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# A Review of the Use of Natural Asphalt in Hot Mix Asphalt for Flexible Pavement Construction

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ABSTRACT

*Natural asphalt is a very important material that has been in use by man for various purposes for centuries. There are numerous advantages, such as being more environmentally friendly as opposed to artificial alternatives, great versatility, and cost-effectiveness, that make it an important natural resource. The use of asphalt mixtures should be tailored within target limits to improve the serviceability of flexible pavements by enhancing their ability to withstand rutting, waviness, fatigue cracking, or moisture damage, which in turn can present opportunities for cost savings and pollution reduction. Most of the work has focused on the application of NAs in asphaltic formulations, considering their good performance in these systems and the binding properties of the mixtures. The primary goals of this research are to examine previous related studies about the use of natural asphalt in the manufacturing of hot-mixed asphalt for the construction of flexible highway pavement and to use some types of natural asphalt in the modification of petroleum asphalt cement properties. This study deals with the description of the resources and uses of natural asphalt in the production of hot-mix asphalt to construct flexible pavements. According to past related studies, the use of natural asphalt as a modifier with petroleum asphalt cement showed improvement of asphalt and hot mixture properties.*

*Keywords: Natural asphalt; lake asphalt; rock asphalt; gilsonite; Marshall test; penetration*

## INTRODUCTION

The economic growth and development of a country can be significantly augmented with reliable transportation infrastructure. India ranks second in terms of the length of the highway and road network, with these modes of transport catering to more than 90 percent and 65 percent of the total passenger and freight traffic in the country, respectively. Though most of these highways are a product of proper planning and construction, regular maintenance is inevitable, which will be determined by several factors, including the nature of the pavement that is employed (Pradipkumar & Parth 2017).

The common understanding of pavement is mostly the uppermost layer. However, in highway engineering, it is viewed as the total depth of the pavement, including the base course, sub-base course, and wearing (surfacing) course. It is a strong and durable layer built on top of the natural subgrade to provide a smooth surface for the movement of motor vehicles. This structure comprises various material layers placed on top of the natural subgrade, and its main purpose is to transfer and convey the loading of the vehicle's axles to the subgrade. The pavement structure should provide a ride of acceptable quality, be resistant to skidding, and minimize noise generation (Shami 2017; Surajo 2016; Mathew & Rao 2007).

Pavement beginning to fail is a serious issue due to its numerous causes. Once the road is opened for traffic, the failure process will start. Initially, the deterioration is quite slow and may not be noticeable, but it typically tends to increase over time. Therefore, neglecting planning, design, construction, and maintenance of highways and roads will result in the risk of losing flexibility and sustainability at an early stage. The focus here is to ascertain the causes of early crack development to prevent the recurrence of such occurrences. Pavement deterioration can be exacerbated in the future by addressing these causes and seeking to eliminate them in future instances. Always present in discussions about failure, including the deterioration of flexible (bituminous) pavements, are ruts, cracks, potholes, settlements, and localized depressions (Shami 2017; Magdi 2015; Neero et al. 2014; Laya et al. 2017).

The use of asphalt mixtures should be tailored within target limits to improve the serviceability of flexible pavements by enhancing their ability to withstand rutting, waviness, fatigue cracking, or moisture damage, which in turn can present opportunities for cost savings and pollution reduction. A hot mix asphalt (HMA) is composed mainly of aggregates and an asphalt binder. It is also interesting that asphalt is among the most utilized binders. Binder's dependency on asphalt mixtures had led to a rapid expansion of asphalt's share of total binder used across all types in the early 1900s. The quality characteristics of asphalts provide a measurable detrimental effect on pavements as they decrease their useful life that leading to lots of repairs, unnecessary damages and cracks of roads, increased cost for maintenance services, and unfavorable environments, as well as danger for vehicles or people. This calls for the need to come up with alternative asphalt mixtures that are based on naturally available materials instead of being confined to ordinary ones (Agha et al. 2023; Ilyaset al. 2021; AL-Hamdou et al. 2016).

The word "asphalt" (or "bitumen") can be used to describe artificial asphalt that is processed from petroleum, which can be termed petroleum bitumen or refined bitumen, and natural deposits that occur in nature. Natural asphalt consists of a substance made of organic and mineral intermixed with water (Bilski 2018; Yen 2008). Organic materials contain a diverse type of hydrocarbons, asphaltenes, and resins, in addition to low amounts of sulfur, oxygen, and nitrogen, as well as vanadium, nickel, and iron within the carbon matrix (Speight 2014).

The use of asphalt – an all-purpose material, dates back a long time in history, even before modern civilization. Due to its natural properties, ecological safety relative to manufactured ones, versatility, and low cost, it has now become an important natural resource. Paving naturally and as one of the building materials, natural asphalts (NAs) can be an effective and green material (Soleiman-Beig et al. 2024; Rondón-Quintana et al. 2023).

There is no proper natural asphalt, but a more correct approach to the problem is to distinguish two types: soluble bitumens and pyrobitumens. These hydrocarbons naturally occur and, as complementary types, are different from ordinary bitumen because they are solid, insoluble, and infusible. Including these types, other common bitumens are pitch, consisting of assorted minerals and asphaltites. Another such instance is paraffin, or petroleum wax, a soft, somewhat brittle, Petroleum-based white or colorless wax. It is made of Hydrocarbons that are saturated and finds applications in the production of candles, polishes, cosmetics, and electrical insulators. Gilsonite, or uintaite, is a solid black organic compound produced from carbonization in oil, with the amount of carbon passed down to about 10–20%. Grahamite or anthraxolite is a volatile impregnated rock that evolves from gilsonite by heat and pressure. The type possesses a higher fixed carbon range of around 35-55% and has a relatively low meltdown temperature despite the high carbon contents. Last of all, glance pitch, sometimes called manjak, is somewhat like gilsonite, but with a greater specific gravity & a percentage of carbon that ranges from twenty percent to thirty percent (Rondón-Quintana et al. 2023; Kelso & Powell 1944; Speight 2015).

## PROBLEM STATEMENT

Despite the widespread use of petroleum-based asphalt in flexible pavement construction, premature rutting, moisture susceptibility, and high maintenance costs persist. A gap remains in identifying sustainable alternatives with better durability, lower environmental impact, and comparable or superior performance. This review aims to explore whether natural asphalt materials can effectively fill this gap.

## OBJECTIVE OF STUDY

This study will focus on reviewing previous research that has been conducted on the incorporation of natural asphalt in the production of hot asphalt concrete for flexible paving of highways; also, it will aim to use a variety of natural asphalt in the modification of properties of petroleum asphalt cement.

## HOT MIXTURE ASPHALT: COMPONENTS AND TYPES

The hot asphalt mixture is a mixture of coarse gravel, fine gravel, the fill material represented by cement or lime, and the binder, which acts as an adhesive. Sieve No. 200 is the particle size classification of the filler material, which is the one that passes through this sieve. The fillers were common Portland cement and limestone. Bituminous mix, plant mix, asphaltic concrete, and hot-mix asphalt (HMA) are other names for this type of asphalt. These materials are known as hot-mixed asphalt HMA and they are various proportions of coarse aggregate combined with asphalt. To perform HMA, three kinds can be distinguished based on the purpose of the application and, aggregate gradation used in the mixture. These types of soil are classified as coarse, dense, open, and fine (Radhi et al. 2024; AL-Saffar 2013; Roberts et al. 1996).

One of the most common errors that HMS HMA designs are likely to make in the mixing process is related to: the asphalt content, shape of coarse sand and fine sand aggregates, percentage of voids or air, the texture of coarse aggregate, grade of aggregates, type and performance grade of the asphalt binder, and the size of aggregate. It can be inferred that excess amounts of asphalt are not only unnecessary but may also be the chief cause of permanent deformation (Kazim et al. 2024; Abed & Al-Azzawi 2012).

