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The Feasibility of Using Lignin as Modifier for Asphalt Cement

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ABSTRACT

Modifying asphalt cement is an effective approach to enhance the performance of asphalt concrete. This study evaluates the physical properties of lignin-modified asphalt (LMA) at various lignin percentages. The initial step involved extracting lignin from the pinus wood sawdust using the soda process. Subsequently, the extracted Soda Lignin Powder (SLP) was characterized through Fourier transformation infrared spectroscopy (FTIR), and Scanning Electron Microscopy-Energy Dispersive X-ray Analysis (SEM/EDX) to examine the changes in the chemical structure of lignin after extraction by soda process. Following this, three asphalt blends containing varying amounts of SLP (2%, 4%, 6%) by weight of asphalt cement were produced to assess physical properties such as penetration, softening point, ductility, and rotational viscosity test. The findings indicate that incorporating SLP into asphalt cement increases stiffness and viscosity compared to virgin asphalt cement, with increasing SLP content. These results suggest that lignin presents significant enhancement to the performance of asphalt cement under high service temperature conditions.

Keywords: Lignin, Asphalt cement, Soda lignin extraction, FTIR, Asphalt viscosity.

1. INTRODUCTION

The flexible pavement is considered durable if it preserves its structural and functional integrity to provide good performance during design life **(Cota et al., 2022)**. Iraq's roads are primarily constructed from flexible pavement, they suffer from several distresses that influence the performance of flexible pavement **(Al-Tameemi et al., 2016; Albayati and Lateif, 2017; Kareem and Albayati, 2022)**. The structural design of flexible pavement is significantly influenced by two environmental factors; temperature and moisture, which affect the pavement materials' behavior. Temperature impacts stiffness, permanent deformation, and the behavior of thermal fatigue cracks within asphalt concrete layers. Additionally, moisture damage in asphalt mixture reduces the adhesion between asphalt cement and aggregate, leading to stripping and potholes **(Sarsam and Lafta, 2014; Albayati and Al.ani, 2017; Taher and Ismael, 2023)**. Modifying asphalt cement is considered one

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of the best ways to enhance the performance of flexible pavement. Instantly, researchers have begun investigating the chemical and physical characteristics of specific materials compatible with asphalt binder components **(Kalampokis et al., 2022)**. To this end, this study aims to improve asphalt cement properties through the addition of lignin powder.

The use of lignin-modified asphalt in the construction of pavements represents one of the effective methods to improve the performance of flexible pavement. The most renewable resource in the world is biomass, which consists of three primary components; cellulose, hemicellulose, and lignin. Cellulose is the most prevalent biopolymer, followed by lignin, which accounts for (15 - 35) % of the weight of wood **(Azadi et al., 2013)**. Lignin is a component found in all vascular plants, which functions as a water sealant and transports water through the cell wall, it bonds cells together in the wood stems thus giving the hardness of the stem and impact resistance **(Laurichesse and Avérous, 2014)**. Lignin, a complex carbon, oxygen, and hydrogen composite, is derived from phenylpropanoid monomers forming an amorphous polymer **(Bajwa et al., 2016)**. It is a natural polymer, featuring three primary phenylpropane units or monolignols; p-coumaryl alcohol, coniferyl alcohol, and simply alcohol **(Guadix-Montero and Sankar, 2018)**. According to the method of extraction, lignin can be classified into several types such as (lignosulfonate, kraft lignin, soda lignin, organosolv lignin, etc.) **(Ma et al., 2021)**. Asphalt is a type of viscous organic liquid composed of hydrocarbon. In recent years, lignin utilized as a modifier for asphalt cement because the chemical composition of lignin is comparable to that of asphalt cement **(Yao et al., 2022)**. LMA has a significant effect on the rheological features of asphalt cement, enhancement of the aging resistance, crack resistance, and fatigue resistance **(Xu et al., 2017; Wang et al., 2019; Ghabchi, 2022)**. **(Xu et al., 2017)** examined the use of lignin as a modifier and partial replacement at 5% and 10% by weight of the asphalt cement, respectively. The rheological characteristics and aging performance of asphalt were specified when comparing LMA to virgin asphalt. The findings exhibited increased viscosity and improved rutting resistance. Furthermore, lignin acts as an antioxidation modifier by reducing the generated carbonyl groups in the asphalt, it causes a significant retard in the aging of asphalt cement.

The study by **(Arafat et al., 2019)** showed that adding 2%, 4%, and 6% of lignin to asphalt cement increased its high-temperature performance grade and improved the resistance to rutting and moisture damage. **(Zhang et al., 2019)** investigated the rheological features of LMA due to aging, the adding 10% of organsolv lignin by weight of bitumen decreased the fatigue life, when the bitumen ages fatigue life was increased at lower grades of strain and decreased at high grades of strain because of the effect of hardness and stiffness. **(Xu et al., 2021)** inspected the influence of the lignin modifier on the engineering performance of the asphalt binder and mixture. The results showed an enhancement the performance at high and low temperatures than virgin asphalt binder after the addition of 5% of lignin by weight of asphalt. Furthermore, increased the softening point, and viscosity, and improved the moisture and rutting resistance. **(Kalampokis et al., 2022)** investigated the characteristic properties of lignin-modified bitumen. The findings show that the addition of 5%, 10%, and 15% of kraft lignin powder by weight of bitumen reduced the penetration values and increased the softening point, this revealed the kraft lignin had a stiffening effect on the reference bitumen. As well as the addition of kraft lignin increased the dynamic viscosity in comparison of reference bitumen at various testing temperatures.

