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Research Article

Challenges of using natural bitumen in paving works: Rutting resistance evaluation of natural bitumen mixture

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ABSTRACT

Natural bitumen (NB) is recognized as one of the most important green energy sources. The major failure of Iraq's flexible pavement is rutting, and this failure in a mixture containing NB has not been previously examined. Therefore, this research aims to evaluate the rutting resistance of treated-NB mixture and compared with the mixture prepared with petroleum asphalt that derived from the distillation of crude oil. NB samples were extracted from sulfur springs located in the western region and collected from five locations (Al-Mamora, Al-Jabal, Attat, Al-Atffa, and Al-Askaree). Two processing stages are required to treat NB before use it in asphalt pavement. First, a drying process is conducted to eliminate moisture. Second, the heat treatment was applied on the NB samples to enhance their performance for different periods, which depend on the specific properties of each deposit. Standard asphalt tests are performed on the virgin and treated NB samples to evaluate their physical properties such as penetration, softening point, flash point, ductility, and specific gravity. The experimental results show that the physical properties of NB samples are considerably enhanced after heat treatment, making them comparable to those of petroleum asphalt. The rutting resistance of treated mixtures was assessed using the wheel tracking test. It was concluded that NB mixtures have lower rut depths than petroleum asphalt mixtures, indicating better resistance to rutting distress. In particular, the best resistance to rutting distress is achieved with NB derived from Al-Atffa sulfur spring, which exhibited a rut depth 75.6% lower than that of petroleum asphalt. This improvement is due to the effect of heat treatment, which works to enhance the hydrocarbon chains. Consequently, the asphalt hardness and the resistance to deformation are increased. In conclusion, NB can be used as a sustainable alternative to petroleum asphalt in paving works while contributing to environmental conservation efforts. However, a main limitations is that heat treatment may negatively affect the aging resistance of NB and can increase the cost of pavement construction.

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INTRODUCTION

Roads are a fundamental element of infrastructure that significantly facilitate transport and fosters economic and social advancement, thereby enhancing commerce and investment. The majority of roads constructed globally are surfaced with asphalt mixtures [1, 2]. The asphalt mixture consists of aggregates and asphalt binder. The aggregates constitute the structural framework of the asphalt mixture, accounting for approximately 95% of the overall mass. Asphalt comprises approximately 5% of the overall mass of the mixture [3].

Asphalt is the backbone of our global infrastructure, providing the key bonding agent for road paving applications [4]. Despite the low volume ratio of asphalt relative to aggregate and its significantly lower hardness, its influence on the qualities of the mixture is more substantial and critical [5]. Furthermore, the asphalt binder cost is seven to eight times greater than that of aggregate. Since it is derived from oil, its price fluctuates with changes in price oil [6]. In addition, the continual depletion of crude oil resources is an essential concern that must be considered when searching for more economical alternative bitumen. Natural bitumen (NB) has become a significant source of raw materials. In general, NB is utilized in many industrial sectors compared to its use in road pavement. Eventually, NB has inspired researchers in recent years to use NB as a friendly alternative to asphalt produced from petroleum refineries in the pavement construction sector since the production of petroleum asphalt generates harmful emissions and consumes energy.

NB, a complex chemical compound, is a black fabric composed of high molecular weight hydrocarbon chains, primarily composed of maltene and asphaltenes, which significantly influence the properties of asphalt. The asphaltenes fraction has a higher molecular weight, and it is distinguished by its aromatic properties. It is responsible for the viscous-elastic capabilities of the asphalt binder. While the maltene fraction increases the adhesion ability and provides better flexibility for the asphalt binder [7, 8]. There are several theories that explain the origin of the formation of NB, but two are considered more significant. The first is the carbide theory, which assumes that the origin of NB results from chemical reactions between carbides of some elements found in the Earth's crust and groundwater under the influence of pressure and heat. The second theory, more reliable and closer to the truth, is the organic origin theory, which explains the origin of asphalt as the decomposition of ancient living organisms by anaerobic bacteria in isolation from the air [9]. NB is a petroleum-derived material that is soluble in carbon disulphide and consists of 72 to 93% carbon, 11% hydrogen, 2% oxygen, and a quantity of nitrogen, sulfur, iron, and nickel atoms [10]. However, the elemental content of NB does not differ significantly from that of refinery asphalt binders [11, 12].

NB is present in several provinces of Iraq and exists in both liquid and solid forms. Anbar Province is one of the most important areas in western Iraq with a high amount of NB. The most important area is Heet, located 170 km west of Baghdad, and known for its many bituminous springs. Its yearly output is approximately 30,000 tons. Iraq is one of the top five countries in terms of proven oil reserves in the world, estimated at around 8.4% [11]. Consequently, this national resource should be utilized and capitalized on. In recent years, NB has been widely studied for use in asphalt paving operations as it is considered an alternative with high returns, stable properties, and low cost. NB mixtures have proven to be a promising material that can be used in paving operations.