Three main types of asphalt, constituted from heated mixes, exist, namely: asphalt made of stone mastic (matrix), open graded mixtures (SMA), and dense graded mixtures. A densely graded mixture is made up of asphalt binder and well-graded, rather rough particles in an HMA mixture. HMA mixtures that are well constructed and well-designed are indecomposable. Because of their ease, nearly all pavement layers are suitable, and all traffic conditions are favorable for dense graded mixtures. Despite their being dense, it is patchy and porous in contrast to relatively thick, compact, graded, and SMA mixes. Crushed stone or crushed gravel, occasionally combined with small amounts of synthetic sand, make up these kinds of mixtures. For surface mixtures and fibers, modified asphalts are highly advised. It increases the performance level concerning the strength & durability of these mixtures as it will help to increase the amount of asphalt that can be employed with them. The types of open-graded mixtures used in the US include Open Graded Friction Courses (OGFC), Porous European Mixes (PEM), and Asphalt Treated Permeable Bases (ATPB). OGFC and PEM only apply to surface or worn courses. SMA is a gap-graded HMA that has a stable stone-on-stone structure held together by a rich filling AC and stabilizing additives, including fibers and/or asphalt modifiers, which enhance rutting resistance and durability (Kazim et al. 2023; National Asphalt Pavement Association and Federal Highway Administration 2001; Brian 2008).

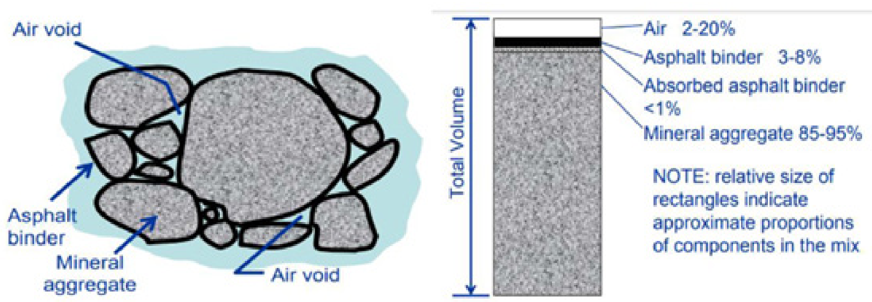


FIGURE 1. Hot mixed asphalt components (Kazim et al. 2023)

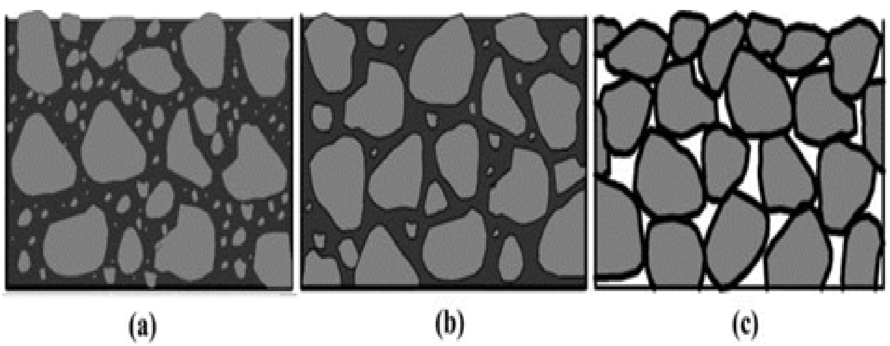


FIGURE 2. Types of hot mixture asphalt: (a) dense-graded, (b) gap-graded, and (c) open-graded (Babalghaith et al. 2022)

## ASPHALT MATERIAL TYPES

Asphalt is a type of coating made from petroleum; however, there are several grades and variations available. At relatively shallow depths, microorganisms and subterranean water combine to create bituminous, or heavy petroleum, compounds. When in such conditions, oxygenated subterranean water attacks and partly solubilizes the oil during the washing action. The high-density molecules also get cleaved by the waterborne bacteria. In the phenomenon known as bacterial erosion, hydrogen is scavenged, and which causes retention of hydrocarbons and heavy oil molecules (Latief 2019). Asphalt is one of the heavy hydrocarbon materials, which can be separated into different grades depending on their physical features and carbon tetrachloride solubility, as well as their chemical structures. In addition, based on its origins, asphalt is either Petroleum (refined) Asphalt or natural asphalt (Soleiman-Beigi et al. 2024; Delano 1893).

## PETROLEUM ASPHALT

Sealed in barrels and referred to as petroleum asphalt or refinery asphalt, petroleum bitumen is a by-product formed during the processing of crude oil. Crude oil is a mixture of hydrocarbons, which are in liquid form and can be found deep below underground oil deposits. Different heating levels are used to refine this combination in distillation and obtain gasoline, diesel, kerosene, and bitumen, among others. This distillation also enables the production of this substance, allowing it to be recovered as a residue from either atmospheric or vacuum distillation processes. The product consists of several highly branched chains as well as other contaminants, including but not limited to sulfur, nitrogen, and other heavy metals. As such, petroleum bitumen asphalt is subjected to further refinement, similar to air blowing, whereby heated air bubbles through asphalt bitumen to enhance its quality and eliminate contaminants. Regardless of its name, this type of asphalt is the most widely produced in the world owing to its relatively low cost, ease of extraction, and uniform characteristics. It is applied in the road construction processes by combining it with aggregates to form asphalt concrete. The process of manufacturing oil in the refinery through various stages is illustrated in Figure 3 (Soleiman-Beigi et al. 2024; Wen et al. 1978).

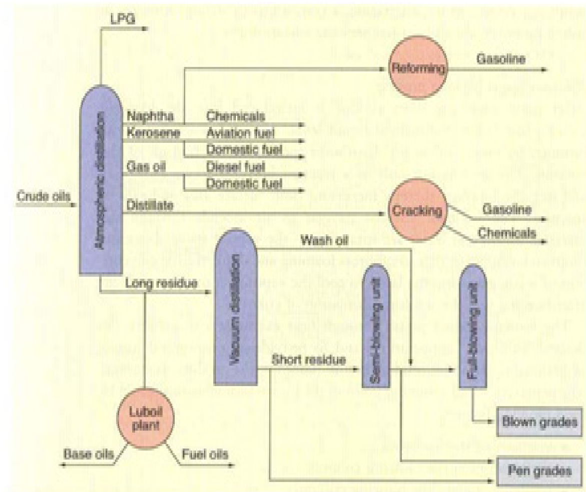


FIGURE 3. The process of refinery oil (Read & Whiteoak 2003)

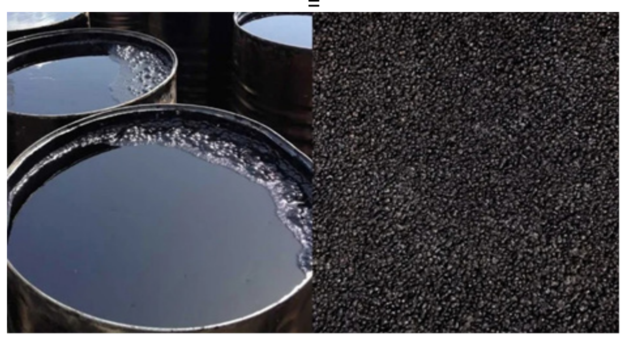

FIGURE 4. Grade asphalt results from the process of refining oil

## NATURAL ASPHALT

Asphalt, in its most natural form, is made up mainly of tightly bound molecular compounds of aromatic hydrocarbons. Natural asphalt (NA) mostly contains carbon, hydrogen, nitrogen, oxygen, sulfur, and small amounts of iron, nickel, and vanadium (Meyer and De Witt, 1990). NA acts as a binding material in asphalt mixtures and has some peculiar characteristics that improve the performance of bitumen. The physical characteristics of Natural bitumen or Natural asphalt have been pictured in Figure 5 (Sun et al. 2022; Meyer & De Witt 1990).

