this project.

III. SAMPLE PREPARATION

The bitumen binder was uniformly mixed with different amounts of lignin which was preheated 1 hour before at 110 degree Celsius. The bitumen is heated at 180 degree Celsius and are together mixed with a dynamic mixer until uniformly combined, without lumps.

IV. LABORTARY TESTS ON BINDERS

A. Penetration Test

Penetration is measurement of hardness and consistency of bituminous material. The penetration of a bituminous material is the distance in tenths of a mm, that a standard needle would penetrate vertically, into a sample of the material under standard conditions of temperature, load and time. The objectives of the penetration test are to determine the consistency of bituminous material and to assess the suitability of bitumen for its use under different climatic condition and type of construction. It is not regarded as suitable for use in connection with the testing of road tar because of the high surface tension exhibited by these materials and the fact that they contain relatively large amount of free carbon.

It is determined by measuring the depth in tenths of a millimetre to which a standard needle (100gms) will be penetrated vertically for 5 sec. For bituminous macadam, penetration macadam, IRC suggest bitumen grade 30/40, 60/80 and 80/100. In warmer region lower penetration grade like 30/40 is preferred, whereas higher penetration grade is used in colder region. Penetration value of bitumen is found out as per IS: 1203-1978.

B. Softening Point Test

The softening point of bitumen or tar is the temperature at which the substance attains a particular degree of softening. It is the temperature (in ºC) at which a standard ball passes through a sample of bitumen in a mould and falls through a height of 2.5 cm, when heated under water or glycerine at specified conditions of test. The binder should have sufficient fluidity before its application in road uses. The determination of the softening point helps to know the temperature up to which a bituminous binder should be heated for various road use applications. Softening point is determined by the ring and ball apparatus.

Higher softening point indicates lower temperature susceptibility and preferred in warm climates. Higher grade bitumen possesses higher softening point than soft grade bitumen. Softening point of various bitumen grades varies between 35°C-70°C. Softening Point of bitumen is found out as per IS: 1205-1978.

C. Ductility Test

The ‘Ductility Test’ gives a measure of the adhesive property of bitumen and its ability to stretch. In a flexible pavement design, it is necessary that the binder should form a thin ductile film around the aggregates so that the physical interlocking of the aggregates is improved. Binder material having insufficient ductility gets cracked when subjected to repeated traffic loads and it provides pervious pavement surface. Ductility of a bituminous material is measured by the distance in centimetres to which it will elongate before breaking when two ends of a standard briquette specimen of the material are pulled apart at a specified speed and at a specified temperature.

Bitumen with low ductility value may get cracked in cold weather. The ductility value varies from 5 to over 100 for different bitumen grades and a minimum value of 75cm is preferred by ISI for bitumen of grades 45 & above. Figure 3.6 and 3.7 shows the briquette mould and ductility testing machine respectively which are used to find out the ductility value of bitumen. Ductility of bitumen was found out per IS: 1208-1978 (Reaffirmed 2004).

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D. Marshall Test

In this method, the resistance to plastic deformation of cylindrical specimen of bituminous mixture is measured when the same loaded at the periphery at a rate of 5cm/min. The test procedure is used in the design and evaluation of bituminous passing mixes. The test is extensively used in in routine test program for the paring jobs. There are two major features in the Marshall method of designing mixes mainly,

(i) Density void analysis

(ii) Stability flow test

The stability of the mix is defined as the maximum load carried by a compacted specimen at a standard test temperature of 600 C. The flow is measured at the deformation in unit of 0.25m between no load and maximum load carried by the specimen during stability test. In these to an attempt is made to obtain optimum binder content to the aggregate mix type and traffic intensity

E. Dynamic Shear Rheometer

The dynamic shear rheometer (DSR) is used to characterise the viscous and elastic behaviour of asphalt binders at medium to high temperatures. This instrument is used to study the rheological properties of asphalt binders. Asphalt binders are viscoelastic. This means they behave partly like an elastic solid (deformation due to loading is recoverable – it is able to return to its original shape after a load is removed) and partly like a viscous liquid (deformation due to loading is non-recoverable – it cannot return to its original shape after a load is removed). The DSR measures a specimen’s complex shear modulus (G*) and phase angle (δ). The complex shear modulus (G*) can be considered the sample’s total resistance to deformation when repeatedly sheared, while the phase angle (δ), is the lag between the applied shear stress and the resulting shear strain. Dynamic shear rheometer is mainly used as a quality control in manufacturing processes.