Two forms of NB are extracted from sulfur springs: a soft form and a hard form. Nevertheless, these forms of NB are not used in asphalt pavement construction without treatment or modification, as their properties are unstable to resist road failures. For example, waste engine oil is used to modify hard NB and enhance its flexibility and workability [13]. Heat treatment is conducted to improve the properties of soft NB by increasing its hardness and viscosity. To explain further, Ahmed et al. [14] used NB from the Abu Al-Jeer sulfur spring and treated it to improve its properties for use in asphalt paving. To enhance its physical properties, NB was heated to 163 °C in a thermal oven for different periods (5, 10, 15, 20, and 25 hours). According to the results, penetration, plasticity, softening point, and other properties improved. Also, according to Abdul-Jaleel and Najres's investigation [11], the heat treatment made NB more rigid and viscous. Additionally, the chemical properties were impacted by a decrease in the ratio of resins and saturated fractions and an increase in the ratio of aromatic and asphaltene fractions. This is because NB was oxidized after applying the heat treatment for various periods (5, 10, 25, 35, and 55 hours).

The harsh environmental conditions and the heavy traffic loads cause an early deterioration of road pavements. Therefore, to avoid early failures in the pavement, it is essential to apply advanced tests to evaluate its long-term performance under critical conditions such as elevated temperatures and high traffic loads [15]. Rutting is one of these advanced tests, which is done to evaluate the ability of the NB mixture to withstand real field conditions. The importance of this understanding lies in the fact that surface cracks reduce the safety of the pavement by allowing progressive displacement of the materials and accumulation of water in these depressions, which causes erosion and eventually leads to premature failure and reduced pavement life [16, 17].

The rutting test is a fundamental test for assessing the resistance of asphalt to permanent deformations. This study addresses a significant gap in this regard, as there are no previous studies assessing the rutting resistance of NB mixture and inadequate studies comparing it with petroleum asphalt. The objective of this research is to study the

rutting resistance of NB mixture, to evaluate the performance of treated NB under the effect of repeated traffic loads, and to measure the rutting depth. The research also aims to improve the physical properties of NB before use by applying heat treatment and investigating the effect of heat treatment on improving the properties. Finally, the final results of treated NB were compared with petroleum asphalt, and its performance and the possibility of using it in paving operations were evaluated.

Impact of Declining Oil Resources on the Asphalt Industry

Oil is today one of the most important commodities worldwide, accounting for almost 33% of total energy consumption, and it plays a major strategic role in the global political and economic dynamics [18]. World oil reserves declined by 0.1% in 2019 compared with 2018 and amounted to 1 733.9 billion barrels. The present world requirement of bitumen is about 100 million metric tons. The continued depletion of oil and its resources is a source of concern for researchers due to its impact on various industries, one of the most important of which is the road industry, which can be directly affected. Researchers expect that by 2030, petroleum extraction operations will begin to decline gradually, resulting in a reduced availability of bitumen for engineering applications [19, 20].

According to reports and future forecasts of global energy, which suggested that oil faces major future challenges and is considered an unlucky and unsuccessful commodity in the coming decades, studies have predicted that the peak of oil will occur in the next three decades. Current estimates indicate that the total global oil reserves are approximately 1,668 billion barrels globally, of which 807 billion are located in the Middle East. It is worth noting that 80% of the Middle East reserves are concentrated in four Arab countries (Iran, Saudi Arabia, Iraq and Kuwait) [21].

In recent years, the global energy demand has risen substantially due to rapid economic development and population growth. It is expected that this increase in demand will be met by relying on fossil fuels (oil, gas, and coal), which will contribute about 80% of the increase in global energy consumption. According to Organization of the Petroleum Exporting Countries reports, the demand rate in 2020 was about 299 million barrels per day. Energy demand may reach about 366 to 370.7 million barrels per day in 2030-2040, respectively. The oil deficit will reach about 10 million barrels per day, which indicates the possibility of an increase in prices of about 150 to 170 dollars per barrel. Hence, reliance on fossil energy consumption is unsustainable. Therefore, the global increase in demand and the continuous depletion of oil resources are concerns in the modern era for the economy and environmental pollution, and also for related industries. When oil decreases, the extraction of petroleum materials will gradually begin to decline [22].

From an environmental perspective, industrial asphalt significantly impacts the environment, as asphalt factories affect air quality and release many different pollutants into the environment, such as carbon dioxide, nitrogen, sulfur oxides, and others. The most critical gases emitted that cause global warming are carbon dioxide, methane, and carbon dioxide [23]. The average concentration of carbon dioxide in the atmosphere in 2020 reached about 415 parts per million, which is a significant increase from its pre-industrial level of 285 parts per million and thus an increase in global warming [24]. Therefore, there is a need for tremendous efforts to reduce its concentration and preserve the environment. In light of the continuous depletion of oil resources and the rising costs of hydrocarbons, there is an urgent need to accelerate the energy transition towards renewable green energy resources that are cheaper and more environmentally friendly such as NB.