Lignin is one of the sustainable resources, it has an important role in transporting water through the cell wall of the planet and bonds cells together in the wood stems thus giving the hardness of the stem, as well as its hydrocarbon compound possess the same chemical

composition of asphalt binder, this makes it the preferred material compatible with asphalt cement. Lignin has a positive effect on the physical and rheological properties of asphalt cement and enhances the other mechanical properties according to all the literature reviews described in above. In this paper, the main contribution was the process of extraction of lignin from biomass wood.
This study aims to evaluate the physical properties of SLP modified asphalt. It consists of three phases; first, extracting wood lignin from pinus wood sawdust using the soda process. Second, characterizing the extracted soda lignin using Fourier Transformation Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy-Energy Dispersive X-ray Analysis (SEM/EDX) to examine changes in the lignin structure after extraction by soda process. Finally, evaluating the physical properties of LMA using penetration test, rotational viscosity test, softening point test, and ductility test.

2. MATERIALS AND TESTS

2.1. Asphalt Cement

Asphalt cement with a penetration grade of (40-50) was utilized in this study. It was supplied from the Al Daurah refinery in Baghdad city. The physical properties of asphalt cement satisfied the specifications of the State Corporation for Roads and Bridges **(SCRB R/9, 2003)**, as outlined in **Table 1.**

Table 1. Physical properties of virgin asphalt cement

Test	Units	Result	ASTM	SCRB
Penetration@ 25°C	1/10 mm	45	D 5	40 - 50
Softening point	°C	51	D 36	-
Flash point	°C	252	D 92	min. 232
Specific gravity	-	1.03	D 70	-
Ductility	cm	138	D 113	min. 100
Rotational Viscosity @ 135°C	mPa.s	667	D 4402	-
After film oven test			D 1754	
Retained penetration@ 25°C	%	62	D 5	min. 55
Retained ductility @ 25°C	%	87	D 113	min. 25

2.2 Lignin

In this study, lignin was extracted from pinus wood sawdust; because it was locally available, has a low cost, and contributes to environmental sustainability by reducing waste **(Fernandes et al., 2021)**. The process of extraction was conducted by sodium hydroxide (NaOH). The extraction process was performed at the (Ministry of Sciences and Technology/Directorate of Materials Research).
The extraction method was described in detail by **(Hussin et al., 2013; Carre et al., 2019).** Initially, pinus wood sawdust was ground and sieved through a 4 mm mesh. An alkaline solution was prepared with 30 % sodium hydroxide (NaOH), a solid-to-liquid ratio of 1:8. Distilled water of 400 ml was added to 50 gm of pinus wood flour this was followed by the addition of 100 ml alkaline solution. The blend was heated and stirred at 90 °C for 3 hrs. After that, the solution was filtered by a vacuum filter to obtain black liquor. Then the black liquor is acidified by adding sulfuric acid (H_2SO_4) with a concentration of 20 % drop by drop

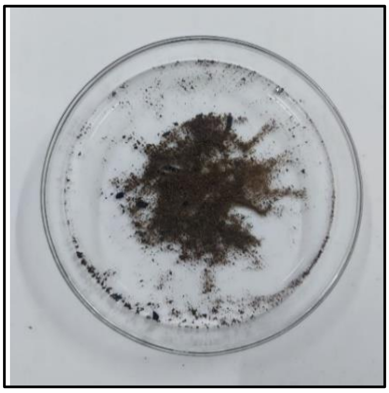
until reaching a pH of 2 and stirred for 2 hrs before being left to settle overnight. After acidification, the precipitate formed was centrifuged at 3500 rpm for 10 minutes to obtain the lignin precipitate. Finally, the precipitate of lignin was dried in the oven at 50 °C for 24 hrs. to obtain purified SLP. **Fig. 1** shows the extraction procedure of soda lignin powder and **Table 2.** Shows the physical properties of SLP.

(a) Pinus wood sawdust

(b) Mixing wood with alkaline solution

(c) Filtering the solution by vacuum filtration apparatus

(d) The black liquor



(e) Soda lignin after drying

Figure 1. Extraction process of soda lignin powder.

Table 2. Physical properties of SLP

Properties	**Value**
Appearance	Brown powder
Average particle size (nm)	514.5
pH value	2-3
The bulk density (gm/cm^3)	0.603

2.3 Characterizing the Extracted Soda Lignin Powder

2.3.1 Fourier Transformation Infrared Spectroscopy (FTIR) Test

Fourier transformation infrared spectroscopy (FTIR) test was utilized to examine the functional groups of the materials **(Xu et al., 2021)**. This test was conducted at the (Ministry of Industry and Minerals/Corporation of Research and Industrial Development). The instrument, Bruker Tensor-27 (German-established) was used in the FTIR test with an average FTIR spectra range of (4000 to 400) cm^{-1}. The functional group of the soda lignin was determined by interpreting the spectrum. Then the measured spectrum was contrasted with the known spectrum to analyze the chemical bonds of soda lignin powder.

2.3.2 Scanning Electron Microscopy-Energy Dispersive X-Ray Analysis (SEM/EDX)

(SEM/EDX) is a combined technique employed to determine the particle size and chemical composition of materials. SEM technique includes scanning the sample's surface with a lower energy electron beam that is directed to the materials. As the beam is approaching and entering the materials multiple reactivity is occur, causing photons and electrons to be emitted from or near the sample surface. In the EDX technique, X-ray emission is activated by irradiation of the surface with a high energy beam of charged particles this produces the emission of an X-ray, which gives the unique characteristic of each element test **(Kumar, 2013)**. This test was conducted at the (Ministry of Industry and Minerals/Corporation of Research and Industrial Development). The instrument, Thermo Fisher Scientific (Czech Republic) was used in the (SEM/EDX) technique.