In this study using dynamic shear rheometer two tests are performed:

- Linear Amplitude Sweep Test
- Multiple Stress Creep Recovery Test

- Multiple Stress Creep Recovery

The Multiple Stress Creep Recovery (MSCR) test is the latest improvement to the Superpave Performance Graded (PG) Asphalt Binder specification. This new test and specification – listed as AASHTO TP70 and AASHTO MP19 – provide the user with a new high temperature binder specification that more accurately indicates the rutting performance of the asphalt binder and is blind to modification. A major benefit of the new MSCR test is that it eliminates the need to run tests such as elastic recovery, toughness and tenacity, and force ductility, procedures designed specifically to indicate polymer modification of asphalt binders. A single MSCR test can provide information on both performance and formulation of the asphalt binder. The Mscr grading reflect the current grade bumping limits.

Standard S grade traffic< 3 million ESAL’s

Heavy H grade traffic> 3 million ESAL’s

Very Heavy V grade traffic> 10 million ESAL’s

Extreme E grade traffic> 30 million ESAL’s

- Linear Amplitude Sweep Test

The Linear Amplitude Sweep (LAS) test applies a cyclic loading with linearly increasing amplitudes on asphalt binder to determine its fatigue performance. The LAS test adopted the DSR instrument using a standard parallel plate of 8 mm in diameter with 2-mm gap between parallel plates. The test method consists of two steps following AASHTO TP 101-14. At first step the rheological properties of the asphalt sample was tested in shear using frequency sweep test. During the frequency sweep test, a strain load with 0.1% in amplitude was applied on the asphalt sample at a frequency range of 0.2–30 Hz. At each frequency, the dynamic shear modulus and phase angle were measured and recorded. After that, asphalt samples were loaded using the strain sweep, in which the 10-Hz frequency is used for oscillatory shear loading.

The testing temperature lies in the range 40-60 degree celsius and in this study the temperature taken is 45 degree celcius.

V. RESULTS

A. Penetration Test

% of lignin added	Penetration value obtained
0	65
5	61
10	57
15	53
20	50
21	48
25	38

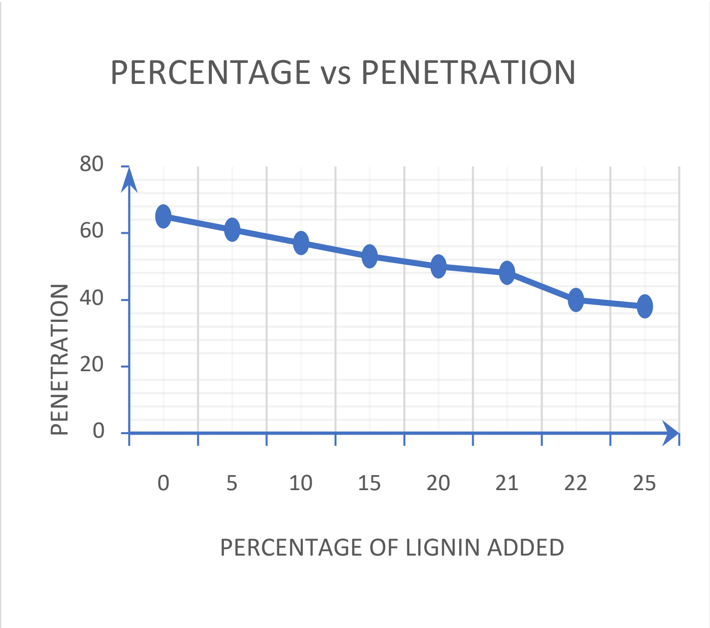

Figure 1: Graphical representation of percentage of lignin replaced Vs Penetration Value