Research Region

Iraq is famous for its provinces that have many NB springs. Among these provinces is Anbar province, which is located in the western region of Iraq. It is the largest province in the country by area, covering one-third of the country and including the Heet District, which is a famous tourist city located on the western side of the Euphrates River, about 190 kilometers northwest of the capital, Baghdad. Heet is considered one of the most important cities in ancient human civilization. The city of Heet enjoys an abundance of NB springs from which asphalt comes out in liquid form. NB springs have attracted the attention of scientists and geologists who want to study the nature of these springs and their mineral formations. From among the many springs in the study area, five were selected for this study. The selected springs were named as follows: Al-Mamora (MS), Al-Jabal (JS), Attat (TS), Al-Atffa (AS), and Al-Askaree (SS). Figure 1 displays the location of these sulfur springs [25].

MATERIALS AND METHODS

Raw Materials

In this study, raw materials were provided from Iraq, and the aim of this study was to increase the economic feasibility and use the national wealth in a holistic way.

Aggregate

The fine and coarse aggregates utilized in this study were collected from Al-Nibaie quarry. The coarse aggregate is the one retained on sieve No. 4, and the fine aggregate is the one passing through it, as per the local specification [26]. The physical parameters of the aggregates were verified with the local standards. According to the results of the fine aggregate test, the dry specific gravity is 2.661 (ASTM C-128), and the absorption is 0.93% (ASTM C-70). Coarse aggregate has an acceptable Los Angeles abrasion rating of 11.6%, below the maximum allowable value of 30%. Water absorption was also 0.19% (ASTM C-127), and the dry specific gravity was 2.63. The particle shape, including flat and

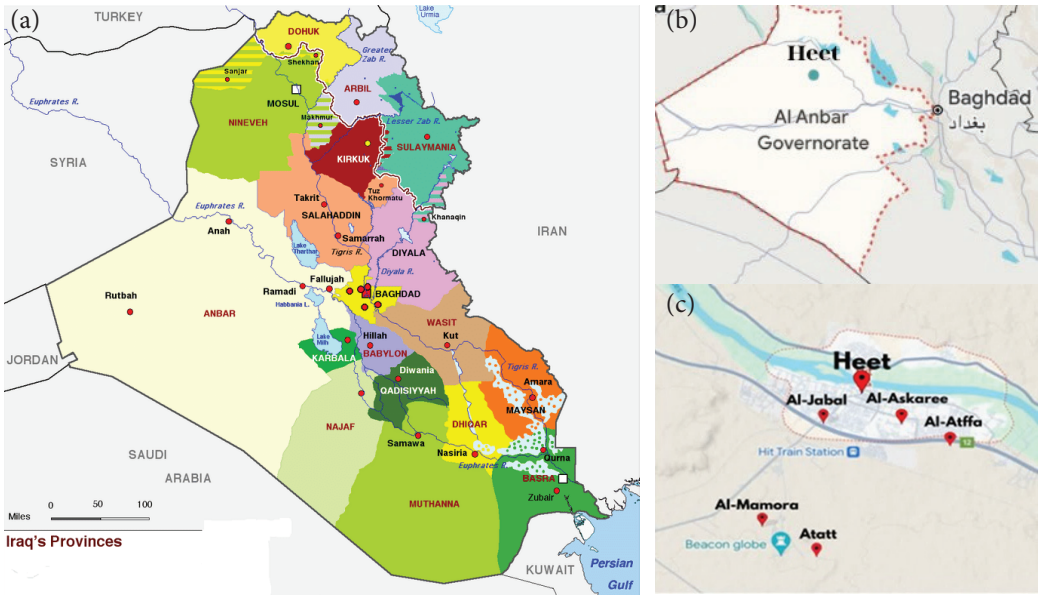


Figure 1. Research region: (a) Iraq map, (b) Anbar governorate location, (c) location of sulfur springs in Heet city [25]. Adapted from: Ewaid SH, Abed SA, Al-Ansari N. Assessment of main cereal crop trade impacts on water and land security in Iraq. Agronomy. 2020;10(1):98. Available at: https://doi.org/10.3390/agronomy10010098 [Open Access]

elongated particles, was analyzed based on ASTM D-4791 and compared with the local criteria. Limestone dust as a filler was supplied from a factory at Karbala, southeast of Iraq. It is a non-plastic material that will pass a No. 200 (0.075 mm) sieve. Physical tests gave a specific gravity of 2.73 and a weight percent passing sieve No. 200 of 94%. The results show that the limestone dust is of high quality and confirm the specifications for use in asphalt. The results of fine, coarse, and filler aggregates are in compliance with the requirements of the Iraqi specification for roads and bridges [26]. The fine and coarse aggregates were screened in the road lab and blended to get the required aggregate that meets the local standards. The overall gradation for the wearing course (Type III-A) is shown in Figure 2.