2.4 Incorporating Soda Lignin Powder (SLP) with Asphalt Cement

The asphalt cement AC (40-50) was blended with three various dosages of lignin (2, 4, 6 % by weight of asphalt) based on the previous studies **(Arafat et al., 2019; Gao et al., 2020)**. The asphalt cement was maintained at a temperature of 150°C and blended with SLP during the mixing process. Initially, SLP was blended at a low-speed shear mixer of 500 rpm to investigate the regular dissipation of soda lignin particles. After 5 minutes, the mixing speed was increased to 3000 rpm and mixed for 30 minutes at 160°C **(Kalampokis et al., 2022)**.

2.5 Physical Properties Test

2.5.1 Penetration Test

The consistency of asphalt cement was identified by the penetration test. Based on the specification **(ASTM D5, 2013)**, it is dependent on the needle penetration test with a weight of (100 ± 0.1) gm that penetrated the asphalt cement sample at 25°C for 5 seconds. **Fig. 2** shows the penetration test.

(a) Penetration test samples (b) The sample while testing

Figure 2. Penetration test.

2.5.2 Rotational Viscosity Test

The viscosity of asphalt binder refers to a fluid's resistance to flow. According to the specification **(ASTM D4402, 2015)**, the rotational viscosity test aims to determine the viscosity of asphalt cement at higher temperatures of construction to confirm that the asphalt cement has sufficient workability. It also measures the temperatures required for the mixing and compaction process to ensure an efficient bonding between the asphalt mixture components. The viscosity was identified at two temperatures; 135°C and 155°C, for virgin and modified asphalt cement using a spindle with a size of 27mm, after equilibrium of the test temperature, the spindle was rotated at 20 rpm. The rotational viscosity is the average viscosity taken after 5 minutes of testing. **Fig. 3** shows the rotational viscometer.

Figure 3. Rotational viscometer.

2.5.3 Softening Point Test

The softening point test was carried out according to the specification **(ASTM D36, 2014)**, it included a steel ball with a weight of 3.5 gm placed above the asphalt cement sample. The temperature was then gradually increased until the steel ball fell through the sample. At this moment, the softening point was recorded. This temperature refers to the capability of the material to flow under higher temperatures experienced in service.

2.5.4 Ductility Test

The ductility test evaluates the adhesion properties of virgin and modified asphalt cement. Based on the specification **(ASTM D113, 2016)**, the ductility of asphalt cement is specified by measuring the distance that a briquet specimen of the asphalt cement will extend before breaking. This test was conducted at 25°C with a rate of pulling 50±2.5 mm per minute.

2.5.5 Penetration Index (PI)

The penetration index (PI) is a numerical measurement utilized to evaluate the temperature susceptibility of asphalt cement. It is calculated based on the obtained results of the penetration test and softening point test by using Eq. (1) **(Dehouche et al., 2012)**.

$$PI=\frac{1952 - 500 * log(Pen_{25}) - 20 * SP}{50 * log(Pen_{25}) - SP - 120} \tag{1}$$

where: Pen_{25} is the penetration at 25°C, 0.1mm, and SP is the softening point, °C

3. RESULTS AND DISCUSSION

3.1 FTIR Spectra Analysis

The average FTIR spectra of soda lignin is in the region of (4000 to 400) cm^{-1} as shown in **Fig. 4**. The absorbance peaks at 3500 cm^{-1} and 3250 cm^{-1} are related to the (–OH) stretching groups. The peaks around 2925 cm^{-1} and 2863 cm^{-1} are typical methoxy groups (O-CH3). The peaks around 1692 cm^{-1} and 1510 cm^{-1} correspond to the vibration of the aromatic ring (C=C), and the absorbance peaks at 1369 cm^{-1} are related to (O-H) bending in phenolic groups. Whereas the peak at 1221 cm^{-1} reverses the presence of (C-O) links. The peak at 1118 cm^{-1} refers to the existence of aromatic (C-H) deformation in syringyl (S) units. Additionally, the peak at 1026 cm^{-1} refers to the existence of (C-O-C) bonds in the guaiacyl unit. Finally, the peak at 825 cm^{-1} reflects the presence of (C-H) bending in aliphatic groups. The existence of all these functional groups above confirms the purified extraction soda lignin powder. The assignments for the IR bands of SLP are shown in **Table 3.**

