University of Baghdad
College of Engineering
JE
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 30 Number 1 January 2024

Assessment of Traditional Asphalt Mixture Performance Using Natural Asphalt from Sulfur Springs

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ABSTRACT

This research utilized natural asphalt (NA) deposits from sulfur springs in western Iraq. Laboratory tests were conducted to evaluate the performance of an asphalt mixture incorporating NA and verify its suitability for local pavement applications. To achieve this, a combination of two types of NA, namely soft SNA and hard HNA, was blended to create a binder known as Type HSNA. The resulting HSNA exhibited a penetration grade that adhered to Iraqi specifications. Various percentages of NA (20%, 40%, 60%, and 80%) were added to petroleum asphalt. The findings revealed enhanced physical properties of HSNA, which also satisfied the requirements outlined in the Iraqi specifications for asphalt cement.
Consequently, HSNA can serve as an asphalt binder to produce asphalt mixtures for flexible paving construction. Notably, HSNA mixtures exhibited greater Marshall stability and stiffness index when compared to traditional mixtures. The results from indirect tensile strength (ITS) and tensile strength ratio (TSR) tests indicated that the 80NA mixture displayed the highest ITS values and a TSR of 81.36%, surpassing the TSR of the mixture incorporating petroleum asphalt by 0.57%.

Keywords: Natural bitumen, Moisture damage, Treatment, Sulfur springs, Mechanical properties

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2024.01.04

Article received: 09/04/2023
Article accepted: 16/07/2023
Article published: 01/01/2024

تقييم أداء الخلطة الاسفلتية التقليدية باستخدام الأسفلت الطبيعي من الينابيع الكبريتية

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قسم الهندسة المدنية، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

استخدم هذا البحث رواسب الإسفلت الطبيعي (NA) من ينابيع الكبريت في غرب العراق. تم إجراء الاختبارات المعملية لتقييم أداء خليط الأسفلت المتضمن NA والتحقق من ملاءمته لتطبيقات الرصف المحلية. لتحقيق ذلك، تم مزج مزيج من نوعين من NA، وهما SNA اللين و HNA الصلب، لإنشاء مادة رابطة تعرف باسم HSNA. أظهر HSNA الناتج درجة اختراق تتوافق مع المواصفات العراقية. تمت إضافة نسب مختلفة من NA (20٪، 40٪، 60٪، 80٪) إلى الأسفلت البترولي. كشفت النتائج تحسنا في الخصائص الفيزيائية لـــ HSNA، والتي استوفت أيضًا المتطلبات المحددة في المواصفات العراقية للمادة الاسفلتية الرابطة. وبالتالي، يمكن أن يعمل HSNA كمادة رابطة اسفلتية في إنتاج خلائط الإسفلت لبناء رصف مرن. والجدير بالذكر أن مخاليط HSNA أظهرت قدرًا أكبر من الاستقرار والصلابة بالمقارنة مع الخلائط التقليدية. أشارت نتائج اختبارات مقاومة الشد غير المباشرة ونسبة مقاومة الشد إلى أن خليط NA80 أظهر أعلى قيم لمقاومة الشد غير المباشرة وايضا نسبة مقاومة الشد بنسبة 81.36٪، متجاوزًا نسبة مقاومة الشد للخليط المشتمل على الإسفلت البترولي بنسبة 0.57٪.

الكلمات المفتاحية: الاسفلت الطبيعي، أضرار الرطوبة، المعالجة، الينابيع الكبريتية، الخواص الميكانيكية.

1. INTRODUCTION

Around 110 million tons of bitumen are required annually around the world. Bituminous pavements need a significant investment of time, money, and energy in construction, repair, and maintenance **(Garcia et al., 2010)**. Hot mix asphalt (HMA) pavement experiences many issues during its service life, such as short and long-term aging caused by the mixing, storage, transportation, and placement of asphaltic mixtures as well as the inadequate resources of bitumen **(Lu and Isacsson, 1998)**. Flexible pavements are most frequently distressed due to traffic loads, environmental effects, fatigue cracking, rutting, and low-temperature cracking **(Qadir, 2013; Al.ani and Al-bayati, 2017; Al-bayati and Lateif, 2017; Al-Azawee and Lateif, 2020; Samor and Sarsam, 2021).**

Recent research concentrated on improving The characteristics of NA through physical and chemical procedures for industrial applications. NA is an oil-based compound traveling through earth fissures from deep rock reservoirs to the surface. If NA reaches the earth's surface, it will cause bitumen springs, and If NA stays close to the surface, it will slowly oxidize, harden, and eventually become mineral bitumen, a solid and stiff substance. Rock asphalt, Trinidad Lake, and Gilsonite are the most widespread types of NA **(Ameri et al., 2011).**

Gilsonite, a bituminous mineral, is black, brittle, and easily ground into powder **(Ameri et al., 2011)**. The modifier gilsonite improves the bonding abilities and moisture resistance of HMA **(Kök et al., 2012; Nasrekani et al., 2017; Jahanian et al., 2017; Lv et al., 2018; Lv**

et al., 2019). Gilsonite is a naturally occurring, dark-colored hydrocarbon made from crude oil. Gilsonite is brittle and hard due to its chemical composition, which contains asphaltenes (around 70%) **(Kök et al., 2012)**. Gilsonite is less expensive than other modifiers, which can significantly lower the price of constructing a pavement **(Akbari Nasrekani et al., 2016)**. Added Gilsonite to the asphalt binder, increasing its viscosity and rigidity. **(Kök et al., 2011; Quintana et al., 2016)**. At high temperatures, gilsonite significantly improves the performance of asphalt binder; however, no positive effect has been observed at low and intermediate temperatures. **(Aflaki et al., 2014; Yilmaz et al., 2017; Ameri et al., 2018)**.
Trinidad Lake Asphalt (TLA) is renowned for having constant qualities, high viscosity and density, exceptional rheological characteristics, and the ability to mix effectively with other types of bitumen **(Fengler et al., 2019)**. Due to their similar chemical makeup, TLA and petroleum bitumen are compatible and have strong temperature stability, chemical stability (good oxidation resistance), and water stability (good adhesivity) **(Widyatmoko and Elliott, 2008; Feng et al., 2011)**. TLA is too hard to be used in bituminous blends alone, so it is typically blended in specific amounts with bitumen derived from petroleum **(Widyatmoko et al., 2005; Russel et al., 2008; Cao et al., 2009; Zou et al., 2020)**. Rock asphalt, a naturally occurring substance, can partially substitute conventional asphalt manufacturing HMA. Rock asphalt has generated interest across the globe as a result of its benefits in terms of lower prices and ease of use when making asphaltic mixtures. As a result of the actions of pressure, heat, oxidation, and bacteria over millions of years, petroleum or oil is infusing organically into rocks like limestone, creating rock asphalt. Therefore, asphalt binders and mineral fillers are the two major elements of rock asphalt. Rock asphalt is a dark substance readily crushable into powder **(Widyatmoko and Elliott, 2008)**. Due to its exceptional qualities, rock asphalt-modified asphalt has recently garnered interest in improving pavement performance **(Arisona et al., 2016; Lv et al., 2018; Cai et al., 2018; Shi et al., 2018; Chunmei et al., 2018).** Several studies have been conducted to evaluate the use of rock asphalt in producing HMA. **(Zeng et al., 2018)** investigated the behavior of a European rocky asphalt-modified mixture and found that the high-temperature behavior, temperature susceptibility, and aging resistance of asphalt binder all dramatically improved with increasing rock asphalt content. North American rock asphalt, which **(Huang, 2014)** examined in terms of its microstructure, changed mechanism, and viscoelastic behavior, revealed that the modification effect of rock asphalt was very good**.** According to (**Li et al., 2015),** rock asphalt can reduce the relaxation potential and increase the stiffness of bitumen mastics.
Iraqi NA is found in sulfur springs, especially in the northern and western regions along the banks of the Euphrates River. According to a study (**Mandeel, 2012)**, adding phosphogypsum and cement kiln dust with a particle size of 100 mm to NA (Eyeen Aljeebal) at weights of 10, 20, 30, and 40% improves its ductility and viscosity. The best amount of this additive was 40%. Additionally, the viscosity and ductility of asphalt samples when chlorinated at various times (0.5, 1, and 1.5 hours), the preferred duration of chlorination is 1.5 hours, with a 40% addition of the material combinations. **(Mahmood et al., 2007)** investigated the characteristics of asphalt collected from sulfur asphalt springs in the Heet area. They also examined the natural samples' ultraviolet rays (UV) and infrared spectroscopy (IR) and contrasted them with the spectra of comparable petroleum samples derived from the Al-Doura Refinery. The findings reveal that natural asphalt and asphalt samples produced by processing Iraqi oil share several characteristics. The UV and IR