Asphalt Binder

Two types of asphalt binder were used in this research: petroleum asphalt and NB. The petroleum asphalt is supplied for the Dora Refinery, which located in southern in Baghdad. It is a hydrocarbon material obtained from the distillation process of crude oil. This specific type of asphalt is widely used in local paving works due to its unique characteristics to resist repeated and heavy traffic loads.

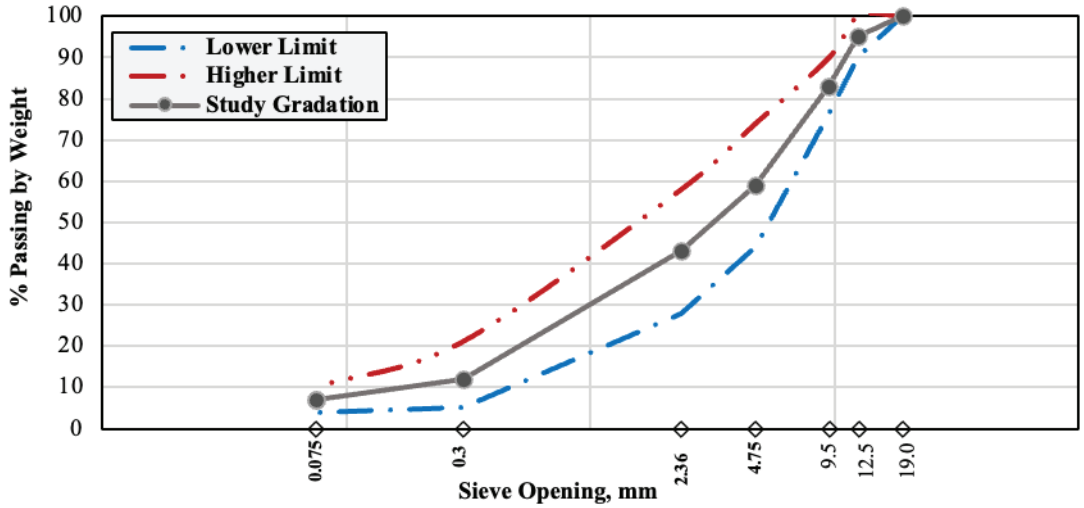


Figure 2. Selected aggregate gradation and criteria limits for wearing layer.

Table 1. Conventional physical tests of asphalt binder

Test	Unit	Test method based on international standards ASTM
Penetration	0.1 mm	D-5
Ductility	cm	D-113
Softening point	°C	D-36
Flash point	°C	D-92
Specific gravity	-	D-70

While the NB samples are supplied from five different sulfur springs, all located in Heet region in Anbar province. Figure 3 illustrates the difference in appearance between petroleum asphalt and NB. In addition, NB is economically more viable as it is widely available throughout the country and is a vital resource that should be encouraged to be invested in and exploited.

Testing Methods

Conventional asphalt tests

To assess the quality of asphalt and ascertain its physical properties, a thorough series of tests must be performed on petroleum asphalt and NB extracted from five different sulfur springs to ensure compliance with local specifications [26]. As presented in Table 1, five asphalt tests were conducted in this research.

NB preparation and processing

NB may vary in properties and composition, making it challenging to achieve consistent results when using its virgin form in road pavement. Furthermore, NB is characterized by its high-water content and few impurities. Hence, it is unsuitable for direct use in paving operations and does not meet the requirements of the Iraqi specification for roads and bridges [26]. Prior to use, NB extracted from sulfur springs must undergo to an initial process of drying and water isolation. The process involves heating NB in a thermal oven to a temperature between 110 °C and 155 °C. The duration of heating varies for each asphalt sample, depending on the water content of the source. The asphalt must not be exposed to temperatures that are too high in order to avoid burning. Once the separation from water is confirmed, the heat treatment process commences. This involves subjecting the NB to high temperatures of 163 °C in a thermal oven. The duration of heating varies for each sample, depending on the desired enhancement of physical properties and ensuring that it is compatible with local specifications.

Figure 4 displays the drying and the corresponding heat treatment hours for NB samples depending on each spring to suit the asphalt used in paving operations according to local specifications. The results indicate that the AS spring has the shortest drying duration, totaling about one and a half hours. This suggests that the spring possesses has the lowest water volume relative to other springs. It also requires the least amount of heat treatment, totaling about two hours, due to its physical qualities similar to those of industrial asphalt.

As presented in the introduction section, the previous research [14] conducted heat treatment on NB extracted from the Abu Al-Jeer sulfur spring and 20 hours is the best period to improve its physical properties, which is approximately the same period (21 hours) applied in this study on NB from TS spring. This implies that these two springs probably have the same water content and physical properties.