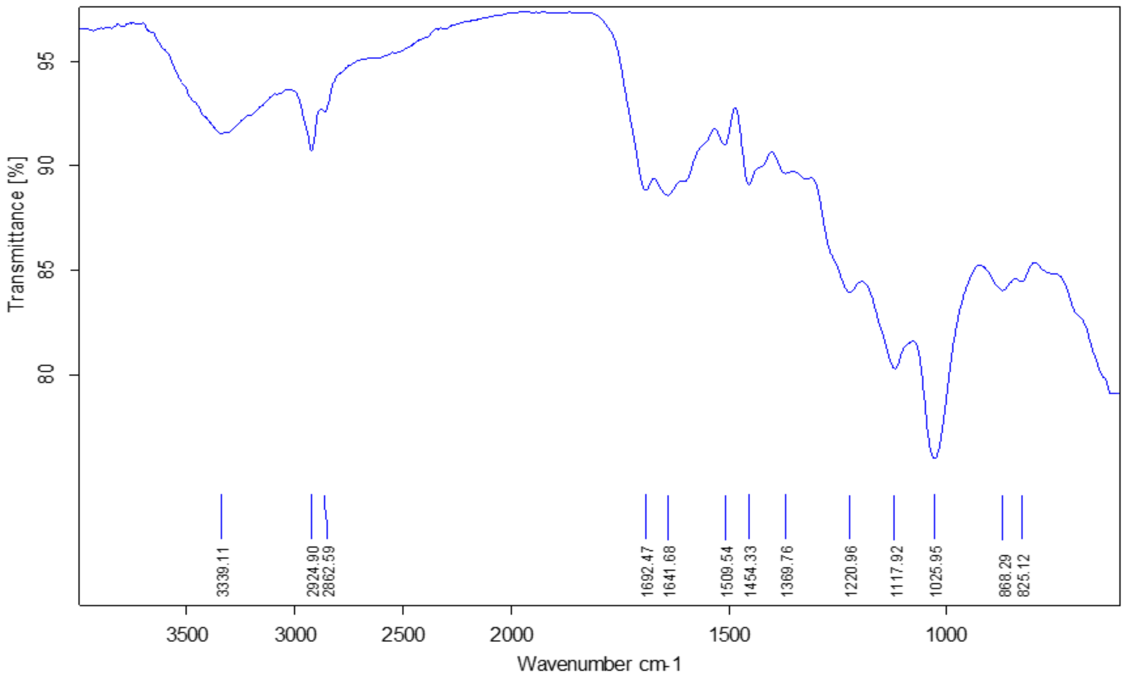


Figure 4. FTIR spectra of soda lignin.

Table 3. The assignments for the IR bands of soda lignin powder

Observed band (cm^{-1})	**Band assignment**
3250 - 3500	-OH bending in stretching groups
2863 - 2925	O-CH3 bending in methoxy groups
1510 – 1692	C=C stretching from the aromatic ring
1369	O-H bending in phenolic groups
1221	C-O stretching in guaiacyl units
1118	C-H bending of syringyl units
1026	C-O-C bonds in guaiacyl unit
825	C-H bending in aliphatic groups

3.2 SEM/EDX Analysis

The surface morphology of soda lignin was characterized by SEM analysis. The SEM analysis shows soda lignin particles are irregular and spherical shaped with open volumes and rough surfaces, the particle size analysis shows lignin consists of particles in the scale of submicron as shown at 30000× magnification of SEM images the lignin particle sizes range from 500 to 520 nm. **Fig. 5** shows the SEM micrograph of soda lignin.

The EDX spectroscopy elemental analysis shows the chemical components of soda lignin consist of a high percent of carbon and oxygen, which is identified as the natural structure of lignin. The weight percent of carbon and oxygen was 46.9 % and 37.3 % respectively. While the percentage of nitrogen was 9.3 %, and the percentage of sulfur was 8.5 %. The other ingredients of soda lignin were sodium, aluminum, and potassium with percentages of 3.1 %, 0.2 %, and 0.3 %, respectively. **Table 4.** shows the element analysis of soda lignin and **Fig. 6** shows the EDX elements map of soda lignin.

Table 4. The element analysis of soda lignin

Element	Atomic (%)	Weight (%)
Carbon (C)	58.4	46.9
Oxygen (O)	34.9	37.3
Nitrogen (N)	9.6	9.3
Sodium (Na)	2	3.1
Sulfur (S)	4	8.5
Potassium (K)	0.1	0.3