B. Softening Point Test

% of lignin added	Softening Point Values
0	50
5	48
10	50
15	52
20	54
21	52
25	47

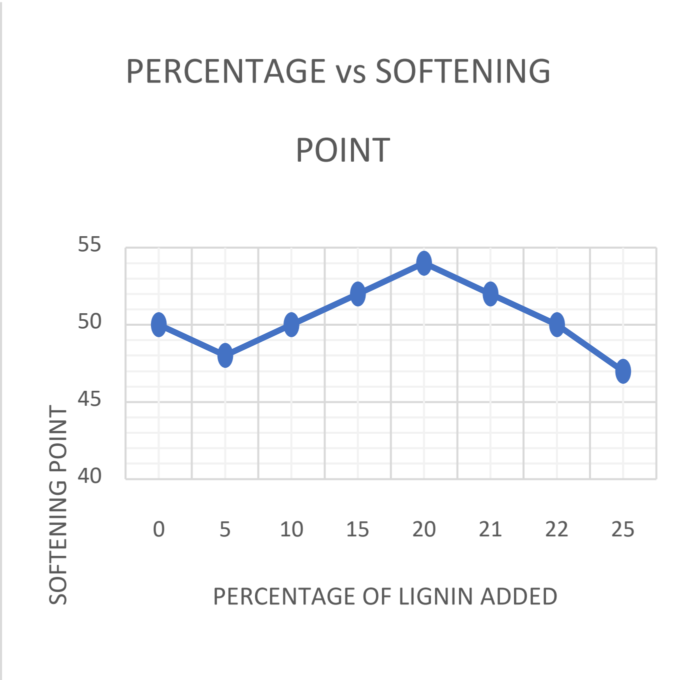

Figure 2: Graphical representation of percentage of lignin added Vs softening point values

C. DuctilityTest

%of lignin added	Ductility value obtained
0	59.3
5	24
10	29
15	33
20	45.5
21	22
25	13.5

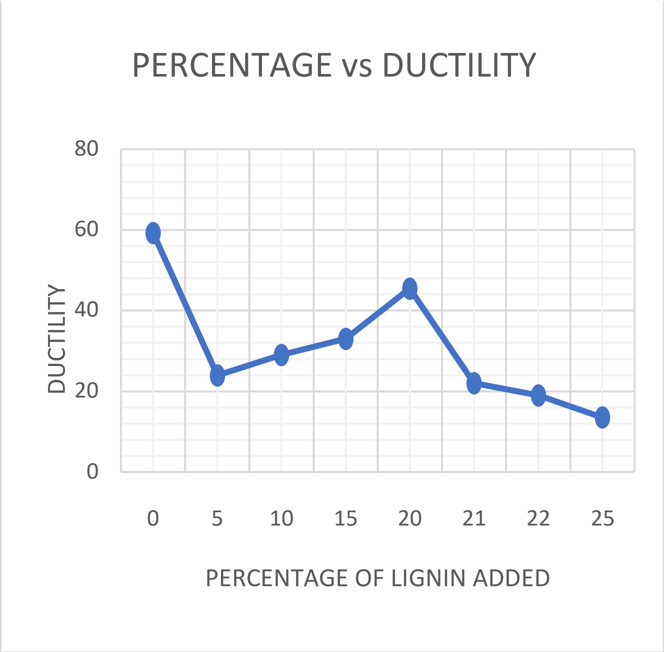

Figure 3: Graphical representation of percentage of lignin added Vs ductility values obtained.

VI. Dynamic Shear Rheometer

- Multiple Stress Creep Recovery

Parameters	VG 30	LBC Binder
% difference of recovery	100%	100%
% difference of Non recoverable creep Compliance(Jnr value)	13.68%	21.83%

The percentage of recovery is same for both bitumen graded VG30 and LBC Binder are concluded as 100%.
The percentage of difference of Non recoverable creep Compliance i.e., the rutting resistance of Bitumen graded VG 30 is concluded to be 13.68% and LBC Binder is 21.38% , that concludes that the elastic recovery of the LBC Binder is greater than VG30 graded bitumen.
When the Jnr value increases rutting resistance of the bitumen increases.