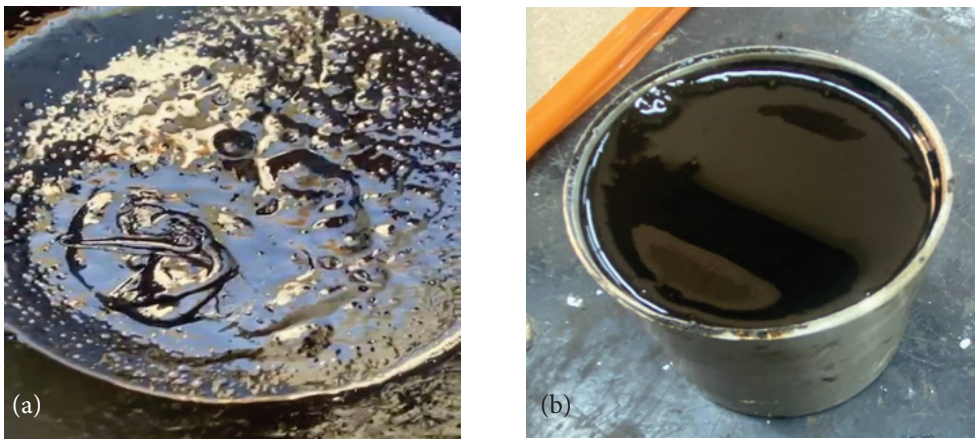


Figure 3. Asphalt types: (a) NB and (b) petroleum asphalt.

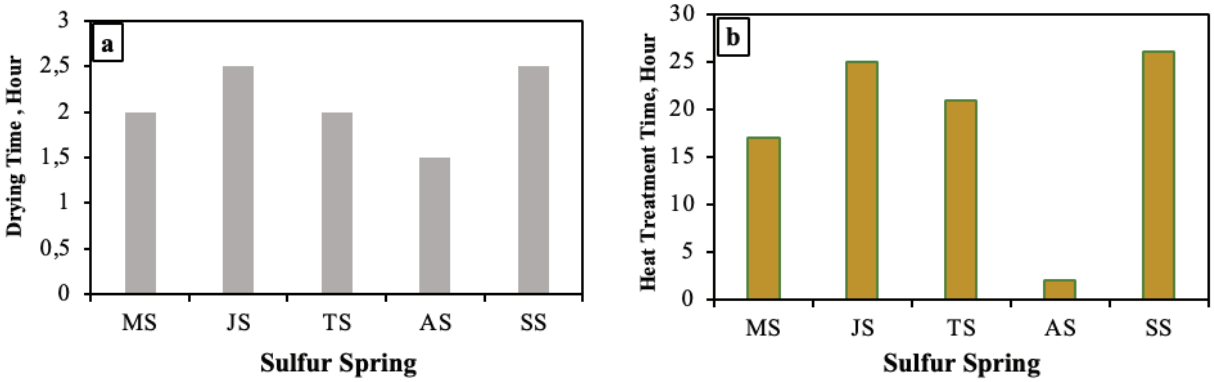


Figure 4. NB treatment: (a) Drying process time and (b) Heat treatment time.

Wheel tracking test

The wheel track test was conducted to evaluate the resistance of petroleum asphalt and NB mixtures to rutting. Based on the procedure in ASTM D6927-15, Marshall design determined that 5%, 5.1%, 4.9%, 5.2%, 4.93%, and 5.3% (by weight of the aggregate) were the optimal asphalt content for petroleum asphalt, TS-NB, JS-NB, AS-NB, SS-NB, and MS-NB mixtures, respectively. The slabs were prepared using a roller compactor. First of all, the aggregate and asphalt were prepared and heated in an oven at a temperature of 150 °C for two hours before mixing. Subsequently, the aggregate and asphalt were removed from the oven and placed in a hot mixing vessel for at least three minutes to ensure that the asphalt covered all aggregate surfaces and ensured the homogeneity of the mixture. After mixing, the homogeneous mixture was placed in a thermal oven to heat it for two hours. Then, it was distributed using a shovel into a preheated mold of dimensions 300×400 mm. After that, the process of compacting the mixture to the required thickness began using a roller compactor device. This device compressed the asphalt mixture molds under controlled conditions that simulated the pressure on site. The mold was left after reaching the required thickness to cool for 24 hours at room temperature to be ready for examination. The sequence of slab preparation is illustrated in Figure 5.



Figure 5. Preparing slabs: (a) preparation the aggregate mix, (b) mixing the aggregate and asphalt, (c) slab preparation, (d) roller compactor device, (e) compacted slab.



Figure 6. Wheel tracker device.