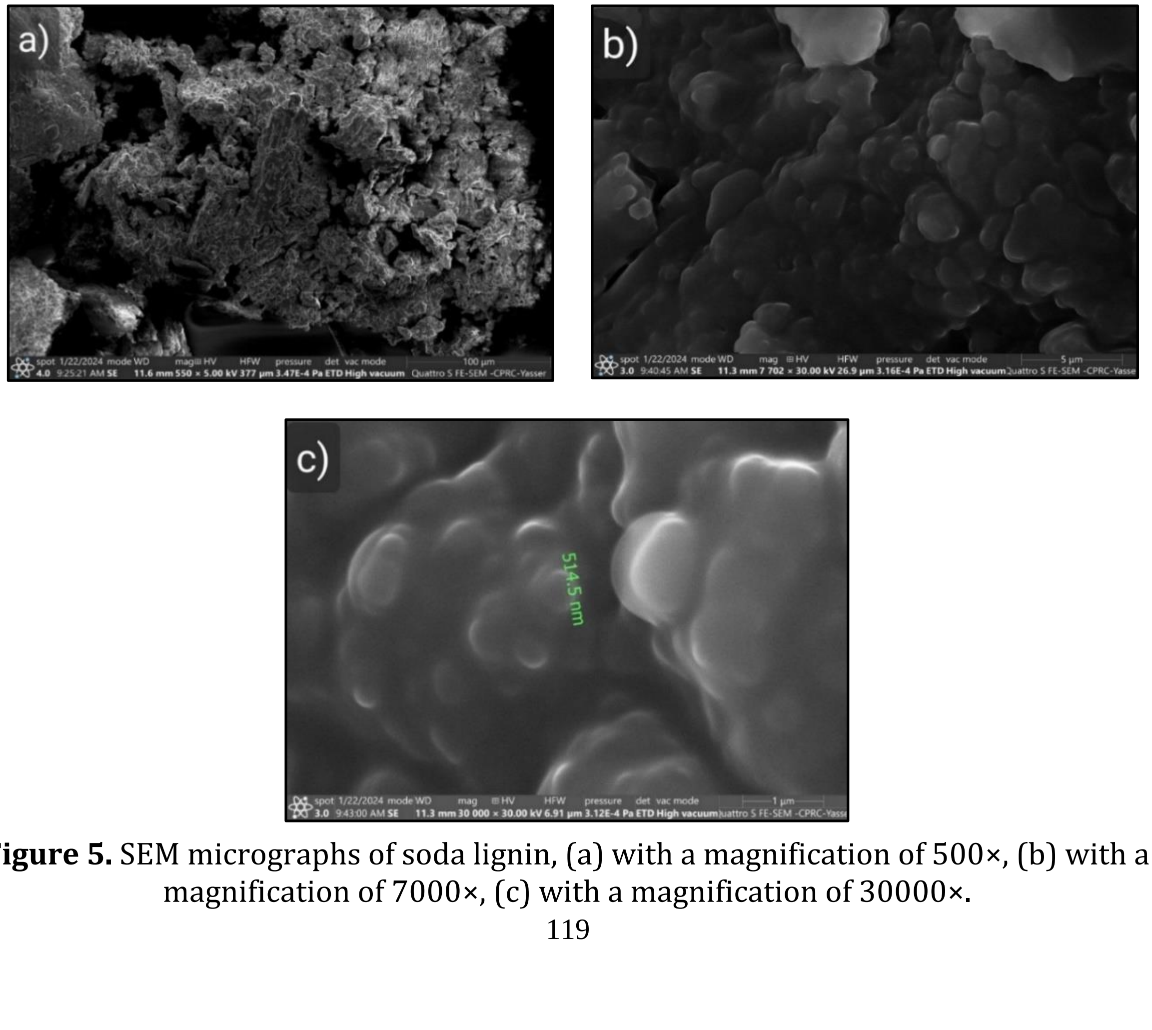


Figure 5. SEM micrographs of soda lignin, (a) with a magnification of 500×, (b) with a magnification of 7000×, (c) with a magnification of 30000×.

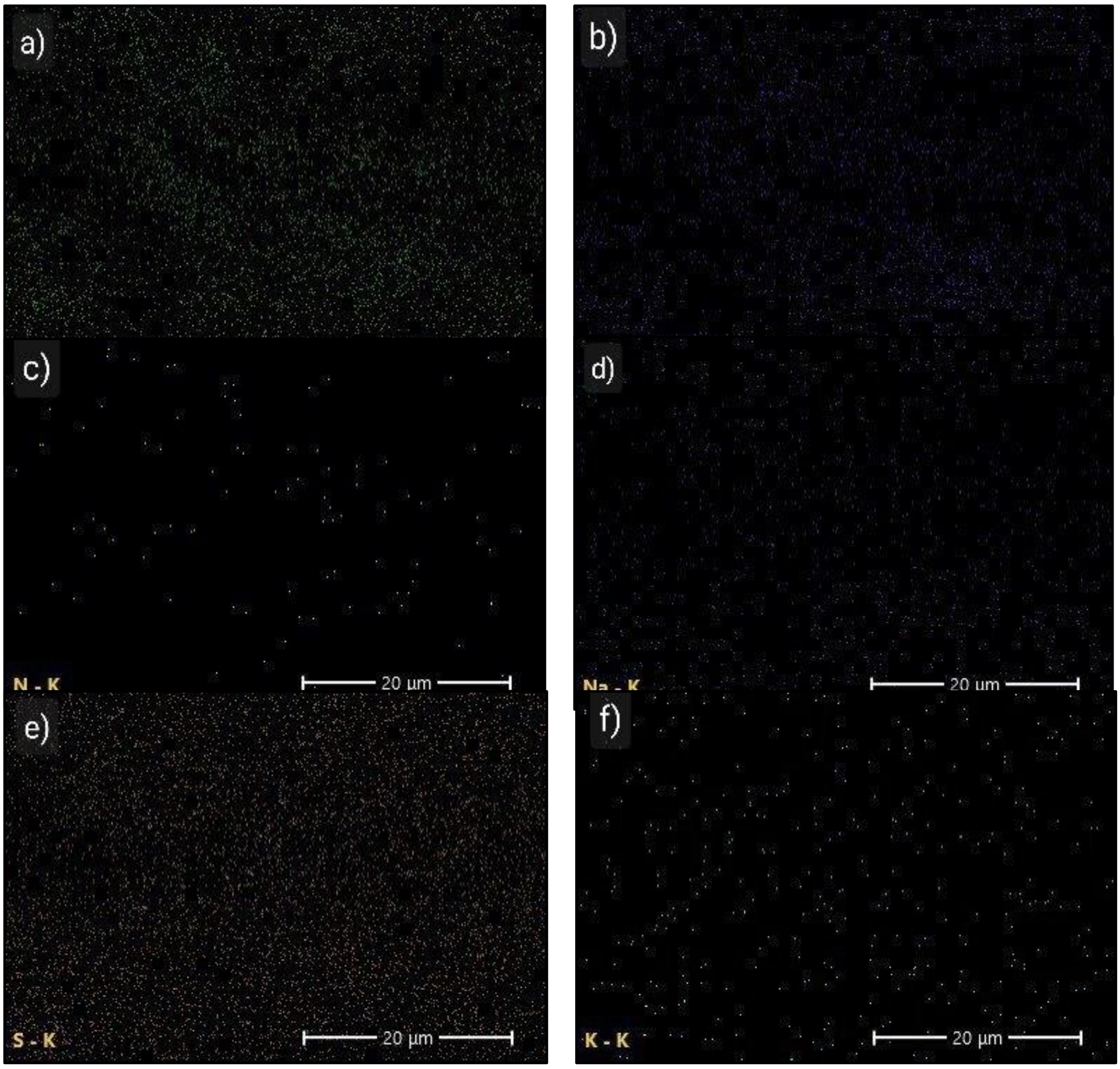


Figure 6. EDX elements map of soda lignin, (a) C element distribution, (b) O element distribution, (c) N element distribution, (d) Na element distribution, (e) S element distribution, (f) K element distribution, continued.