- Linear Amplitude Sweep Test

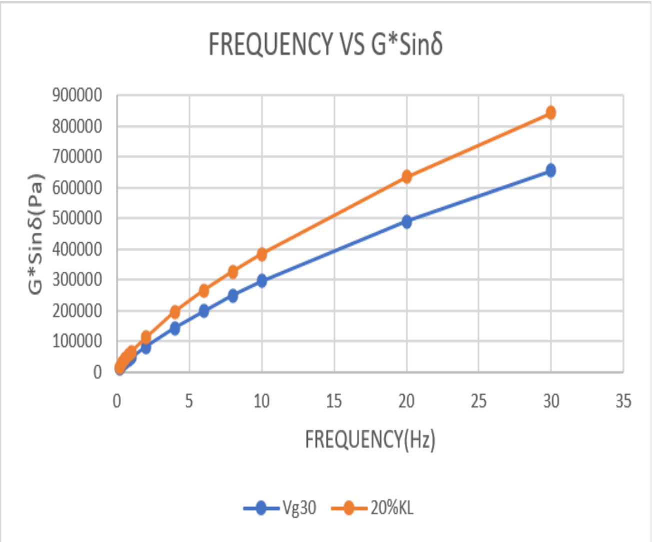

Figure 4: Graphical representation of frequency Vs G*sin delta of Vg30 and 20% LBC binder

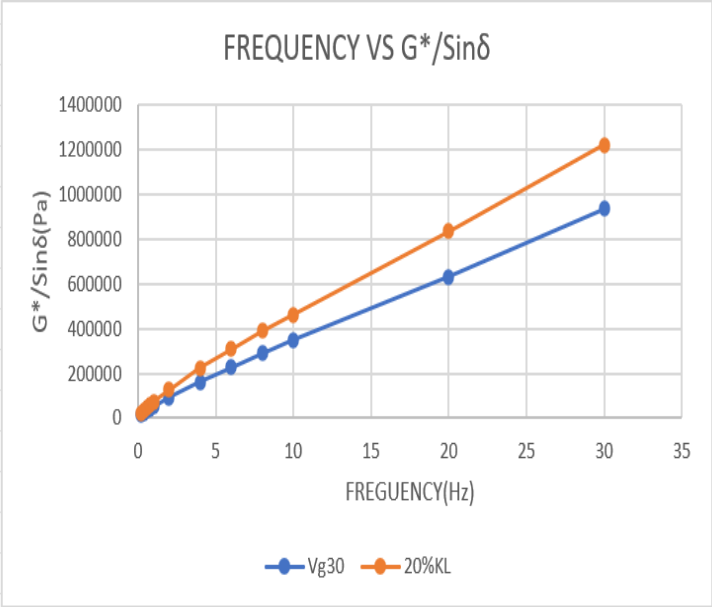

Figure 5: Graphical representation of frequency Vs G*/sin delta of Vg30 and 20% LBC binder

From figure 4&5 we can conclude that the rutting resistance and fatigue resistance of LBC binder is higher that that of VG 30 bitumen.

VII. CONCLUSION

1. By analysing the results of Penetration, Softening Point and Ductility test values of the Lignin modified bitumen of percentages-0,5,10,15,20,21,25, the optimum percentage of lignin that can be replaced into the bitumen is 20%.
2. By performing Multiple stress creep recovery using Dynamic Shear Rheometer apparatus, the percentage recovery of both VG30 and LBC binder is the same i.e., 100% while the rutting resistance of LBC Binder is more than that of VG30 i.e., 21.83%.
3. Linear Amplitude Sweep test performed using Dynamic Shear Rheometer apparatus, the Rutting Resistance of the LBC binder is greater than VG30 and Fatigue Resistance of LBC binder is greater than VG30.
4. From the analysis of Marshall Stability test the stability and bulk specific gravity of both the VG30 and LBC binder is the same.

VIII. SCOPE OF THE PROJECT

- To enhance the property of conventional material
- To utilize waste from paper industries
- To reduce carbon emission during road construction.

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