The wheel track test is used to evaluate the depth of ruts and the rate of deformation resulting from moving and concentrated loads that are controlled in the laboratory. Also, the test is conducted according to the EN 12697-22-2003 standard. The test is performed after the slab has been conditioned at the test temperature for 4 hours. Then, the machine is operated by running a loaded wheel back and forth over the surface of the asphalt slab. The applied load was 70 psi at a temperature of 50°C. The deformation of the sample is measured after 10000 cycles (20000 passes). Figure 6 displays the wheel track device.

RESULTS AND DISCUSSION

Physical Properties of Petroleum Asphalt and NB

Physical tests were conducted on petroleum asphalt and NB (before and after treatment) to evaluate their properties and compliance with local specifications [26]. The results of the physical properties are provided in Table 2. It was reported that petroleum asphalt met all the requirements stipulated by the local specifications. Meanwhile, it is evident that virgin NB had a significantly higher penetration value compared with the specification limits, which indicates that it is softer. Likewise, the rest of the physical tests revealed that they were all incompatible with the requirements implied in the specification.

It is necessary to treat NB to improve its physical properties and quality in order to enhance its ability to withstand mechanical stresses and increase its resistance to environmental factors. This helps ensure that the materials used in paving perform well. Differences in the properties of the NB samples depend primarily on their depositional sources (variations in mineralogical and chemical compositions). In addition, the ecological-geological condition of each sulfur spring can increase these differences. As a clarification, over time, the physical properties of NB can change continuously as it might endure oxidative degradation when exposed to sunlight and air.

Heat treatment was performed to increase NB stiffness and significantly improve its performance in resisting permanent deformations, especially rutting failure. The results of the physical tests of NB after treatment exhibited a significant improvement in the properties. This improvement is due to exposure to high temperatures during the heating phase, which lasted for different hours depending on the nature of each spring. This high temperature leads to oxidation on its surface, and continuous mixing and heating contribute to the oxidation of all asphalt molecules. This leads to a change in the consistency of the asphalt, increases its hardness, and gives it a dark black color. These outcomes align with the findings from the recent literature [14, 27].

Table 2. Physical properties of petroleum asphalt, virgin NB and treated NB

Asphalt Type		Property				
		Penetration	Ductility	Softening Point	Flash Point	Specific Gravity
Petroleum Asphalt		42	>100	53.5	324	1.0200
Virgin NB	MS	130	68.0	39.0	180	1.0400
	JS	143	63.7	35.0	158	1.0520
	TS	120	66.7	43.2	175	1.0300
	AS	58	65.0	42.5	175	1.0280
	SS	142	64.0	36.2	177	1.0400
Treated NB	MS-17 hr.	45	>100	52.0	248	1.0431
	JS-25 hr.	44	>100	53.5	232	1.0540
	TS-21 hr.	44	>100	53.5	240	1.0327
	AS-2 hr.	45	>100	52.3	238	1.0300
	SS-26 hr.	45	>100	56.0	245	1.0441
Specification Requirements [26]		40-50	>100	-	232 Min.	-

According to the outcomes of the physical properties of NB after applying heat treatment, the best spring was AS since it recorded the shortest treatment time compared to the rest of the springs. Its consistency is characterized by being of the solid type due to its low degree of penetration, which is close to the penetration of petroleum asphalt. On the other hand, the process of treating SS by heating was considered the longest, as it took 26 hours. The long treatment period is attributed to its consistency and its high content of water, which affects its physical properties.

The results indicate a significant improvement in the softening point for all samples of NB, as it increased by 33.3%, 52.8%, 23.8%, 23%, and 54.6% for MS, JS, TS, AS, and SS, respectively. Improvement in softening points indicates an increase in the thermal stability of NB, which leads to the preservation of the mechanical properties of asphalt when exposed to different traffic loads or to high temperatures in the summer.

According to the ductility test findings, the ductility value of petroleum asphalt meets the requirements of a limit of more than 100 cm. Meanwhile, all virgin NB samples do not comply with this limit. These lower values of ductility reveal that NB is very soft and sticky. After heat treatment, the ductility values of the NB samples increased, which demonstrates that NB became brittle and stiff.

Table 2 indicates that the flash point value for petroleum asphalt reached 324 °C. This value has already met the general specification of roads and bridges [26], which is more or equal to 232 °C. Meanwhile, virgin NB samples were below this limit. In such cases, fire and explosion hazards increase. Flash points are improved for all treated NB, enhancing the safety requirement.

The specific gravity of NB helps to evaluate its quality and suitability for use in particular applications, especially on road pavement. The specific gravity is affected and changed by the impurities and composition in NB. Thus, it can vary based on NB source. A high specific gravity demonstrates that NB is denser, which makes it more durable and resistant to permanent deformation. On the other hand, the presence of lighter hydrocarbons indicates that NB has low specific gravity, which can lead to weaker and less stable material [28]. According to the results, the specific gravity of NB samples is greater than that of petroleum asphalt. In addition, heat treatment increased its values. This can be attributed to the fact that NB has heavy hydrocarbons [29].