3.3 Physical Properties Test

3.3.1 Penetration Test

The penetration test was used to evaluate the consistency of virgin and modified asphalt cement. As exhibited in **Fig. 7**, it's obvious that the higher percentage of lignin in asphalt cement tends to lower the value of penetration. This indication the SLP-modified asphalt has become harder and stiffer due to the lignin absorbing the light components of asphalt leading to an increase in the asphaltene content. In turn to **Fig. 7**, the virgin asphalt displayed a penetration value of 45, which reduced to 40 with a 2% SLP addition, indicating a stiffness increase of approximately 11.1%. A 4% SLP incorporation further reduced the penetration value to 33, reflecting an increase in stiffness of about 26.7%. At a 6% SLP content, the stiffness increased even more with a penetration value of 28, equating to a 37.8% increase in stiffness compared to virgin asphalt. These findings align with previous research results **(Norgbey et al., 2020; Xu et al., 2021)**, which revealed the ability of lignin to enhance the stiffness of asphalt cement.

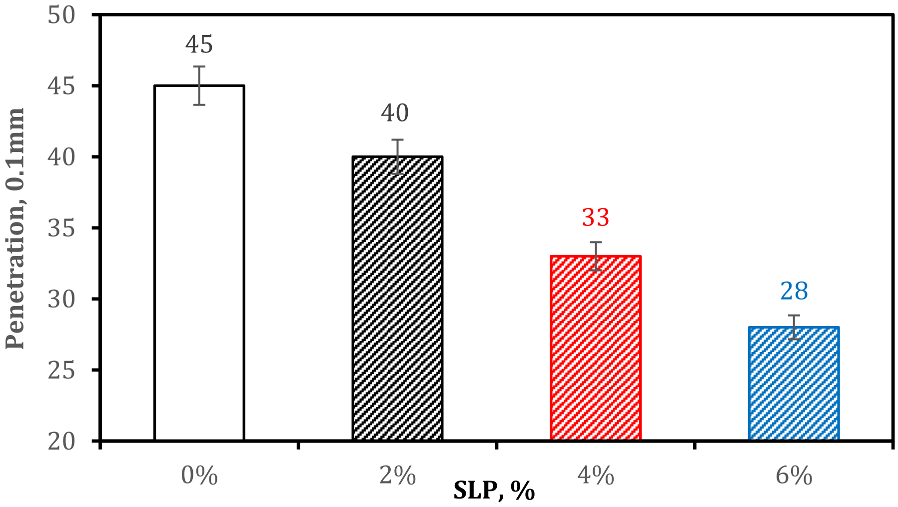


Figure 7. Effect of soda lignin content on the penetration at 25°C.

3.3.2 Rotational Viscosity Test

The viscosity of asphalt has been the most utilized factor to evaluate the workability of asphalt cement. According to the specification **(ASTM D6373, 2016),** an appropriate viscosity (less than 3000 mPa.s) ensures acceptable workability, providing sufficient fluidity during pavement compaction. **Fig. 8** displays the viscosity values of virgin and LMA, containing 2%, 4%, and 6% SLP. Consistent with viscoelastic materials, both virgin and modified asphalts exhibited a decrease in rotational viscosity with an increase in temperature.

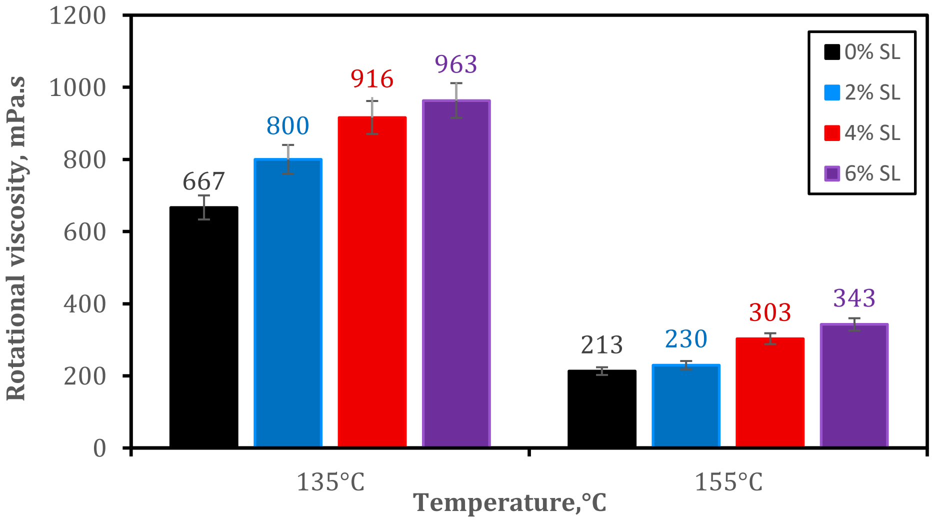


Figure 8. Rotational viscosity test results.