analyses of the asphalt sample show the presence of heavy organic compounds present in asphalt obtained from refineries.
This study intends to benefit from the NA resources produced naturally in the west of Iraq, representing untapped national wealth. The study aimed to determine the physical properties of NA and apply industrial treatment to improve those properties before using NA as an asphalt binder in local paving.

2. MATERIALS

2.1 Traditional Asphalt

The most often used asphalt for paving in Iraq's central and southern regions is Asphalt Cement, with a penetration grade of 40–50 (AC (40–50)). It was delivered from the Al-Dora refinery, south of Baghdad.

2.2 Natural Asphalt

Two types of NA (soft and hard), as seen in **Fig. 1**, are transported from the Abu-Jeer region in Heet City, which is located in the western part of Iraq (Al-Anbar province). NA has considerably different physical characteristics than traditional asphalt produced in tightly regulated refineries. Notwithstanding the finding of a prior study by **(Muttar et al., 2009),** which claimed that the characteristics of springs NA are identical to those of industrial bitumen. Thus, using NA for flexible pavement production requires industrial treatments.

Figure 1. Natural Asphalt from Abu-Jeer (a) Hard NA and (b) Soft NA.

2.3 Fine and Coarse Aggregates

The aggregates required for this project are transported from the hot mix plant of Amanat Baghdad in Daurah. According to the **(SCRB, 2003),** coarse aggregate has been produced in a variety of sizes ranging from ¾ in. (19mm) to No. 4 (4.75mm), and fine aggregate sizes range from No. 4 to No. 200. Aggregates were sieved and recombined in the lab to make the chosen gradation to create an identical, regulated gradation. The chosen gradation is depicted in **Fig. 2. Table 1.** displays the aggregates' physical characteristics.

Table 1. Physical Characteristics of Aggregates (Coarse and Fine).

Property	ASTM Specification	Results	Specification Limits **(SCRB, 2003)**
Coarse Aggregate			
Wearing (Los Angeles Abrasion), %	C-131	12.7	30 Max
Bulk Specific Gravity	C-127	2.61	---
Water Absorption, %	C-127	0.22%	---
Fractured Pieces,%	D-5821	97	90 Min
Flat and Elongated Particles,%	D-4791	4	10 Max
Fine Aggregate			
Water Absorption, %	C-128	1%	---
Bulk Specific Gravity	C-128	2.655	---

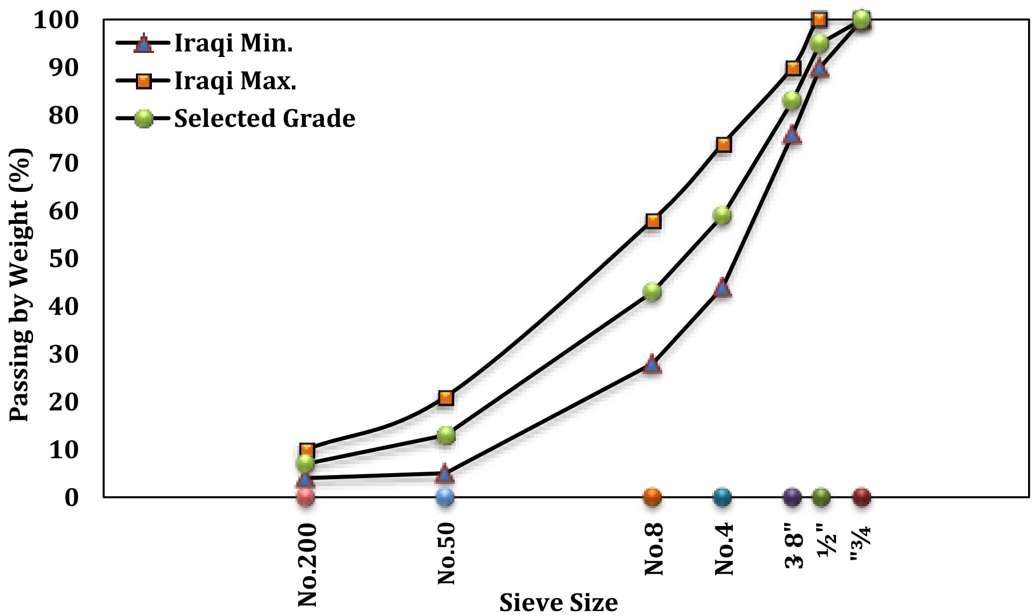


Figure 2. Aggregate Gradation Curve for Wearing Layer.

2.4 Mineral Filler

The limestone filler of the study was shipped from a lime factory in Karbala, located in Iraq's southeast. Based on laboratory tests, the specific gravity of limestone filler was 2.7, and the limestone particles passing through sieve no. 200 were larger than 95 percent of the total weight.

3. Test Program

3.1 Natural Asphalt Treatment

The first stage of treatment for soft NA (SNA) involved stirring it in 500 ml steel containers throughout the two hours of oxidation in a hot oven at a temperature of 110 °C to ensure water expulsion. After the water has been removed from SNA, it is essential to do several tests to determine the substance's physical characteristics and whether employing NA in local HMA is appropriate. The two different NA (soft and hard) were mixed in a mixer at a constant temperature of 170°C for an hour at 1000 revolutions per minute **(Erkus et al., 2020)** during the second stage of treatment, as shown in **Fig. 3**. On the top of the cap, there is a thermostat attached to the heater plate that is submerged in bitumen through a channel. This process was done to get a mixture with penetration grade that meets the requirements of Iraqi specifications and then added to the conventional asphalt by 20, 40, 60, and 80% by weight of bitumen.

Figure 3. High Shear Mixer.

3.2 Asphalt Traditional Tests

To evaluate the performance of NA, tests such as penetration, flash point, softening point, specific gravity, and ductility were conducted following ASTM D-5, ASTM D-92, ASTM D-36, ASTM D-70, and ASTM D-113, respectively. The previous asphalt tests were conducted for traditional asphalt, soft NA (SNA), hard NA (HNA), hard and soft NA (HSNA) after they were mixed in the mixer and HSNA that was treated by mixing with traditional asphalt in several percentages. Bituminous mixtures containing 20%, 40%, 60%, and 80% HSNA are denoted as 20NA, 40NA, 60NA, and 80NA, respectively.

3.3 Thermo Scientific- Axia ChemiSEM Test

The elemental analysis of AC (40–50), NA, and treated NA was conducted using the Thermo Scientific Axia ChemiSEM Scanning Electron Microscope device, as seen in **Fig. 4**. Compared to conventional Scanning Electron microscopy (SEMs), the Thermo Scientific Axia ChemiSEM continuously gathers energy dispersive X-ray spectroscopy (EDS) data in the background. It processes the SEM and EDS data concurrently using special algorithms, enabling it to simultaneously display the morphology and elemental composition of the sample in real-time.