Increasing the heat treatment periods, specified early in Figure 4 (b), will change the mechanical and chemical responses of NB. This can probably make NB stiffer and may cause an early brittle failure. The results of a previous study [30] supported this observation.

Rutting Resistance Assessment

The rutting depth of each type of asphalt mixture was recorded over 10,000 cycles, as shown in Figure 7. The number of loading cycles with cumulative rut depth measurements in this research provided a similar increasing trend to those in previous works [17, 31, 32]. The results revealed that the largest decrease in rutting depth was for NB when compared with petroleum asphalt, where the decrease percentages were 75.6%, 70.4%, 50.6%, 51.6%, and 64.4% for each of AS, MS, SS, JS, and TS, respectively.

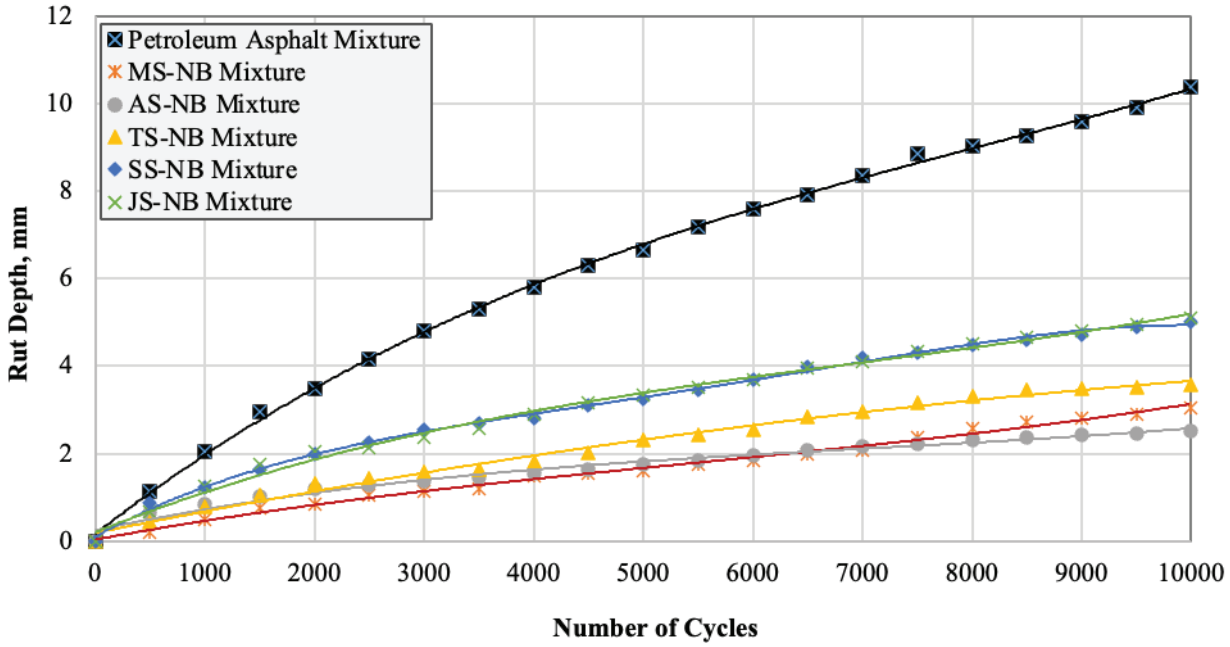
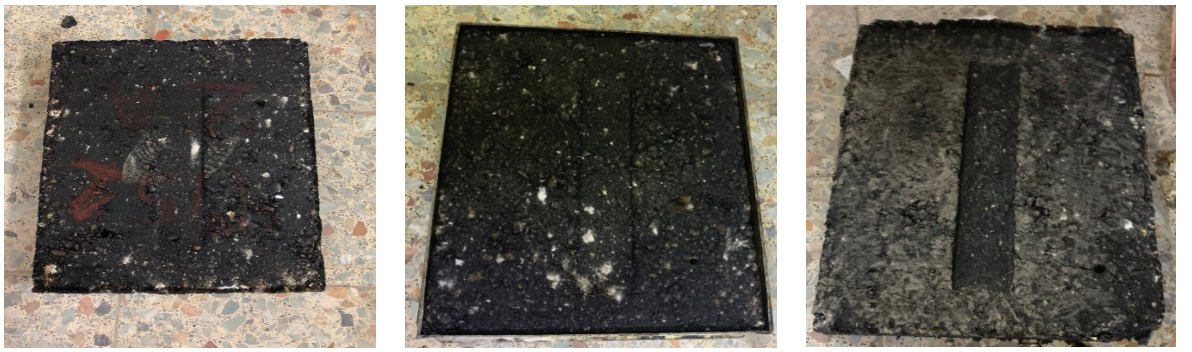


Figure 7. Rut depths of petroleum asphalt and treated NB mixtures.