At 135°C, the virgin asphalt showed a viscosity of 667 mPa.s, which increased by 19.9%, 37.4%, and 44.4% with the addition of 2%, 4%, and 6% SLP, respectively. However, at 155°C the LMA showed an increase in viscosity by 7.98%, 42.2%, and 61% at the same SLP content. It is evident that the SLP modified asphalt maintains a higher viscosity than virgin asphalt through all of the temperatures. These results agreed with previous research **(Batista et al., 2018; Gao et al., 2020).**

3.3.3 Softening Point Test

Fig. 9 illustrates the softening point values of asphalt cement with different percentages of SLP, the higher softening point value achieved at the higher percent of SLP. The adding 2%, 4%, and 6% of SLP raised the softening point by 1.96%, 5.88%, and 9.8% respectively. This result of a combination of the SLP with asphalt made it harder, these findings showed an enhanced performance at high temperatures. The softening point having an inverse correlation with penetration values, and the reduction of penetration values conform to this conclusion. This result conforms with previous studies **(Wang et al., 2019; Feng et al., 2023)**.

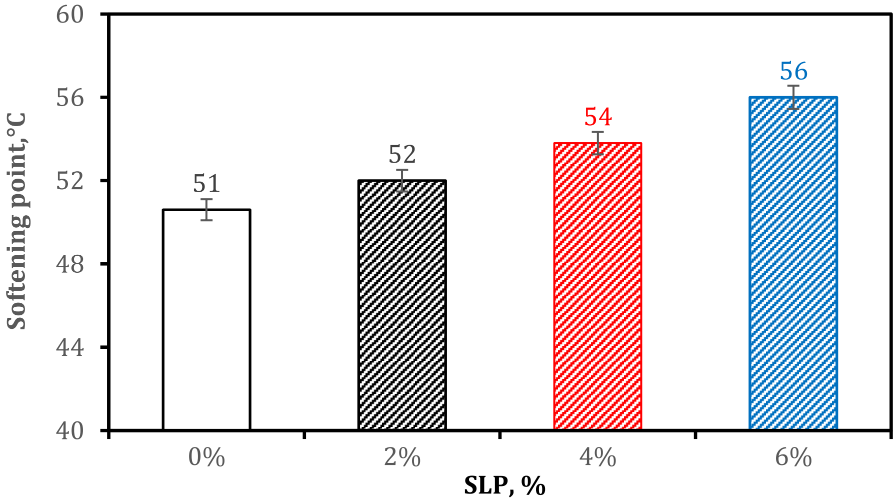


Figure 9. Effect of soda lignin content on the softening point.

3.3.4 Ductility Test

The ability of asphalt cement to elongate without breakage was assessed by the ductility test. **Fig. 10** clarified the ductility values of asphalt cement with different percentages of SLP, the higher percent of SLP given a lower value of ductility. The adding 2%, 4%, and 6% of SLP reduces the ductility values from 138 cm for virgin asphalt to 61 cm at 6% SLP. The reason for that is that SLP dispersed in asphalt cement reduces asphalt cement's ability to elongate.

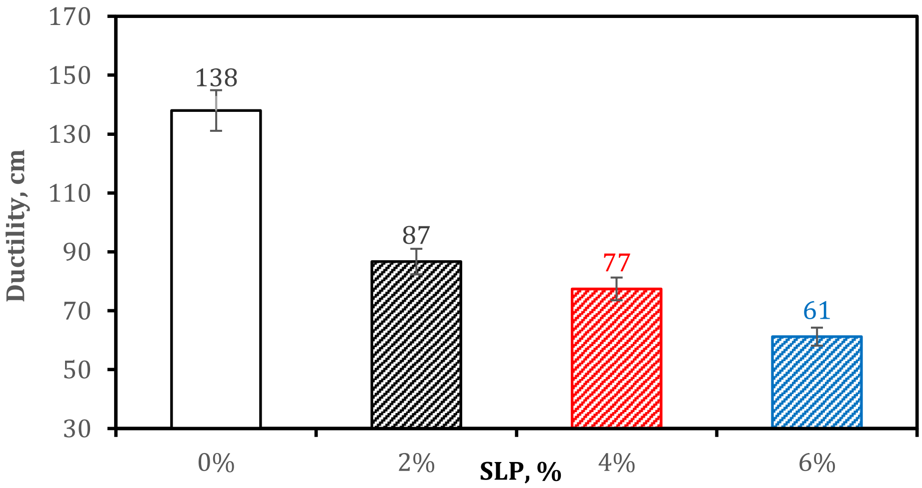


Figure 10. Effect of soda lignin content on the ductility.

The reduction in ductility of asphalt cement indicates that lignin enhances performance at high-temperature conditions by reducing the susceptibility to deformation due to the asphalt cement becoming less sensitive to temperature changes and preserving its stiffness. This agrees with previous studies **(Zahedi et al., 2020; Wu et al., 2021)**

3.3.5 Penetration Index (PI) Results

The temperature susceptibility of the virgin and modified asphalt cement is assessed in terms of the penetration index (PI). The higher PI value revealed lower temperature susceptibility. **Fig. 11** displays the PI values of asphalt cement with different percentages of SLP. The results show that the initial PI value of virgin asphalt is -1.29, which increased with increasing the SLP content, with the addition of 6% SLP increasing the PI value by 18.6%. This revealed that modified asphalt cement has lower temperature susceptibility than virgin asphalt and the temperature variations have a lower effect on the performance of modified asphalt cement. This result agrees with the previous study **(Yu et al., 2021)**.