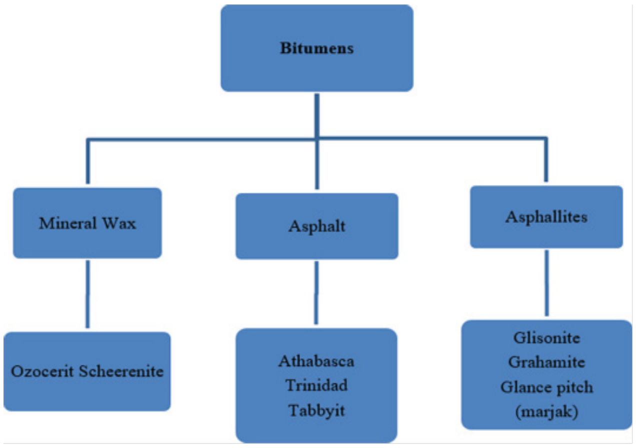


FIGURE 5. Natural asphalt (bitumen) based on physical properties (Soleiman-Beigi et al. 2024)

## ROCK ASPHALT

Country rocks that are irregularly packed with fossil fuels and ichnoliths are the natural source of Natural Rock Asphalt (NRA). The accumulation of nitrogen-rich material and marine fossils is the result of sedimentation and evolution spanning thousands of years. It derives from the sedimentation of fracture minerals and the remains of marine fossils from the Jurassic Period. It's often used in the modification of asphalt binder to enhance the rigidity and strain characteristics of asphalt mixtures. There are three main types of natural asphalt: sedimentary asphalts, lake-type asphalts, and rock asphalts, which have different grades of purity. For many, the term natural asphalt conjures the image of natural rock asphalt - the most widely recognized natural asphalt deposit (Mohammed et al. 2021; Du & Liu 2012; Rozental et al. 2007).

Rock asphalt is a natural, mineral-rich material that can serve as a substitute for conventional asphalt binder in HMA mixes. In several parts of the globe, rock asphalt has attracted interest due to its lower cost and straightforwardness in its utilization during mixture preparation and application. Rock asphalt is formed as a result of oil being soaked into a rock-like limestone and then heated up, compressed, oxidized, and acted on by bacteria throughout millions of years. Two primary components of rock asphalt, therefore, are asphalt binder and mineral fillers. Rock asphalt is a black, amorphous material that readily crushes into a powder. As a result of the type and quantity of its constituents and the type of physical and chemical transformation, rock asphalts exhibit motor properties that vary widely across a long period. Being an ecologically friendly building material, rock asphalt is a natural material that undergoes chemical modification under no conditions and readily integrates with bitumen. Whenever modified, it improves the high-temperature robustness and durability when in application. Figure 6 shows the rock asphalt appearance (Sun et al. 2022; Mohammed et al. 2021; Rozental et al. 2007; Widyatmoko & Elliott 2008).

FIGURE 6. The rock asphalt appearance [blog.iranbroodat.com]

## LAKE ASPHALT

Lake bitumen is frequently referred to as one of the most well-known varieties of natural bitumen and is recognized as an almost solid or viscous substance. One well-known and commercially relevant variant form is called Trinidad Lake bitumen. In crude bitumen, also known as lake asphalt or liquid natural bitumen, this substance exists in a viscous and sticky state. In its liquid state, it is a viscous material that contains a significant quantity of bitumen and is essentially thick, black, and tar-like. Usually, to improve the flow of the liquid state material, which is desirable during transportation, it is stored and carried at higher temperatures of about 150 degrees Celsius. Generally, liquid natural bitumen is located within or entrapped by sand or sandstone reservoirs, this is frequently extracted using in situ extraction techniques or via oil sand mining. However, rigid natural bitumen has been heavily utilized as a constituent in asphalt materials and is also solid at normal indoor temperatures. On the other hand, Liquid natural bitumen needs processing to be transformed into an applicable form, such as light oil or other petroleum products. The differences in viscosity and other physical properties between solid and liquid natural bitumen can be mainly attributed to their different molecular structure and states of the natural resources. Trinidad lake bitumen is a good example of liquid natural bitumen, which has high viscosity but can be easily changed into a liquid state at higher temperatures and therefore becomes solid at lower temperatures (Soleiman-Beigi et al. 2024; Li et al. 2015; Anupam et al. 2023; Charles & Grimaidi 1996).

In the preparation of the pavement surface course, the modified bitumen with 50 penetration grades obtained by blending Trinidad Lake bitumen and petroleum bitumen 160/220 at a 50:50 ratio was successfully used. It becomes apparent that grade 50 rated penetration is regarded as hard bitumen, which is often needed where the pavement wearing surfaces require more rigidity. Nonetheless, FTIR is the centre of attention of pavement engineers looking for the chemical structure of bitumen. The lake asphalt can be seen in Figure 7 (Zhang et al. 2020).

FIGURE 7. AASHO standard H&HS design trucks (Martin et al. 2011)

## GILSONITE

Occurring as a bituminous substance with an insoluble nature, Gilsonite is a thick, molecular oil that has undergone oxidation and polymerization for millions of years in nature. It occurs in rock fractures having a few tens of centimeters to several meters in width and a depth of several hundred meters or more. Due to prolonged co-existence with harsh surroundings, its characters are very stable and resistant to aging. Gilsonite was first discovered in the 1860s but was not applied to anything until the mid-1880s when it was used primarily for waterproofing purposes. Today, however, Gilsonite is attractive to use as a new type of modifier because of its excellent road performance, simple construction method, reasonable costs, and economics. Use of lower pavement oasis, asphalt modified using Gilsonite, is a simple and efficient way of minimizing the extensive damage caused to roads by rutting and water damage, thereby extending road life and enhancing the road surface. (Sun et al. 2022; Liu et al. 2014; Shi et al. 2018; Lu et al. 2010).

Also, Gilsonite is Natural bitumen also known as Asphaltite, Uintaite, or Asphaltum, which are mostly deposited in the USA, Russia, Iran, and China. Gilsonite is a mineral that is formed as crude oil is removed from the earth's reservoir and brought up to the surface through geological cracks. This is soft material that can be easily milled into powder. Due to its brittle and hard nature, Gilsonite has been predominantly used for waterproofing in construction works and structures. The appearance of the structure of the gilsonite is illustrated in Figure 8 (Anupam et al. 2023; Ameri et al. 2011; Sun2012).

FIGURE 8. Structure appearance of Gilsonite (Sun et al. 2022; Boden & Tripp 2012)

Among the different forms of Gilsonite that can be found, the vertically elongated ones are the most abundant in the mass because they do not deviate from any set configurations within the formations. The mass Gilsonite is also black and has smooth circular structures that look like shattered geological glass. Its delicate structure allows it to be readily crushed. For Gilsonite the specific gravity numbers go between 1.03 and 1.10. It has a melting temperature ranging from 120°C to 175°C. Gilsonite has no worth for penetration. Organic solvents, asphaltenes, and nitrogen are known to be characteristics of Gilsonite. As a rule, this particular substance can be used for roads, bridge surfaces, airports, or tunnels, which is easy to make, handle, or move for construction. When making pavement for a roadway, Gilsonite can be incorporated into the asphalt binder or the aggregates during the mixing cycle at the construction site (Sun et al. 2022; Jahanian et al. 2017; Sun, Zhang& Cui 2015).