(a) AS-NB (b) MS-NB (c) TS-NB



(d) JS-NB (e) SS-NB (f) Petrolum Asphalt

Figure 8. Slabs with ruts after wheel track test.

Notably, AS exhibited the lowest rutting depth among all samples, measuring only 2.52 mm.

The reason for the low rutting depth and good rutting resistance of NB can be attributed to the effect of heat treatment, which leads to the creation of interlocking chains of hydrocarbons by interlocking free radical molecules in NB. It enhances the cohesion of the NB structure and makes it more rigid and more resistant to heat and operating conditions. Also, the improvement in the softening point and penetration leads to increased resistance to rutting since the rigid and thermally stable asphalt is less susceptible to deformation when subjected to loads. In other words, due to heat treatment, treated NB achieved higher stiffness, and the findings on the treated NB mixture are consistent with the above since anti-rutting performance is enhanced. These outcomes are in line with the conclusions of recent research [33]. In addition, NB contains asphaltene in large quantities, and the asphaltene content increases as a result of heat treatment. This increase leads to improved flexibility of NB and enhanced resistance to permanent deformations, as it enhances the bonding between molecules by increasing the polarizing materials in asphalt, which enables it to withstand high loads without deterioration. This conclusion is in agreement with findings from previous study [34]. Figure 8 presents the slabs after the wheel track test for petroleum asphalt and treated NB.

In summary, NB extracted from sulfur springs is suitable for flexible pavement that is constructed in areas with high-temperature climates, especially in improving their rutting resistance. In fact, this conclusion has been proved by early studies [35-37] as they use other types of NB, such as Gilsonite, rock asphalt, and Trinidad Lake asphalt. This enhancement is mostly due to NB's high asphaltene content.

CONCLUSION

NB is a promising, low-cost natural material compared to petroleum asphalt. In this study, the rutting resistance of NB mixtures was evaluted after applying heat treatment on NB derived from five different springs. This treatment enhanced the physical properties of NB to conform to the standard requirements of petroleum asphalt.

NB is very compatible with petroleum asphalts as they are derived from crude oil. However, the physical properties of virgin NB were not in the specification standards of petroleum asphalts. It is poor in hardness, softening point, ductility, and flash point but high in specific gravity. Thus, NB was heated to 163 °C to remove water before direct use. The duration of treatment depended on the origin of each spring and the degree of enhancement in its physical properties. Also, it is highly recommended to avoid increasing the heat treatment periods for NB beyond those specified

in this research to avoid the brittleness issue of asphalt and difficulties during compaction.

The structural and solidification changes in NB were essentially attributed to the loss of light components during the heat process. The physical properties of NB were improved significantly by heat treatment, which decreased the degree of penetration, increased the ductility, raised the softening point, and improved the flash point. It had properties like petroleum asphalt and was within the specification limits.

The wheel tracking test was conducted for petroleum asphalt and NB. The rut depths (mm) of asphalt mixtures were 10.36 for petroleum asphalt, 5.11 for JS-NB, 5.01 for SS-NB, 3.57 for TS-NB, 3.06 for MS-NB and 2.52 for AS-NB, respectively. The results clearly show that NB offered a greater resistance to rutting failure than petroleum asphalt. The AS-NB mix also showed the minimum rut depth, which was reduced by 75.6% compared with the petroleum asphalt. The strength of NB is due to its structure and the influence of heat treatment, which increases its hardness and improves its flexibility and resistance to deformation.

Finally, the findings showed the good mechanical performance of NB in resisting loads and operating conditions, especially at high service temperatures. This highlights its potential as a viable alternative to petroleum asphalt in the producing of flexible pavements in terms of resistance against rutting failure. Nonetheless, despite these enhancements in NB mixture performance, two main limitations in this research must be addressed in future works: heat treatment costs and the aging issue of NB. Therefore, it is recommended to modify NB with fibers, waste materials, nanomaterials, and fillers, which can be beneficial in reducing the treatment costs, avoiding the negative effects of aging for NB pavement, and enhancing the properties of NB.

The use of NB in flexible pavement would reduce the consumption of petroleum asphalt, substantially lower the cost of materials, and produce environmental benefits. Nevertheless, it is worth noting that many features of NB have still not been examined well. Therefore, efforts should be intensified to further research and conduct more intensive future studies on NB. Accordingly, pavement engineers would be able to understand its performance behavior at a deeper level by studying the chemical composition and its effect. This is in addition to investigating the impact of temperature on the rheological properties as a result of the aging by applying aging and rheological tests.

In Iraq, there are many deposits of NB covering large areas. However, this natural resource has not been properly exploited. Thus, the future attention of policy makers in government must focus on the exploitation and application of NB, especially in road construction, to achieve two main advantages: reducing environmental effect and improved sustainability.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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