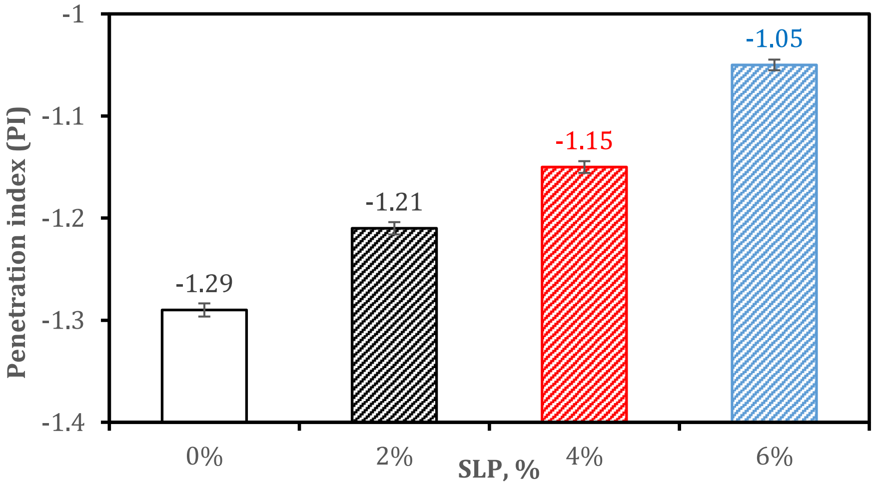


Figure 11. Effect of soda lignin content on the penetration index.

4. CONCLUSIONS

In this study, lignin was extracted from pinus wood sawdust by soda process and then added to asphalt cement with a percentage of (2,4,6) % by weight of asphalt cement. FTIR test and SEM/EDX analysis were utilized to characterize the extracted SLP. The physical properties of modified asphalt were measured through a series of tests. Based on the obtained results, the following conclusions are stated:

1- SLP was extracted from pinus wood sawdust with high efficiency and purity. However, polymer molecules were generated with a fine practical size and submicron scale according to SEM analysis of soda lignin have particle size with a range of (500-520) nm.
2- The results of FTIR show the functional groups of soda lignin, it can be seen hydroxyl groups (-OH), methoxy groups (O-CH3), carbonyl groups (C-O), aromatic groups (C=C), and aliphatic groups (C-H). The presence of these functional groups confirms the purified extraction SLP.
3- The penetration values of asphalt cement are decreased with the addition of SLP. The penetration value was reduced by 37.8 % when adding 6% of SLP, the softening point was

increased by 9.8% with the addition of 6% of SLP due to incorporating SLP with asphalt cement made virgin asphalt stiffer. This improved the performance at high temperatures.

4- The incorporation of SLP with asphalt cement improved the rotational viscosity. At 135°C the viscosity was increased by 44.4% when adding 6% of SLP, while at 155°C the viscosity of virgin asphalt cement was 213 mPa.s which increased by 61% when adding 6% of SLP.

5- The ductility was decreased with the addition of SLP, adding 6% of SLP in asphalt cement leads to a reduction in the ductility by 55.6%. This result indicates that lignin enhances the performance at high-temperature conditions.

6- The penetration index was increased with increasing the SLP content, the addition of 6% of SLP in asphalt increased PI from -1.29 for virgin asphalt to -1.05. This reflects that modified asphalt cement resists the high-temperature susceptibility.

7- Based on all the considerable tests performed in this study, the recommended percentage of SLP to improve the physical properties of asphalt cement is 6% by the weight of asphalt cement.

NOMENCLATURE

Symbol	Description	Symbol	Description
AC	Asphalt cement	LMA	Lignin modified asphalt
ASTM	American Society for testing and material	pH	Power of hydrogen
EDX	Energy dispersive X-ray	SCRB	State Corporation for Roads and Bridges
FTIR	Fourier transformation infrared spectroscopy	SEM	Scanning electron microscopy
		SLP	Soda lignin powder

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Credit Authorship Contribution Statement

Aya K. Asad: Writing – original draft. Amjad H. Albayati: Writing – review and editing, validation, conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have evidence to affect the work reported in this paper.

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إمكانية أستخدام اللجنين كمحسن للإسفلت الأسمنتي

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الخلاصة

يعتبر الإسفلت الأسمنتي المعدل طريقة فعالة لتحسين أداء الخرسانة الإسفلتية. تقوم هذه الدراسة بتقييم الخواص الفيزيائية للإسفلت المعدل باللجنين عند نسب مختلفة من اللجنين. تضمنت المرحلة الأولية أستخلاص اللجنين من نشارة خشب الصنوبر بأستخدام عملية الصودا. المرحلة التالية، تضمنت تحديد خصائص مسحوق الصودا لجنين المستخلص، وتم تحقيق ذلك من خلال إختبار فوريه الطيفي بالاشعة تحت الحمراء، والمجهر الألكتروني الماسح – تحليل الأشعة السينية المشتتة للطاقة لأختبار التغيرات الحاصلة في التركيب الكيميائي للجنين بعد الأستخلاص بعملية الصودا. بعد ذلك، تم تهيئة ثلاث خلطات إسفلتية بكميات مختلفة من مسحوق الصودا لجنين بنسب (2%، 4%، 6%) من وزن الإسفلت الأسمنتي لتوصيف الخواص الفيزيائية مثل الأختراق، نقطة الليونة، الأستطالة، وأختبار اللزوجة الدورانية. حيث تشير النتائج أن استخدام مسحوق الصودا لجنين في الإسفلت يزيد من الصلابة واللزوجة مقارنة باللإسفلت الأسمنتي المرجعي، مع زيادة محتوى مسحوق الصودا لجنين. تشير هذه النتائج الى أن اللجنين يقدم تحسيناً كبيراً لأداء الإسفلت الأسمنتي في ظل ظروف درجات حرارة الخدمة المرتفعة.

الكلمات المفتاحية: اللجنين، الإسفلت الأسمنتي، أستخلاص الصودا لجنين، أختبار فوريه الطيفي بالأشعة تحت الحمراء، لزوجة الإسفلت.