## NATURAL ASPHALT COMPONENTS

Natural asphalt is made up of numerous components and materials, which capture a certain essence of the composition. The principal ingredients and raw materials present in natural asphalt are hydrocarbons. Natural asphalt mostly consists of hydrocarbons, which are organic compounds made of hydrogen and carbon atoms. These hydrocarbons are the products of centuries of biodegradation and modification of organic materials. Asphaltenes belong to high molecular weight hydrocarbons and are formed through an intricate mixture. They provide viscosity, adhesion, and binding properties to the natural asphalt. Resins are another component found in natural asphalt. They are intermediates of hydrocarbon molecules, which mainly affect the natural asphalt's cohesive and deformation characteristics. Mineral Matter, which contains all sorts of inorganics. However, the content of mineral matter and specific mineral matter can differ in concrete depending on the natural asphalt's geographical/ geological origin. Such minerals may include silica, calcium carbonate, iron oxide, and clay minerals. Volatile substances such as lighter hydrocarbons and water. It is observed that these volatile components can enhance the flow and workability of the natural asphalt within certain temperature ranges. The qualitative and quantitative composition of natural asphalt nut may differ from one region to another, depending on its origin and geological structure. Different deposits and different areas may have different relations of hydrocarbons, asphaltenes, resins, and mineral matter, which result in different properties and characteristics. It should be added that the composition of natural asphalt is in distinction from petrochemical asphalt, which is manufactured because it passes through separative processes to change its properties. In general, specific properties of natural asphalt, such as viscosity, adhesion, and hardness, which determine its applicability in construction, road works, or industrial needs, are explained by the fact that it consists of hydrocarbons, asphaltenes, resins, and mineral matter (Yahit 2023; Lins et al. 2008; Zhang et al. 2009).

## NATURAL ASPHALT AND PETROLEUM ASPHALT DIFFERENCES

Natural Asphalt possesses a high softening point attribute of large molecular weight that is estimated to range between a few thousand and over ten thousand. It follows that out of the two, NA and petroleum bitumen, the latter has better integrity and fewer impurities. The natural gilsonite asphalt can withstand the free base oxide because it has a high nitrogen content, while TLA's sophistication is comparable to petroleum asphalt. Functional N-containing groups such as pyrole and benzoyl ammonia nitrogen constituents are known to be incorporated into the nitrogen framework. Even though natural bituminous asphalt possesses a great ability to resist weathering forces, petroleum asphalts last for a few years outdoors and get oxidized in no time because of the impact of ultraviolet (UV) radiation. However, trichloroethylene black on the aggregate surface during the extraction of the asphalt mixture remains unaffected even after a score of washes. This is because NA contains a very high nitrogen content and has a distinct affinity for stone (Sun et al. 2022; Shen 1999; Shen 2001).

## ASSESSMENT OF NATURAL ASPHALT PROPERTIES

The data about asphalt oxidation implemented further down, and specifically about Abdul-Jaleel, & Najres (2012), up until 2020, show that natural asphalt oxidizes at high temperatures over longer periods. It begins on the surface and, with continuous mixing and heating, eventually oxidizes all of the asphalt's molecules, resulting in a solid, glossy, dark black oxidized texture. Before and following oxidation, the rheological characteristics undergo substantial changes. In the former scenario, a low level of penetration is noted, whereas a high degree of material softening and an extension of the oxidation duration result in a decrease in the absolute value of penetration32. Asphaltene index IA and Gastl index IC were also calculated using manual column liquid-solid chromatography and extraction in parallel with a solvent and precipitant. The oxidation process load increased in the fractional asphaltene compared with that of the molten parts. The FT-IR, UV-Visible, and HNMR spectra revealed a change in the physical properties of oxidized asphalt because there was a chemophysical relationship between the chemical content and the rheological properties of the oxidized asphalt. The figures that follow provide examples: The impact of aging on asphalt penetration values is shown in Figure 9, the softening capacity of asphalt about aging is shown in Figure 10, and the relationship between IA and viscosity for asphalt is defined in Figure 11.

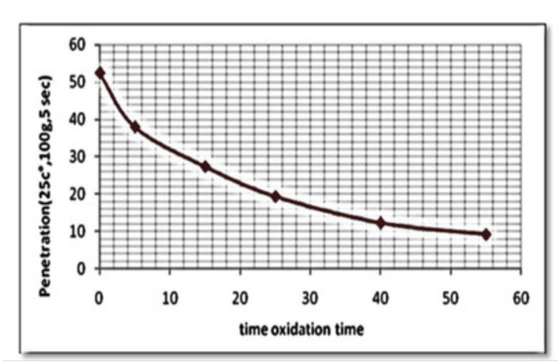


Figure 9. The impact of aging on asphalt penetration (Abdul-Jaleel & Najres 2012)

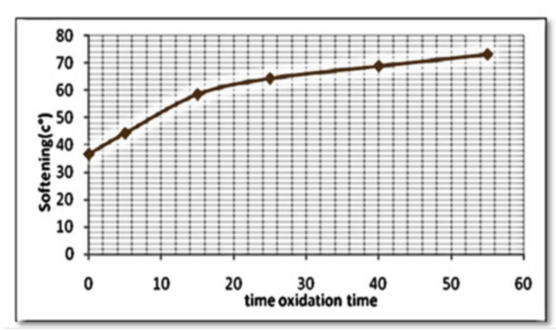


FIGURE 10. The impact of aging on asphalt softening (Abdul-Jaleel & Najres 2012)

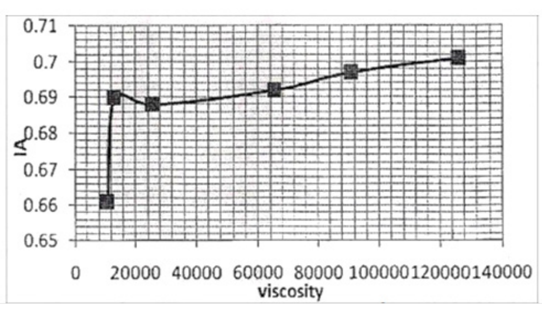


FIGURE 11. Relationship between IA and Viscosity for asphalt (Abdul-Jaleel & Najres 2012)

In a study conducted by Kök, B. V., et al. 2012, it was shown that dynamic creep test, indirect tensile strengths, and Marshall stability & stiffness modulus allow for the determination of the efficiency of natural asphalt in hot mix asphalt Marshall's elastomer. Syrian natural asphalt, which had an asphalt percentage of 17% and a mineral fraction of 83%. It was further shown that natural asphalt modified values were 1% lower than control mixtures' values. Evaluated in terms of stiffness modulus, natural asphalt modified mixtures were stiffer than control mixtures. The evaluation of the natural asphalt-modified mixes' and control mixtures' moisture susceptibility was conducted throughout three freeze-thaw cycles. Although the degree of resistance was not very high, the modified-asphalt mixtures were less moisture susceptible than the control materials. It was notable that the addition of natural asphalt to the mixtures markedly reduced the susceptibility to permanent deformation. The provided data confirms efficient usage of natural asphalts. Figure 12 demonstrates the indirect tensile stiffness modulus of the Bend asphalt mix, while Figure 13 shows the results for tensile strength values. From Figure 14, the tensile strength ratios of the Bend asphalt mix can be seen.

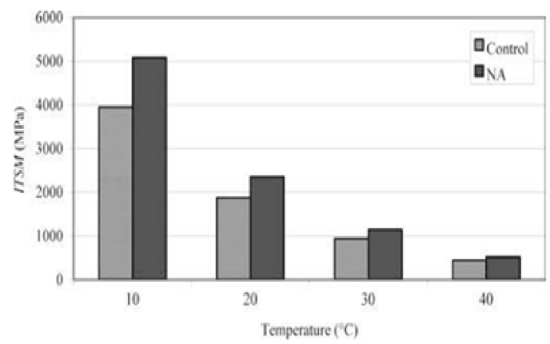


FIGURE 12. Indirect tensile stiffness modulus of asphalt mix. (Kök et al. 2012)

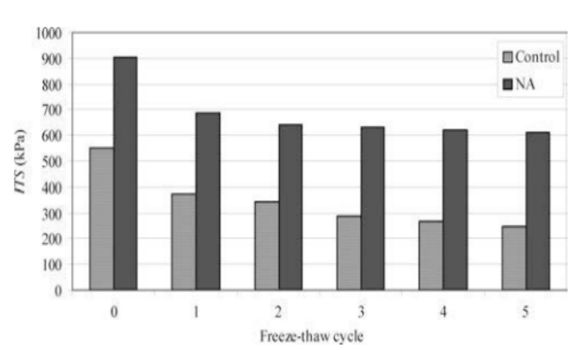


FIGURE 13. Indirect tensile strength values of asphalt mix (Kök et al. 2012)