Figure 4. Thermo Scientific Axia ChemiSEM**.**

EDS analysis, or EDX analysis, is an effective method for examining chemical composition at the microscale. EDS analyzes the X-rays produced when an electron beam scans over a sample in conjunction with scanning electron microscopy (SEM). This method can identify almost all of the elements in the periodic table. Applications ranging from process and quality control to failure analysis and basic research depend on the data offered by EDS**.** One elemental analysis technique that uses the distinctive X-rays produced by an electron beam is called elemental mapping. By depicting the distinctive X-ray intensities or elemental concentrations in two dimensions, the approach makes the distribution of the constituent elements in the specimen visible. In EDS, the characteristic X-ray spectra produced by the electron beam are recorded pixel by pixel when the electron beam is two-dimensionally scanned across a specimen area. To create an elemental map, these spectra depict pixel-by-pixel the target elements' computed concentrations or X-ray intensities **(Vesseur, 2019)**.

3.4 Marshall Test

Specimens are prepared, compacted, and tested using the ASTM D6927-15 Marshall procedure. For each specimen, the aggregate gradation for the wearing course is mixed. After two hours of heating, the asphalt cement and aggregates are combined at temperatures up to 135 °C and 150 °C, respectively. The heated aggregate was coated with asphalt cement by adding various amounts of asphalt (4, 4.5, 5, 5.5, and 6% by aggregate weight). The mix was stirred for at least three minutes to achieve homogeneity; the aggregates were entirely covered with asphalt cement. In the Marshall test, a hot mixture is placed in the mold and compacted by a Marshall hammer for 75 blows on both sides of the specimen. Standard cylindrical molds measuring 102 mm in diameter and 64 mm in height are used, and they have been heated to 130°C for the test.

3.5 Moisture Damage Test

The adhesive and cohesive deterioration brought on by moisture in asphalt concrete can weaken the bonds between the aggregate and bitumen, reducing the load-bearing capacity of the pavement **(Caro et al., 2008)**. The ASTM D 4867M-96 is used in this study to determine how moisture-sensitive asphalt concrete is. Six specimens with an air-void percentage of 7±1 % for each type of combination were selected. According to NCHRP Report No. 425 guidelines, each combination should be compacted to 7±1 % void before the test begins by adjusting the number of blows. In this research study, each mix should be compacted by adjusting the number of blows on 42 blows to reach the 7±1 % air voids. Three samples were put through a vacuum saturation at a level of 55–80% saturation, a 16-hour freeze-thaw cycle at -18°C, and a 24-hour immersion in a water bath at 60°C, then soaking in a water bath for 1 hour at 25±1 C° to adjust the temperature of the conditioned samples. The other three samples were submerged for 20 minutes in a 25 °C water bath. The tensile strength ratio, also known as the TSR, is calculated by dividing the tensile strength of the samples in the conditioned state by the tensile strength of the samples in the normal condition. The following Eqs. (1). and (2). can be used to determine the TSR value

$$ITS = \frac{2000*P}{\pi\ t\ D} \tag{1}$$

$$TSR = \frac{ITS\ con.}{ITS\ uncod.} * 100 \tag{2}$$

where:

ITS is the indirect tensile strength, KPa
P is the applied load required to fail the sample, N
t is the sample height, mm
D is the sample diameter, mm.
TSR is the tensile strength ratio, %
ITS_{cond} is the average ITS of the moisture-conditioned groups, KPa
ITS_{uncond} is the average ITS of the moisture-unconditioned groups, KPa

4. RESULTS AND DISCUSSION

4.1 Asphalt Properties

The physical characteristics of AC (40–50), HNA, and SNA after water removal are depicted in **Table 3.** It should be noted that SNA displays high penetration and low viscosity values, so it cannot be used to produce HMA instead of traditional asphalt. On the other hand, HNA shows a very hard texture as its penetration value is less than the lower limit of the Iraqi specifications **(SCRB, 2003).**
The SNA was treated by combining it with various proportions of HNA to obtain a mixture (HSNA) with a penetration grade that meets Iraqi specifications **(SCRB, 2003)**. After several attempts, the appropriate mixing ratio was determined to be 55% HNA and 45% SNA. As indicated in **Table 4,** HSNA does not meet the specification limits, so it was mixed with traditional asphalt in different proportions (20, 40, 60, and 80%) to enhance its properties. The results demonstrated an improvement in the physical properties of HSNA, and it met Iraqi criteria for asphalt used in flexible pavement construction. As a result, HSNA can be employed as a building material in asphalt concrete constructions.

Table 3. Physical Properties of Traditional Asphalt (40-50) and NA.

Test	Units	Results			Specification Limits (**SCRB, 2003)**
		AC (40-50)	SNA	HNA	
Penetration, (25 °C, 100g, 5 sec)	1/10 mm	47	203	3	40 – 50
Ductility, (25°C, 5 cm/min)	cm	>150	150>	0	≥ 100
Softening Point	°C	52	32	79	-
Flash Point	°C	245	175	230	232 min.
Specific Gravity, at 25 C°	-	1.02	0.98	1.1	-
Rotational viscosity, at 135 C°	Pa.s	0.488	0.206	-	-

Table 4. Physical Properties of HSNA after Treatment.

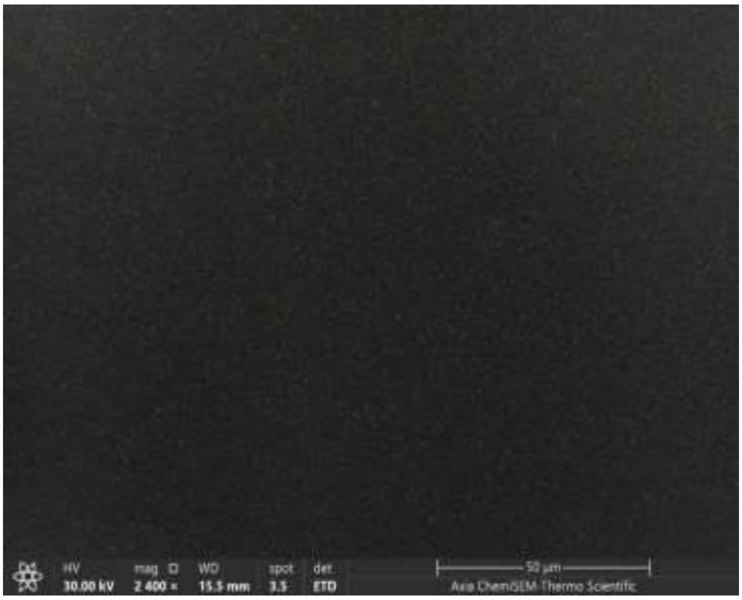
Test	Results					Specification Limits **[SCRB, 2003]**
	HSNA	20NA	40NA	60NA	80NA	
Penetration, 1/10 mm	43	46	45.4	44.8	44	40 – 50
Ductility, cm	93	139	132	111	102	≥ 100
Softening Point, C°	56	52	53	54	55	-
Flash Point, C°	210	245	240	235	230	232 min.
Specific Gravity	1.06	1.027	1.032	1.04	1.045	-