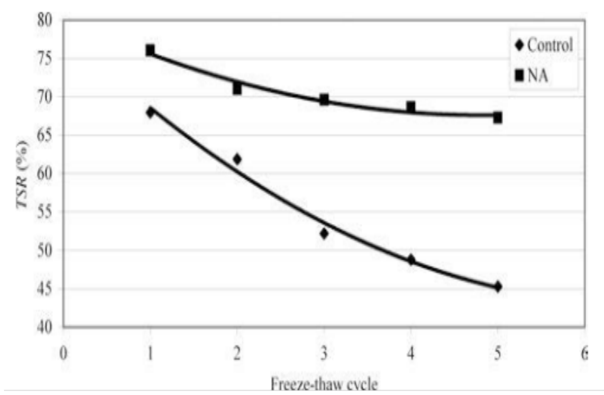


FIGURE 14. Indirect tensile strength ratios of asphalt mix (Kök et al. 2012)

Yilmaz, M., & Çeloğlu, M. E. 2013 produced three different forms of NA (American Gilsonite (AG), Iranian Gilsonite (IG), and TLA) along with SBS, which Yilmaz and Çelohlu (2013) tested as bitumen modifiers. It was shown by the Marshall test results, that the mixes with 60% TLA modified binder MB60%TLA, had the highest stability values before and after applying conditioning, which was the step where the samples were immersed in water at 60˚C for 24 hours, whereas the unmodified mixtures, being the control ones had the lowest stability values. Let us notice, it was determined that mixes with MB60% TLA had a pretreatment stability that was 46.8% higher and a post-treatment stability of 45.6% higher than their control mixture. The conditioning of the two combinations resulted in very close stable values, still mixtures with 10% AG modified binder system MB10%AG delivered better stability values than those of 9.5% IG system modifier mixtures mb 9.5%Ig. Based on the results as well, such tests confirmed that in comparison to blends with 3.8% SBS modified binder MB3.8 % SBS, all three blends tested with NA modified binders had greater stability values. The figures show mixture test results before and following conditioning.

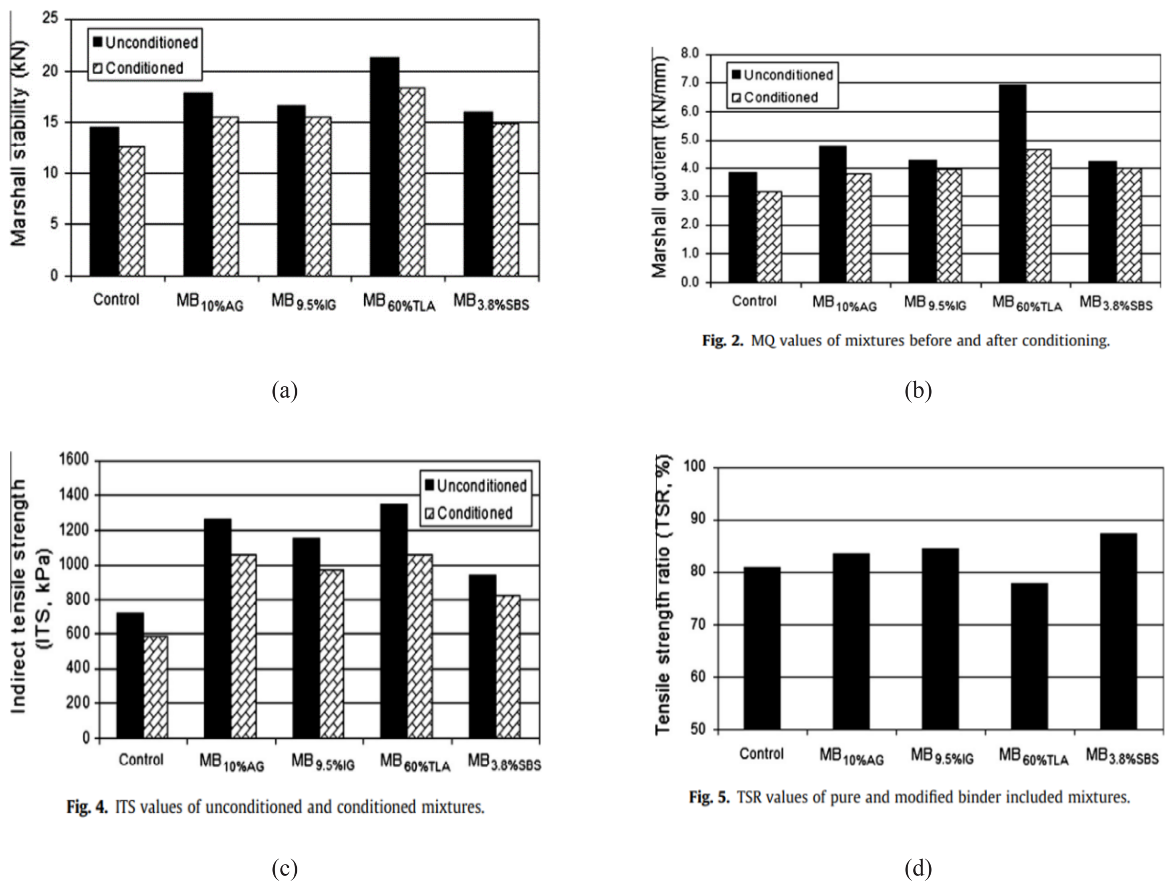


FIGURE 15. Mixture tests (a). Marshall stability values of mixtures (b). MQ values of mixtures before and after conditioning, (c). ITS values of unconditioned and conditioned mixtures (d). TSR of Pure and Modified Binder Mixtures

Abdul-Jaleel et al. 2016 reported that the NA springs situated in Western Iraq's Al-Anbar province were examined in terms of their springs NA chemical properties. The study's main objective was to focus on TA separation, and for this, two methods were used, namely, column chromatography and extraction chromatography. Paraffinic content was 45.23%, aromatic content was 28.39%, resin content was 21.66%, and asphaltene content was 10.20%. The secondary objective was to modify the rheological and thermal properties of NA by adding limestone in the amounts of 5, 15, 25, and 35%, which gave good outcomes as can be seen in Figures 16, 17, 18, and 19.

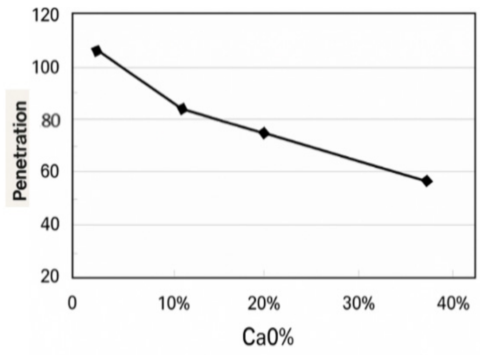


FIGURE 16. Relationship between penetration and CaO% (Abdul-Jaleel et al. 2016)

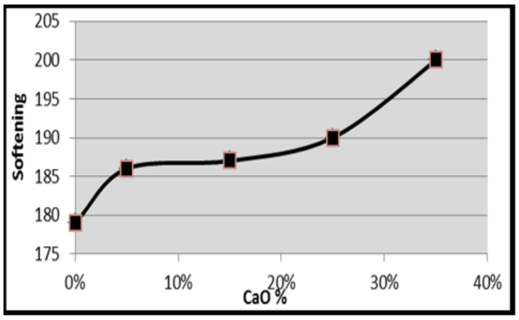


FIGURE 17. Relationship between softening and CaO% (Abdul-Jaleel et al. 2016)