4.2 Thermo Scientific- Axia ChemiSEM Test Results

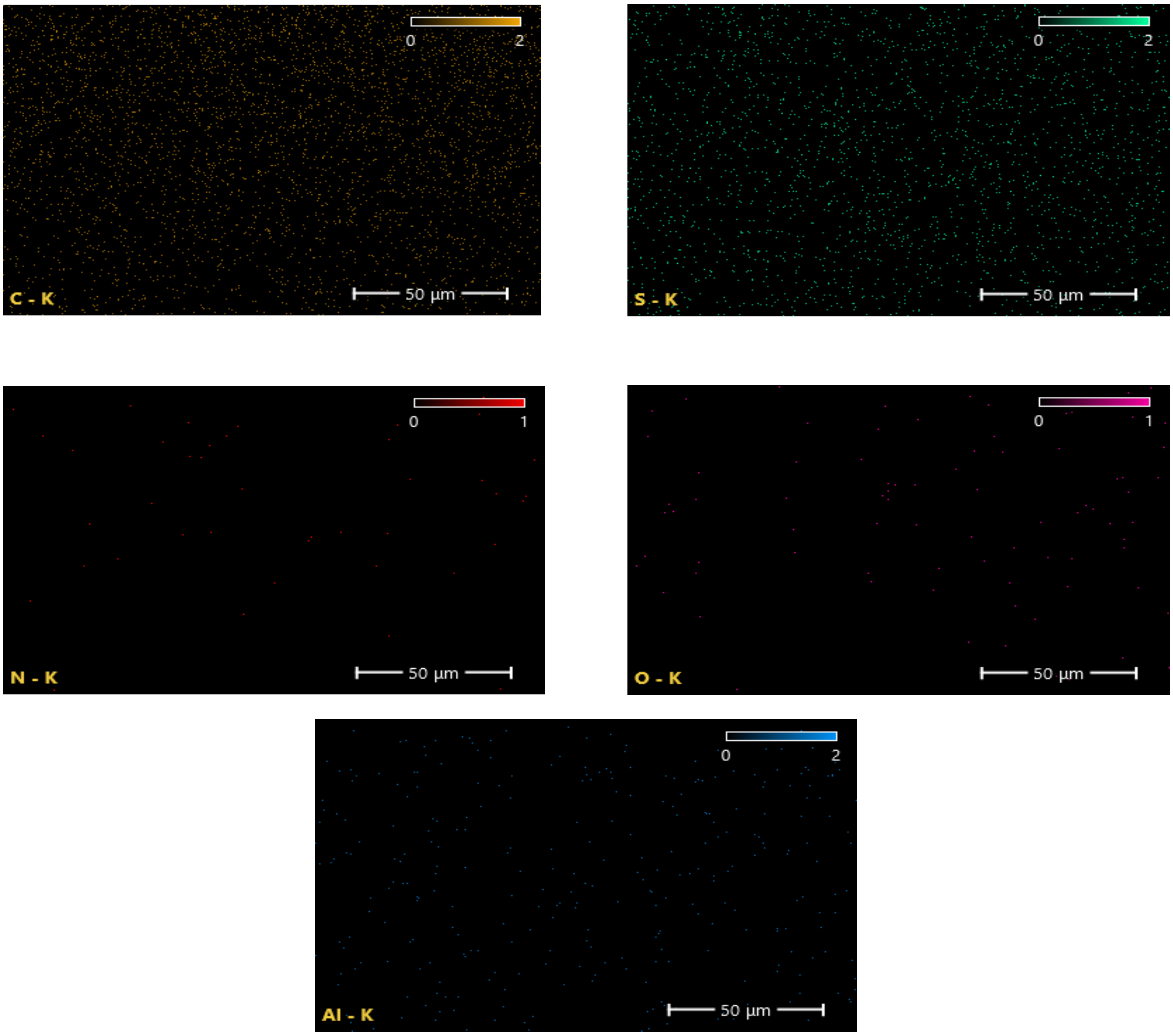
It is necessary to understand the chemical makeup of the NA and determine whether it is similar to that of conventional asphalt obtained from crude petroleum refineries to have widespread use of the NA for excellent performance. **Table 5** shows the EDS elemental analysis of AC (40–50), NA, and treated NA. The results revealed that the NA and treated NA had larger heteroatoms, such as O, N, and S. The heteroatoms and their composition significantly impact the chemical and physical characteristics of asphalt binders. This will increase the stiffness of the binder. The larger amount of heteroatoms and, consequently, the higher degree of association and molecular organization in this NA may cause its improved high-temperature characteristics (better rutting resistance) **(Michalica et al., 2008)**. The Axia ChemiSEM test results also show the different morphology and EDS elemental mapping. **Figs. 5, 6, and 7** depict the Axia ChemiSEM micrograph and EDS elemental mapping of AC (40-50), HNA, and SNA, respectively. The EDS elemental mapping shows the elements' spread on each binder's surface.

Table 5. Elemental Analysis of AC (40-50), NA, and Treated NA.

	Carbon (C), %	Oxygen (O), %	Nitrogen (N), %	Sulfur (S), %	Aluminum (Al),%	Silicon (Si), %	Calcium (Ca), %
AC(40-50)	82.8	3.4	4.6	8.4	0.8	-	-
SNA	80.6	3	5.2	9.4	1.8	-	-
HNA	77.1	8.1	4.9	7.3	0.5	0.6	1.5
HSNA	78.1	7	5.4	7.7	0.9	0.3	0.6
20NA	83.5	3.8	4.9	7.8	-	-	-
40NA	79.6	6.2	5.2	8.2	0.8	-	-
60NA	78.3	6.8	5	8.5	0.8	-	0.6
80NA	78	7.2	5.3	8.6	0.9	-	-



(a) Axia ChemiSEM Micrograph.



(b) EDS Elemental Maps of Micrograph in (a)

Figure 5. Axia ChemiSEM Micrograph and EDS Elemental Maps of AC(40-50)

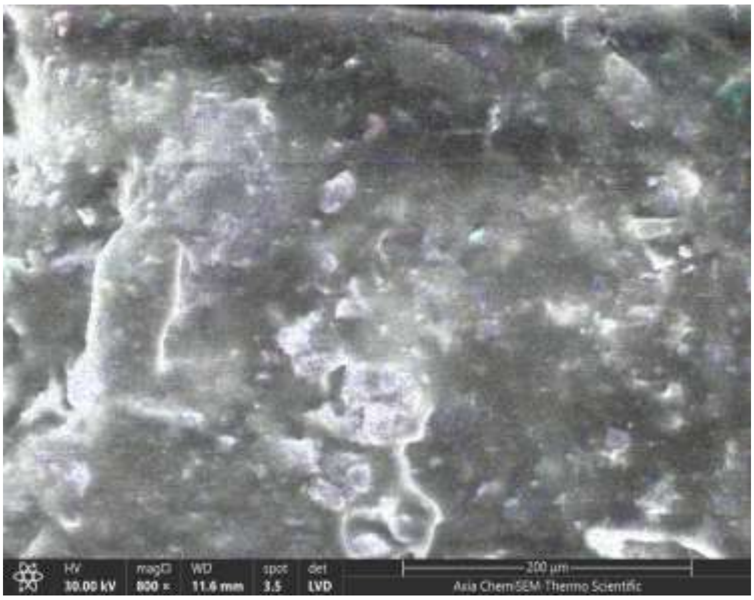
4.3 Marshall Properties

The traditional and treated HSNA mixtures were prepared with optimum asphalt content (4.96%). Air voids (AV), voids filled with asphalt (VFA), voids in mineral aggregates (VMA), and bulk density are given in **Table 6.** All the mixtures meet the Iraqi specification **(SCRB, 2003)** regarding volumetric properties.

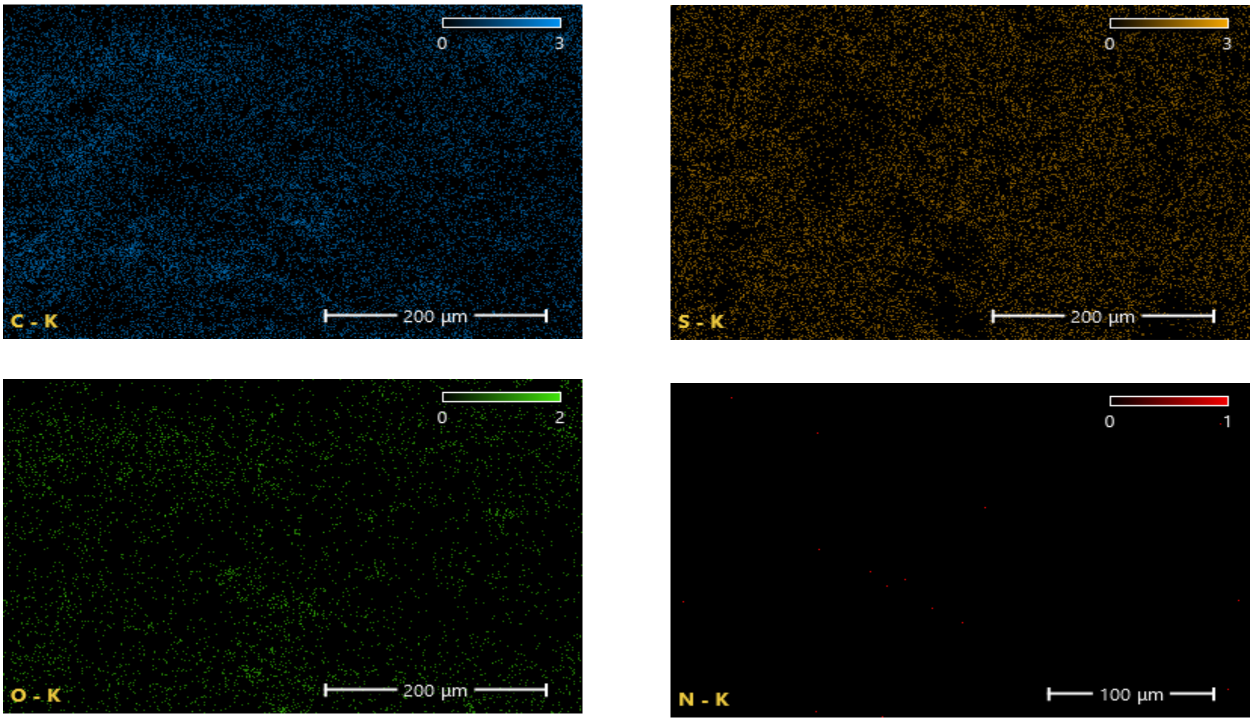
Table 6. Volumetric Properties of Mixtures.

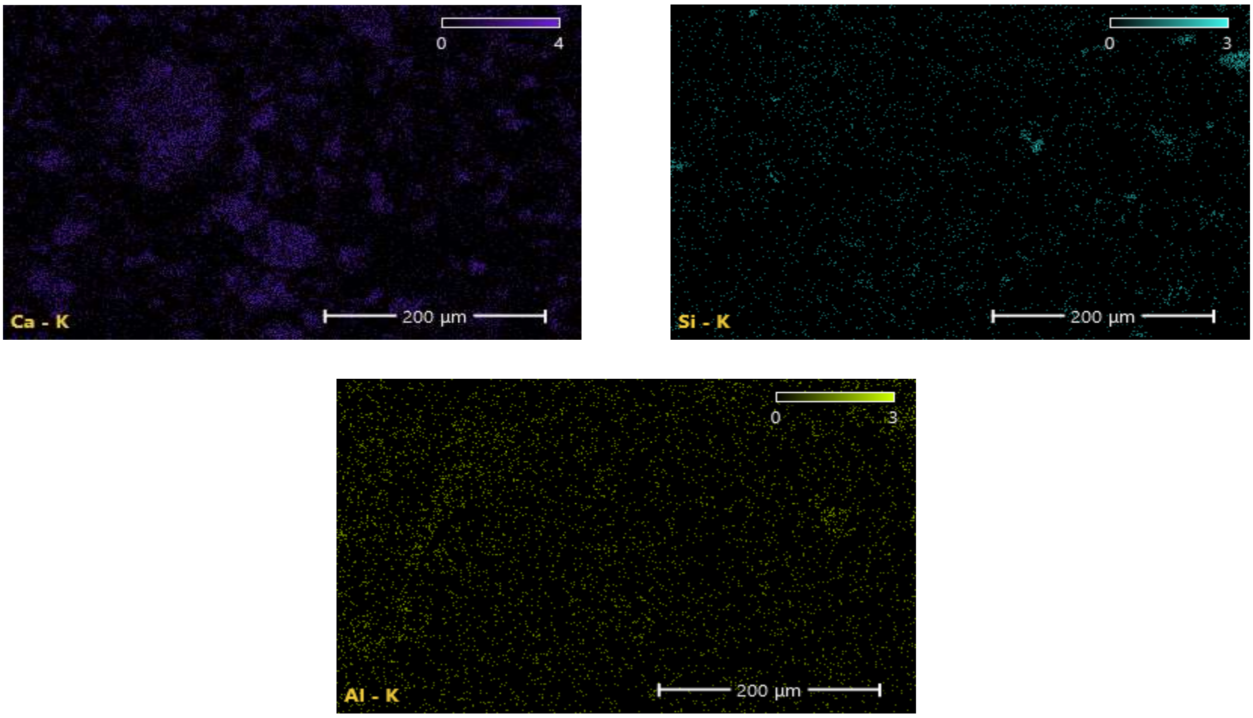
Mixture Properties	Specification Limits **[SCRB, 2003]**	Mixture Type				
		AC(40, 50)	20NA	40NA	60NA	80NA

Bulk Density	-	2.3404	2.34	2.339	2.337	2.336
AV, %	3-5	4.1	4.11	4.14	4.22	4.26
VMA, %	14 Min	15.7	15.7	15.73	15.8	15.84
VFA, %	-	73.9	73.8	73.7	73.3	73.1



(a) Axia ChemiSEM Micrograph.