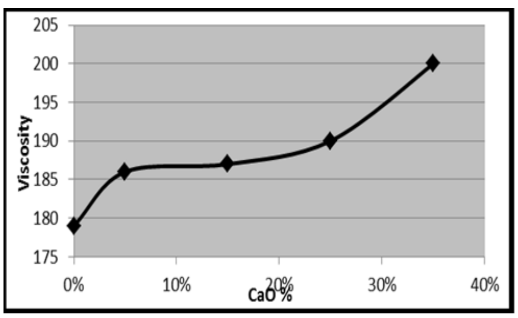


FIGURE 18. Relationship between viscosity and CaO% (Abdul-Jaleel et al. 2016)

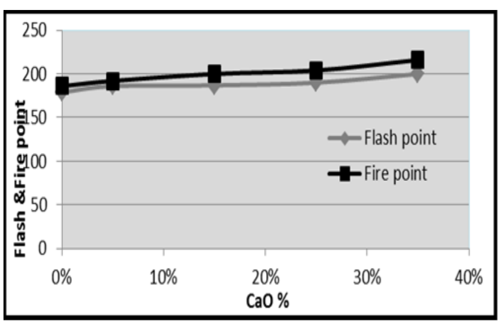


FIGURE 19. Relationship between flash and fire point and CaO% (Abdul-Jaleel et al. 2016)

Nejres, A. M. et al. 2022 evaluated the alluvial system of natural asphalt sourced from Al-Qayyarah/Iraq utilizing techniques of column chromatography and infrared spectrophotometer to analyze its chemical structure. Additionally, different amounts of commercially available low-density polyethylene (LDPE) and eggshell powder (ESP), which are food waste products, were added to the natural asphalt. Using column chromatography, the asphalt was fractionated into four basic components in a procedure known as SARA. The ratios, as set forth by the amount of paraffin (28.58%), Asphalt (20.04%), resins (19.88%), and aromatics (29.34%), assessed the quality of asphaltene. The study found that the ratios of the aromatic and resin parts were greater than that of the asphaltene parts, while the latter contributed a negative penetration index. The findings revealed natural asphalt with immobilized micro- or nanoparticles and rheological characteristics that were improved by the two additives (ESP and LDP). They also demonstrated a soluble type of colloid structure. Numerous physical and thermal tests, such as those for softening and penetration, as well as those for ductility, viscosity, and water absorption, supported this.

About Mohammed et al. 2024, the western part of Iraq stopped using natural asphalt (or NA) deposits from sulfur springs. In the lab, the effectiveness of an asphalt layer that contained NA was also evaluated to ascertain whether it was suitable for local pavements. To do this, a binder known as Type HSNA was created by combining two types of NA: soft SNA and hard HNA. The penetration grade of the HSNA that was created met Iraqi requirements. Petroleum asphalt was mixed with up to 80% NA in percentages of twenty percent, forty percent, sixty percent, and 80%. Improvements in HSNA's physical properties were also noted, and the material satisfied the requirements of Iraqi asphalt cement standards. It follows then that HSNA can be utilized as an asphalt binder in the formulation of asphalt mixtures for flexible paving construction. What is even more interesting is that HSNA mixtures, compared to conventional mixtures, displayed improved Marshall stability and stiffness index. Indirect tensile strength (ITS) and tensile strength ratio (TSR) testing revealed that the mixture 80NA had the highest strength values, with an ITS of 81.36% TSR, surpassing the petroleum asphalt mixture's TSR by 0.57%. Data on a few physical characteristics of natural asphalt and petroleum asphalt (40–50), both before and after treatment, are shown in Tables 1 and 2. The Marshall, ITS, and TSR test results are displayed in Figures 20, 21, and 22.

TABLE 1. Physical Properties of petroleum asphalt (40-50) and Natural Asphalt

| 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, 5cm/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 | - |
| Rational viscosity, at 135°C | Pa.s | 0.488 | 0.206 | - | - |

*Sumber*: Mohammed et al. (2024)

TABLE 2. Physical properties of HSNA after treatment

| Test | Results | | | | | Specification Limits (SCRB, 2003) |
|---|---|---|---|---|---|---|
| | HNA | 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 | - |

*Sumber*: Mohammed et al. (2024)

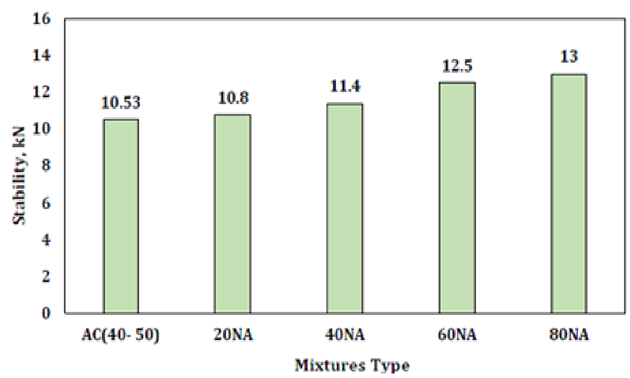


FIGURE 20. Marshall Stability Results (Mohammed et al. 2024)

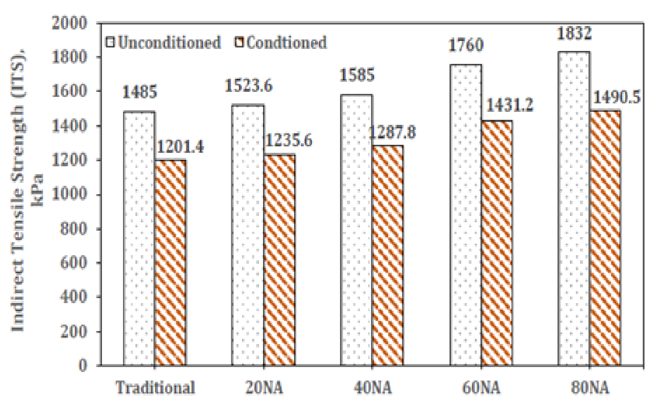


FIGURE 21. The ITS for unconditioned and conditioned mixes (Mohammed et al. 2024)

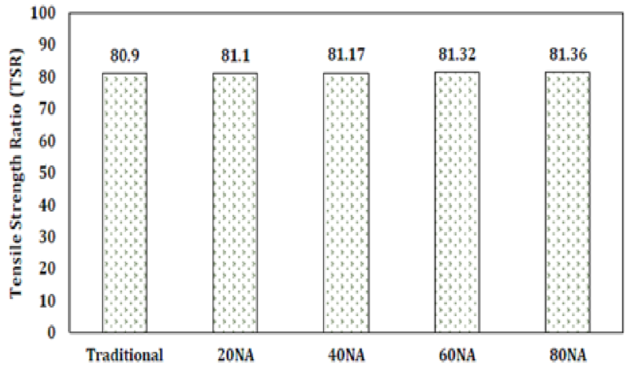


FIGURE 22. TSR for petroleum and HSNA-treated mixes (Mohammed et al. 2024)

Ahmed et al. (2024) examined the feasibility of using natural asphalt for local asphalt concrete mixtures. For this purpose, the natural asphalt was heated up to 163° C for some time. So, after being heat-treated, NA underwent laboratory testing. According to the findings, heating NA for roughly 20 hours allows it to achieve the physical characteristics required by Iraq. Also, treated NA was found to be able to withstand temperature fluctuations gentler than those of petroleum-based asphalt. The research further established that NA improves the mechanical properties quite effectively. Specifically, the NA mixture yielded the highest indirect tensile strength, with a tensile strength ratio of 81.2%, a slight increase of 0.37 percent over the standard American mixes. In conclusion, NA blends function admirably. In Iraq, where NA is abundant and inexpensive, when the costs of the filling and thermal treatment industries are taken into consideration, NA is beneficial for the development of asphalt concrete technology in the future for the creation of flexible pavement. Table 3 lists the physical characteristics of the NA original asphalt and regular asphalt (40–50). Table 4 lists Marshall traits. Figure 23 shows the penetration index values.