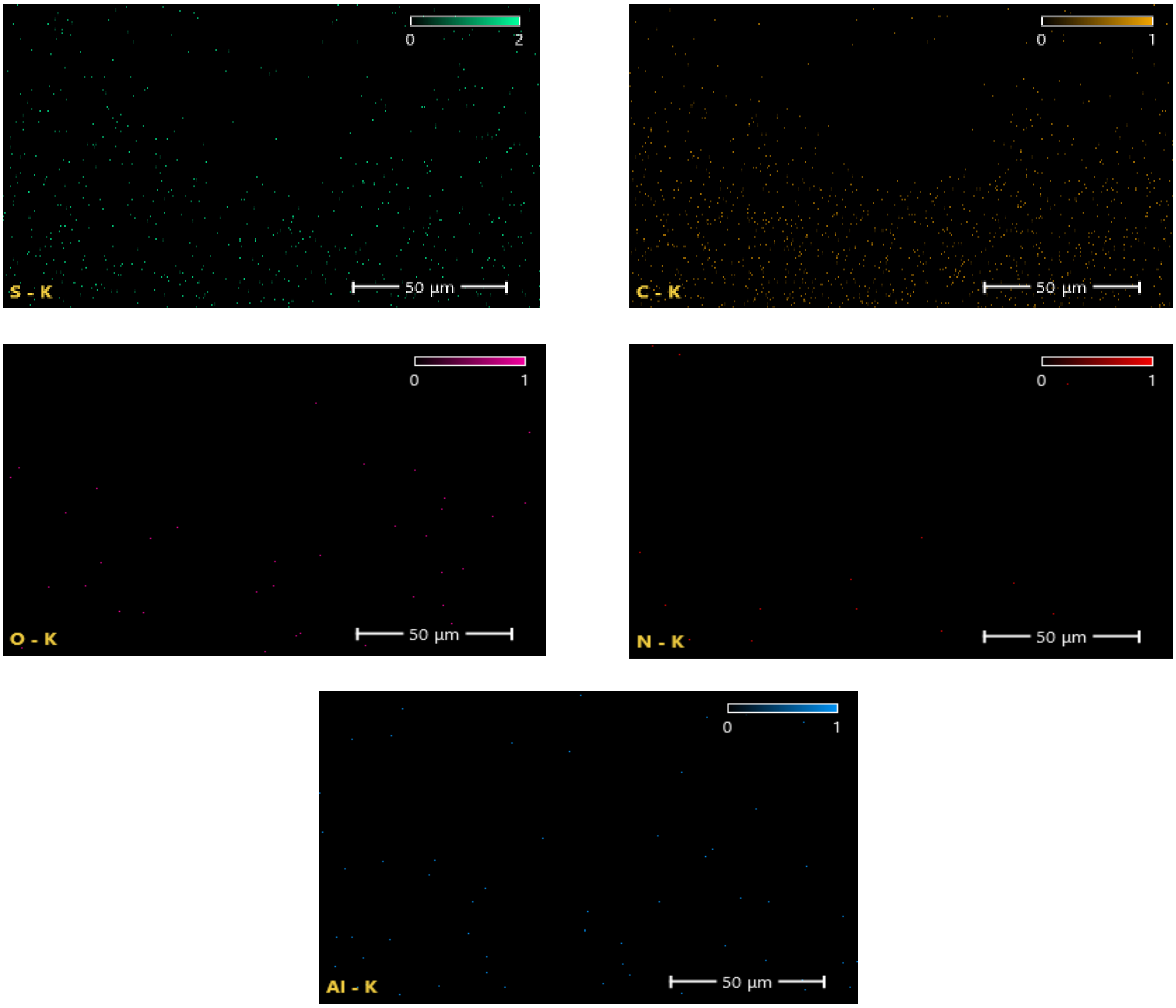




(b) EDS Elemental Maps of Micrograph in (a)

Figure 6. Axia ChemiSEM Micrograph and EDS Elemental Maps of HNA.

(a) Axia ChemiSEM Micrograph.



(b) EDS Elemental Maps of Micrograph in (a)

Figure 7. Axia ChemiSEM Micrograph and EDS Elemental Maps of SNA.

The ASTM D 6927 standard was followed when conducting the Marshall stability and flow test, a performance indicator for bituminous mixtures. **Figs. 8 and 9** depict the Marshall stability and Marshall stiffness index for all mixtures. The results are the averages of three samples. Comparing the stability of the mixes to the traditional mix, adding 20%, 40%, 60%, and 80% HSNA increases stability by 2.5%, 8.2%, 18.7%, and 23.5%, respectively. The change in the Marshall stiffness index, which measures the mixtures' rigidity, performed similarly to that of the stability. The 80NA mixture has 6% more stiffness than the traditional mix.

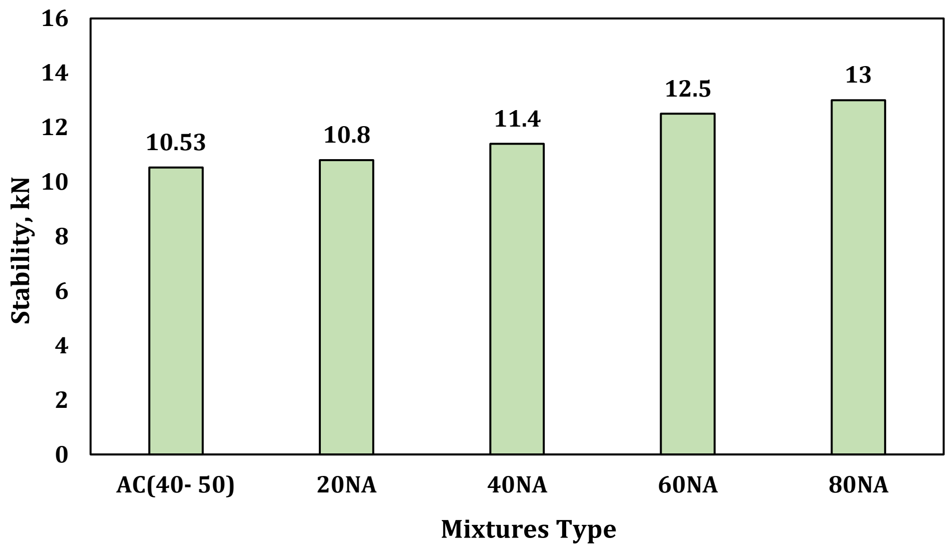


Figure 8. Marshall Stability Results.

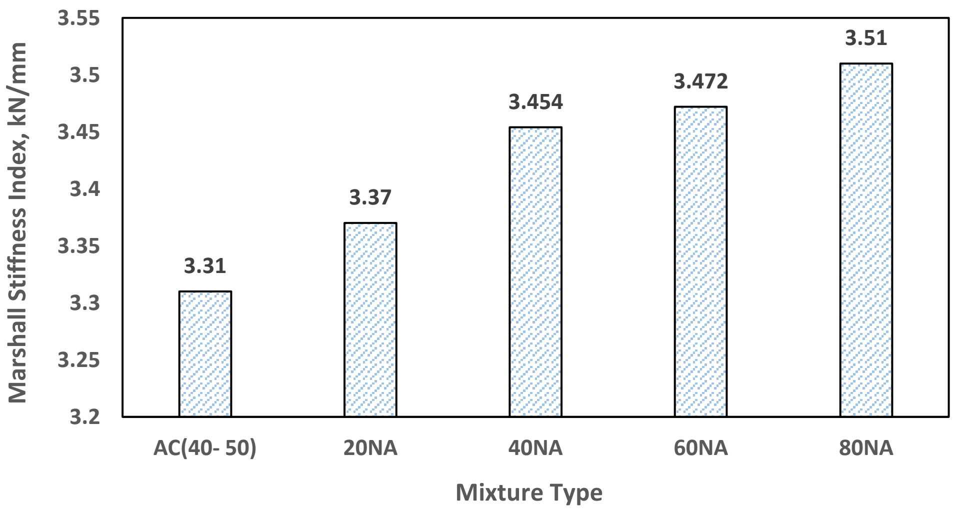


Figure 9. Marshall stiffness index Results.

4.4 Moisture Damage Resistance

Fig. 10 provides the tensile strength values for all mixture types for unconditioned (dry) and conditioned specimens. According to the results, the mixture with 80% HSNA had better dry and conditioned tensile strength values than other mixtures among the specimens because adding HSNA stiffens the binder. Hence, the stiffness of the mixtures is increased by adding binders that have been treated with HSNA. As a result, adding HSNA to mixtures causes an increase in ITS. **Fig. 11** displays the TSR values for each type of mixture used in this study. Based on TSR values, all mixtures satisfied the Superpave requirements for the 80% lower TSR value limit. The mixture with 80% HSNA has the best TSR value. Moreover, it is slightly greater (by 0.57%) than the TSR of the traditional mixture.

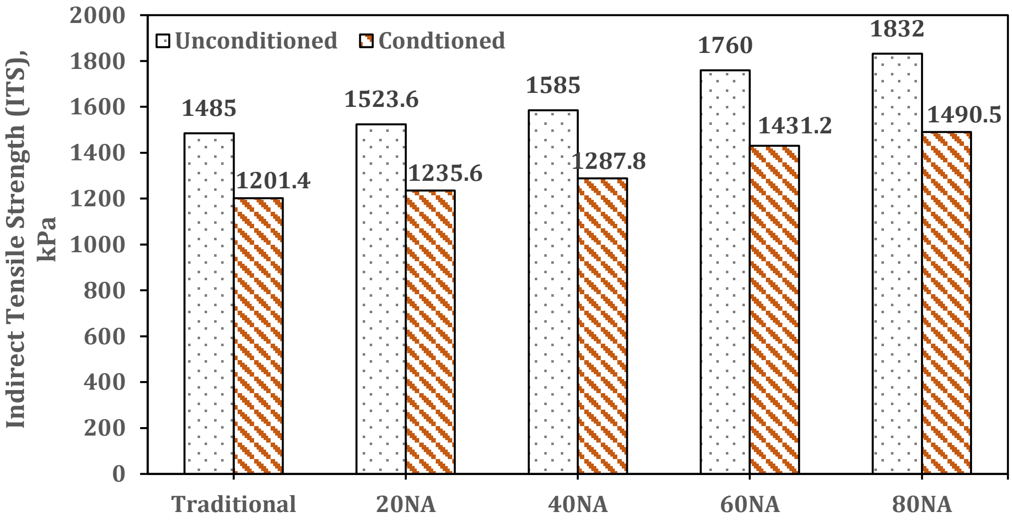


Figure 10. The ITS for Unconditioned and Conditioned Mixtures.