TABLE 3. Physical characteristics of original NA and normal asphalt (40–50)

| Test | Test Results | | Requirement |
|---|---|---|---|
| | HNA | 20NA | |
| Penetration, 1/10 mm | 47 | 146 | 40 – 50 |
| Ductility, cm | >150 | 103 | ≥100 |
| Softening Point, °C | 52 | 36 | - |
| Flash Point, °C | 245 | 180 | 232 min. |
| Specific Gravity | 1.02 | 1.00 | - |
| Rotational viscosity, Pa.s | 0.488 | 0.233 | - |

*Sumber*: Ahmed et al. (2024)

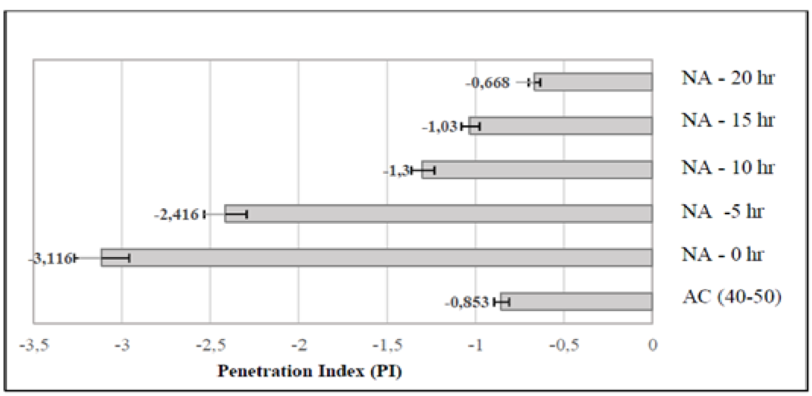


FIGURE 23. Penetration index (Ahmed et al. 2024)

TABLE 4. Marshall Characteristics

| Marshal Property | Conventional Mix | NA Mix | Specification Requirements |
|---|---|---|---|
| Opyimal Binder Content, % | 4.96 | 4.93 | 4-6 |
| Stability, kN | 10.53 | 12.38 | 8 minimum |
| Flow, mm | 3.18 | 3.65 | 2-4 |
| MQ, kN/mm | 3.31 | 3.39 | - |
| Bulk Density,gm/cm3 | 2.34 | 2.34 | - |
| Vv, % | 4.10 | 4.20 | 3-5 |
| VMA, % | 15.70 | 15.70 | 14 minimum |
| VFB, % | 74.00 | 72.00 | - |

*Sumber*: Ahmed et al. (2024)

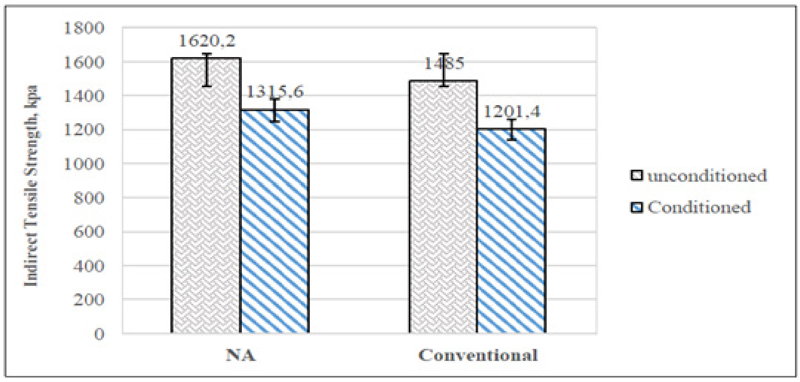


FIGURE 24. ITS for unconditioned and conditioned mixes (Ahmed, F. et al. 2024)

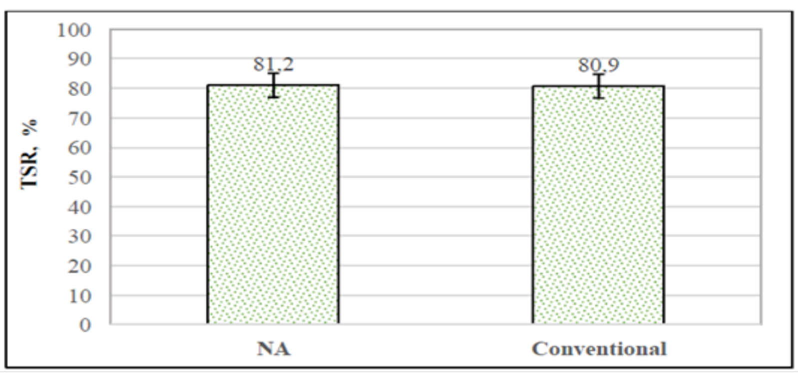


FIGURE 25. TSR values for conventional and NA mixes (Ahmed, F., et al. 2024)

## THE EFFECT OF GILSONITE ON THE PROPERTIES OF HOT MIXTURE ASPHALT

Zhong, K., et al. 2008 used PG 58 asphalt modification, which used two varieties of gilsonite, Xinjiang and North American Gilsonite. The service-wise assessment of PG shows that no clarity is obtained at lower service temperatures. The percentages of modification were also described to be 5, 10, 15, and 20 wt% %. It's not clear what the modification process is. Among the methods used are the DSR and BBR tests for viscosity and rheology. As the gilsonite content increased, PG and viscosity showed an upward trend, becoming more stable and appropriate at higher temperatures. The application of gilsonite to the base asphalt had an impact on the asphalt's low temperature performance; nevertheless, gilsonite would not have a significant negative impact on the asphalt's low temperature performance in tiny amounts. Xinjiang and North American gilsonite dosages should not exceed 15 weight percent and 8 weight percent, respectively. It has been demonstrated that Asphalts modified with Xinjiang gilsonite outperformed those changed with North American gilsonite.

Suo, Z., & Wong, W. G. 2009 tested three asphalt mixtures: normal asphalt concrete wearing course (ACWC), stone mastic asphalt (SMA), and gilsonite-modified asphalt (GM-ACWC) using ITF and ITSM testing at temperatures of ten, twenty, thirty, and forty degrees Celsius. The GM-ACWC asphalt mixtures were created by engineering features such as the addition of a touch of gilsonite. By the Marshall method, the aforementioned combinations were subjected to short-term aging after being compressed in a gyratory compactor. Furthermore, a fatigue damage model was developed, and a finite element analysis was performed to examine the cracking resistance behavior of the mixes. In the GM-ACWC, AC 60/70 pen asphalt is used as the base binder. Unfortunately, there was no clear explanation of how the asphalt modification was conducted. The authors employed reputable methods to characterize the observable physical properties of the gilsonite, but they did not include rheological analysis. The results confirmed the expectation that the GM-ACWC mixture has a longer effective life before cracking begins to dominate. On the other hand, its overall fatigue resistance strength was found to be lower than that of the other mixtures. The authors recommended employing the GM-ACWC mixture in high-traffic areas and regions exposed to high service temperatures.

By using a Colombian gilsonite for both dry and wet modification, Reference Rondón-Quintana et al. (2015), quantified the change in an HMA combination's characteristics. Using the material modifiers, rheology tests were performed on an AC sixty to seventy pen asphalt base with weight capacities of five percent, ten percent, and fifteen percent.  For twenty minutes, the two chemicals were mixed at 160 degrees Celsius. For a rheological characterization, the researchers used DSR equipment. Using the Marshall technique, HMA was modified. Tests for ITS, RM (10, 20, 40 °C), and permanent deformation at 60 °C were performed. The basal asphalt's rigidity and high-temperature performance were both improved by the inclusion of gilsonite. Additionally, an increase in the strength as well as stiffness of the modified mixture was reported, even though the void content increased. Wet-modification of the mixture with G/AC = 10% resulted in higher mechanical strength and stiffness. Gilsonite helped to increase the HMAs' resilience to rutting. The gillsonite-containing HMAs were just as wet and failure-resistant as the control mixture.