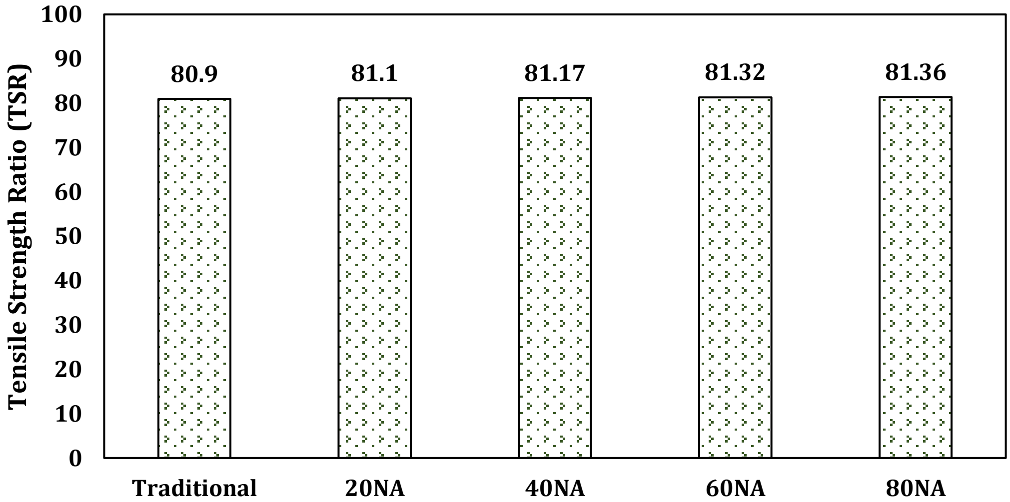


Figure 11. TSR for Traditional and HSNA-Treated Mixtures.

5. CONCLUSIONS

In this study, NA was treated by mixing two types of NA (SNA and HNA) and then mixing it with different proportions of refined asphalt. The necessary tests were carried out for NA after receiving industrial treatments to determine its physical and chemical properties to be used for paving work. Bituminous mixes made with binders containing 20, 40, 60, and 80% NA by asphalt weight were subjected to mechanical testing, and the performances of the mixtures were compared. The following are the main conclusions:

1. The resulting HSNA had a penetration grade that met Iraqi requirements. After treating HSNA with petroleum asphalt, the physical properties of HSNA were enhanced. As a result, combining HSNA with refined asphalt in various proportions could yield asphalt that meets Iraqi specifications for asphalt used in road construction.

2. Mixtures with HSNA have Marshall stability greater than traditional mixtures by 2.5%, 8.2%, 18.7%, and 23.5% for mixtures 20NA, 40NA, 60NA, and 80NA, respectively. According to the Marshall stiffness index, the 80NA mixture showed a 6% stiffer behavior than the traditional mixture.

3. The treated HSNA mixture had the highest ITS values before and after conditioning. All mixes met the Superpave specifications for the 80% lower TSR value limit, and the 80NA mixture has the highest TSR. Moreover, it is slightly higher (by 0.57%) than the TSR of the traditional mixture.

NOMENCLATURE

Symbole	Description	Symbole	Description
ASTM	American Society for Testing and Materials	TSR	Tensile strength ratio
AC (40–50)	Asphalt Cement with Penetration Grade (40-50)	TLA	Trinidad Lake Asphalt
AV	Voids in Total Mix	VFA	Voids Filled with Asphalt
HNA	Hard Natural Asphalt	VMA	Voids in Mineral Aggregate
HSNA	Mix of Hard and Soft Natural Asphalt	20NA	Bituminous mixture containing 20% HSNA
HMA	Hot mix asphalt	40NA	Bituminous mixture containing 40% HSNA
ITS	Indirect Tensile Strength	60NA	Bituminous mixture containing 60% HSNA
NA	Natural Asphalt	80NA	Bituminous mixture containing 80% HSNA
SNA	Soft Natural Asphalt		

REFERENCES

Aflaki, S., Hajikarimi, P., Fini, E.H., and Zada, B., 2014. Comparing Effects of Biobinder with Other Asphalt Modifiers on Low-Temperature Characteristics of Asphalt. *Journal of Materials in Civil Engineering*, *26*(3), pp. 429–439. Doi:10.1061/(asce)mt.1943-5533.0000835

Akbari Nasrekani, A., Naderi, K., Nakhaei, M., and Mahmoodinia, N., 2016. High-temperature performance of gilsonite-modified asphalt binder and asphalt concrete. *Petroleum Science and Technology*, *34*(21), pp. 1783–1789. Doi:10.1080/10916466.2016.1230750.

AL-Azawee, E.T., and Latief, R.H., 2020. The Feasibility of Using Styrene-Butadiene- Styrene (SBS) as Modifier in Iraqi Bituminous Binder. *Journal of Engineering Science and Technology,* 15(3), pp. 1596 – 1607.

Al.ani, A.F.H., and Al-bayati, A.H.K., 2017. Influence of temperature upon permanent deformation parameters of asphalt concrete mixes. *Journal of Engineering*, 23(7), pp. 14-32. . Doi:10.31026/j.eng.2017.07.02.

Al-bayati, A.H.K., and Lateif, R.H., 2017. Evaluating the Performance of High Modulus Asphalt Concrete Mixture for Base Course in Iraq. *Journal of Engineering*, 23(6), pp. 14–33. Doi:10.31026/j.eng.2017.06.02.

Ameri, M., Mansourian, A., Ashani, S.S., and Yadollahi, G., 2011. Technical study on the Iranian Gilsonite as an additive for modification of asphalt binders used in pavement construction. *Construction and Building Materials*, *25*(3), pp. 1379–1387. Doi:10.1016/j.conbuildmat.2010.09.005.

Ameri, M., Mirzaiyan, D., and Amini, A., 2018. Rutting Resistance and Fatigue Behavior of Gilsonite-Modified Asphalt Binders. *Journal of Materials in Civil Engineering*, *30*(11), pp. 1–9. Doi:10.1061/(asce)mt.1943-5533.0002468.

Arisona, A., Nawawi, M., Nuraddeen, U. K., and Hamzah, M., 2016. A preliminary mineralogical evaluation study of natural asphalt rock characterization, southeast Sulawesi, Indonesia. *Arabian Journal of Geosciences*, *9*(4), pp. 1–9. Doi:10.1007/s12517-015-2288-3.

Caro, S., Masad, E., Bhasin, A., and Little, D. N., 2008. Moisture susceptibility of asphalt mixtures, Part 1: Mechanisms. *International Journal of Pavement Engineering*, *9*(2), pp. 81–98. Doi:10.1080/10298430701792128.

Cao, W. D., Yao, Z. Y., Liu, S. T., and Cui, X. Z., 2009. Performance of modified asphalt with Trinidad Lake Asphalt used as a waterproofing material for bridge deck pavement. *Journal of Testing and Eval*uation, 37(5), pp. 463–467. Doi:10.1520/JTE000355.

Cai, L., Shi, X., and Xue, J., 2018. Laboratory evaluation of composed modified asphalt binder and mixture containing nano-silica/rock asphalt/SBS. *Construction and Building Materials*, *172*, pp. 204–211. Doi:10.1016/j.conbuildmat.2018.03.187.

Chunmei, Z., Yuntao, L., Xiaowei, C., Shihan, L., Xiaoyang, G., Huijie, Z., and Yun, L.S., 2018. Effects of plasma-treated rock asphalt on the mechanical properties and microstructure of oil-well cement. *Construction and Building Materials*, 186, pp. 163–173. Doi:10.1016/j.conbuildmat.2018.07.133

erkuş, Y., Kök, B., And Yilmaz, M., 2020. The Effects of Iraq Natural Asphalt on Mechanical Properties of Bituminous Hot Mixtures. *Teknik Dergi*, 33(2), pp. 11641–11660. Doi:10.18400/tekderg.664187.

Fengler, R. Z., Osmari, P. H., Leite, L. F. M., Nascimento, L. A. H. do, Fritzen, M. A., and Aragão, F. T. S., 2019. Impact of the addition of Trinidad Lake Asphalt (TLA) on the rheological and mechanical behavior of two asphalt binders. *Road Materials and Pavement Design*, *20*(2), pp. S827–S840. Doi:10.1080/14680629.2019.1633789.

Feng, X., Zha, X., and Hao, P., 2011. Research on design technology of TLA modified asphalt mixture. *Open Materials Science Journal*, *5*, pp. 140–146. Doi:10.2174/1874088X01105010140.

García, Á., Schlangen, E., van de Ven, M., and Sierra-Beltrán, G., 2010. Preparation of capsules containing rejuvenators for their use in asphalt concrete. *Journal of Hazardous Materials,* 184(1–3), pp. 603–611. Doi:10.1016/j.jhazmat.2010.08.078.

Huang, W., 2014. Research on Characteristic Behavior for North American Rock Asphalt and Asphalt Mixtures. Doctoral dissertation*, South China University of Technology)*.

Jahanian, H. R., Shafabakhsh, G., and Divandari, H., 2017. Performance evaluation of Hot Mix Asphalt (HMA) containing bitumen modified with Gilsonite. *Construction and Building Materials*, *131*, pp. 156–164. Doi:10.1016/j.conbuildmat.2016.11.069.

Kök, B. V., Yilmaz, M., and Guler, M., 2011. Evaluation of high temperature performance of SBS + Gilsonite modified binder. *Fuel*, *90*(10), pp. 3093–3099. Doi:10.1016/j.fuel.2011.05.021.

Kök, B. V., Yílmaz, M., Turgut, P., and Kuloğlu, N., 2012. Evaluation of the mechanical properties of natural asphalt-modified hot mixture. *International Journal of Materials Research*, *103*(4), pp. 506–512. Doi:10.3139/146.110654.

Lu, X., and Isacsson, U., 1998. Chemical and rheological evaluation of ageing properties of SBS polymer modified bitumens. *Fuel, 77*(9–10), p. 961–972. Doi:10.1016/s0016-2361(97)00283-4.

Lv, Q., Huang, W., Sadek, H., Xiao, F., and Yan, C., 2019. Investigation of the rutting performance of various modified asphalt mixtures using the Hamburg Wheel-Tracking Device test and Multiple Stress Creep Recovery test. *Construction and Building Materials*, *206*, pp. 62–70. Doi:10.1016/j.conbuildmat.2019.02.015.

Lv, Q., Huang, W., Tang, N., and Xiao, F., 2018. Comparison and relationship between indices for the characterization of the moisture resistance of asphalt–aggregate systems. *Construction and Building Materials*, *168*, pp. 580–589. Doi:10.1016/j.conbuildmat.2018.02.177.

Lv, S., Wang, S., Guo, T., Xia, C., Li, J., and Hou, G., 2018. Laboratory evaluation on performance of compound-modified asphalt for rock asphalt/Styrene-Butadiene Rubber (SBR) and Rock Asphalt/Nano-CaCO3. *Applied Sciences (Switzerland)*, *8*(6), P. 1009. Doi:10.3390/app8061009.

Li, R., Karki, P., Hao, P., and Bhasin, A., 2015. Rheological and low temperature properties of asphalt composites containing rock asphalts. *Construction and Building Materials*, *96*, pp. 47–54. Doi:10.1016/j.conbuildmat.2015.07.150.

Mandeel, T.A.J., 2012. Viscosity and ductility improvement of natural asphalt in (Heet-Anbar) areas using industrial waste for the purpose of recycling. *Tikrit Journal of Pure Science*, *17*(4), pp.120-128.

Mahmood, B. A. A., Abdul-kareem, A. H., and Yasser, A. A. M., 2007. Studying the possibility of investing in sulfur springs in the Heet region for building and construction purposes. *Iraqi Journal of Civil Engineering*, 9(1), pp. 14- 3. In Arabic.

Muttar, A. A., Zedan, T. A., and Mahmood, B. A., 2009. Analytical Comparison Study for Asphalt and Water of Heet Sulphurous Springs, *Journal of University of Anbar for Pure Science*, 3(1). (in Arabic)

Nasrekani, A.A., Nakhaei, M., Nader, K., Fini, E., and Aflaki, S., 2017. Improving moisture sensitivity of asphalt concrete using natural bitumen (Gilsonite). In Proceedings of the Transportation Research Board (TRB 2017), the 96th Annual Meeting Washington, DC USA (pp. 8-12).

Qadir, A., 2013. Rutting performance of polypropylene modified asphalt concrete*, International Journal of Civil Engineering,* 12(3), pp.304–312.

Quintana, H. A. R., Noguera, J. A. H., and Bonells, C. F. U., 2016. Behavior of Gilsonite-Modified Hot Mix Asphalt by Wet and Dry Processes. *Journal of Materials in Civil Engineering*, *28*(2), P. 04015114. Doi:10.1061/(asce)mt.1943-5533.0001339.

Russel, M., Uhlmeyer, J.S., Anderson, K., and Weston, J., 2008. Evaluation of Trinidad Lake Asphalt Overlay Performance. (No. WR-RD 710.1).

SCRB/R9, 2003. General Specification for Roads and Bridges, Section R/9, Hot-Mix Asphalt Concrete Pavement, Revised Edition, State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq.

Samor, Z. A. and Sarsam, S. I., 2021 Assessing the Moisture and Aging Susceptibility of Cold Mix Asphalt Concrete. *Journal of Engineering*, 27(2), pp. 59–72. Doi:10.31026/j.eng.2021.02.05.

Shi, X., Cai, L., Xu, W., Fan, J., and Wang, X., 2018. Effects of nano-silica and rock asphalt on rheological properties of modified bitumen. *Construction and Building Materials*, *161*, pp. 705–714. Doi:10.1016/j.conbuildmat.2017.11.162.

Vesseur, E.J., 2019. Live color SEM imaging. *Microscopy and Microanalysis*, 25(S2), pp.562-563. Doi:10.1017/S1431927619003544.

Widyatmoko, I., and Elliott, R., 2008. Characteristics of elastomeric and plastomeric binders in contact with natural asphalts. *Construction and Building Materials*, *22*(3), pp. 239–249. Doi:10.1016/j.conbuildmat.2005.12.025.

Widyatmoko, I., Elliott, R. C., and Read, J. M., 2005. Development of heavy-duty mastic asphalt bridge surfacing, incorporating trinidad lake asphalt and polymer modified binders. *Road Materials and Pavement Design*, *6*(4), pp. 469–483. Doi:10.1080/14680629.2005.9690016.

Yilmaz, M., and Erdoğan Yamaç, Ö., 2017. Evaluation of Gilsonite and Styrene-Butadiene-Styrene Composite Usage in Bitumen Modification on the Mechanical Properties of Hot Mix Asphalts. *Journal of Materials in Civil Engineering*, 29(9), P. 04017089. Doi:10.1061/(asce)mt.1943-5533.0001938 .

Zou, G., Xu, X., Li, J., Yu, H., Wang, C., and Sun, J., 2020. The effects of bituminous binder on the performance of gussasphalt concrete for bridge deck pavement. *Materials*, *13*(2), P. 364. Doi:10.3390/ma13020364.

Zhang, C., Li, Y., Cheng, X., Liang, S., Guo, X., Zhao, H., and Song, Y., 2018. Effects of plasma-treated rock asphalt on the mechanical properties and microstructure of oil-well cement. *Construction and Building Materials*, *186*, pp. 163–173. Doi:10.1016/j.conbuildmat.2018.07.133.