In the research conducted by Quintana et al. (2016), the ratio G/AC was studied at 5, 10, and 15 in a Gilsonite-modified asphalt concrete mixture. Two approaches, wet and dry, were used within monotonic and dynamic loading conditions. Based on the results, it was found that Gilsonite's incorporation in 5% and 10% ratios significantly improved the mechanical strength and stiffness under dynamic and monotonic loading conditions. More specifically, the effect was pronounced with the dynamic loading condition when a 10% Gilsonite ratio was used in the mixture. Positioning emphasis on the non-modified and non-heated method, an enhancement of stiffness by 9% at temperature 10 °C, 28% at 20 °C, and 105% at 40 °C was achieved. Similar temperature positioning using the wet modification process increased the stiffness values by 25%, 53%, and 154%, respectively. Hence, Gilsonite performs well when used in enhancing the deformation and rutting resistance of the mixtures, especially suitable for the temperatures. It is important to however note that at low temperatures, the layers of the mixture, especially asphalt layers, may become too brittle, which may make it prone to low temperature fatigue cracking resistance. For further analysis, it was also noted that the modified mixtures had comparable TSR values with the unmodified, suggesting no negative effect of Gilsonite on TSR values.

Akbari Nasrekani et al. 2016 and Nasrekani et al. 2017, used the PG 58-22 asphalt binder to which gilsonite (sieve #200) at 5 wt% and 10 wt% was added as a modifierIt was heated and combined with the gilsonite for one hour at 6500 rpm at 180 °C. A Superpave gyratory compactor was used to create the control and modified asphalt mixtures. For the asphalt binders, the authors conducted DSR and softening point tests. Dynamic creep tests were performed on the asphalt mixtures at 54.4 °C. The purpose of the study was to assess the performance of asphalt mixtures and binders under high service temperatures. Gilsonite also increases the asphalt binder's stiffness and elasticity. Both the asphalt mixture and the enhanced asphalt binder increased the resistance to rutting. For warmer climates, they recommend using asphalt concrete treated with gilsonite. A year later, a related study that concentrated on moisture damage was published. In the later investigation, the chemical characteristics and functional groups of the modified asphalt were examined using FTIR. Additionally, the researchers computed the materials' indirect tensile strength in both the dry state and the freeze-thaw cycles. Samples treated with gilsonite exhibited favorable behavior in damp conditions. The enhancing impact did not, however, differ significantly between the 5 and 10 weight percent gilsonite dosages.

About Sabouri et al. 2018, enhanced PG 58-22 and PG 64-22 binders with 4, 8, and 12 weight percent gilsonite were used. Additionally, they included 3 and 5 weight percent SBS to compare them. The gilsonite-modified asphalts were made by heating the base asphaltic binders to 140 degrees Celsius and then mixing them with gilsonite for 15 minutes at 150 rpm. After that, the speed was raised to 4500 revolutions per minute for 30 minutes to ensure the mixture was homogenized. DSR and LAS rheological characterization of the asphalts treated with gilsonite were investigated. Their investigation shows that gilsonite does a decent job in the LAS test with strains of below 10 percent and increases the stiffness of the base asphalt. In addition, they conducted an FPB fatigue test at 25 °C and created asphalt mixtures. They decided on the asphalt that had been modified by 12 weight percent gilsonite for the asphalt combination with gilsonite, since it produced the greatest results in the LAS. At medium and high temperatures, it has been noted that the gilsonite-modified asphalts function better. Longer fatigue life was demonstrated by the gilsonite-modified asphalt mixture in the FPB test.

Mirzaiyan et al. 2019 investigated the impact of SBS and gilsonite as asphalt binder enhancers. PG 58-22 and PG 64-22 were the two binder sources. Figures 26 and 27 present results obtained from a high-temperature performance test of asphalt binders' rutting resistance pre- and post a short-term aging process. This is clear from the figures that both before and after the short-term aging process, the G*/sin(δ) of binders modified through the inclusion of Gilsonite and SBS was greater than that of base binders. This suggests that the modified binders are more resistant to rutting than the neat bindersAs illustrated in Figures (2-8) and (2-9), for instance, the gains in high temperature performance of PG 58-22 and PG 64-22 with 12% Gilsonite are approximately 23% and 29%, respectively. The high temperature performance of PG 58-22 and PG 64-22 with 5% SBS improves by roughly 24% and 22%, respectively, in line with the preceding pattern.

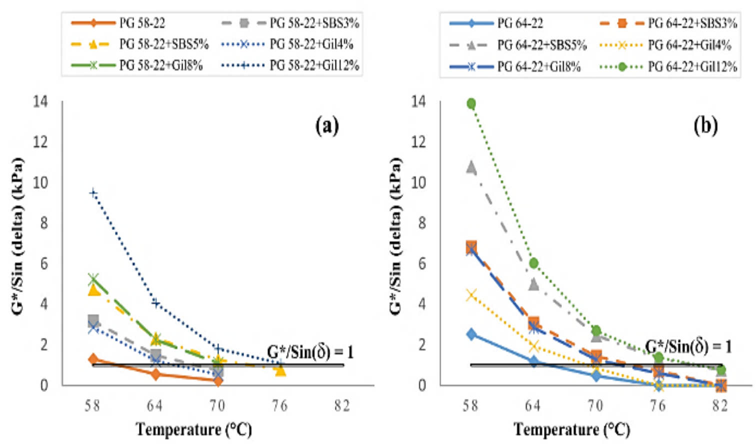


FIGURE 26. Pre-aging G*/sin (δ) Results for Natural and Improved Binders. (a). PG58-22, (b) PG 64-22 . (Mirzaiyan et al. 2019)

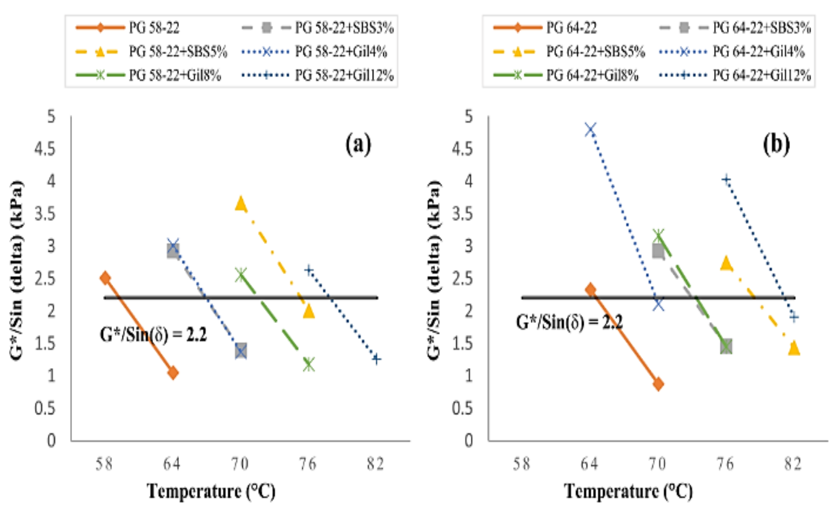


FIGURE 27. After aging, G*/sin (δ) yields results for both improved and natural binders. (a). PG 58-22 , (b) PG 64. (Mirzaiyan, D., et al. 2019)

According to Sobhi et al. (2020), for Warm Mix Asphalt (WMA), the authors evaluated the mechanical performance and the durability of the asphalt mixtures modified with a composite (Sasobit and Gilsonite) and with Sasobit only. The Marshall stability tests showed that Sasobit, in particular, improves the stability value by approximately 16.5% over the control. The addition of Gilsonite even further boosts the stability, with increases of 22.9% and 36.7 % for 5% and 9% Gilsonite, respectively, in a binder modified with 3% Sasobit. However, this increase in stability does not seem to continue at higher proportions of Gilsonite content. This is likely due to a decrease in the fracture behavior of the mixtures due to increased brittleness. Sasobit also improves the resistance against plastic deformation as demonstrated by a lowered Marshall flow value. The flow values of the composite modifier are also found to be lower than neat and Sasobit-modified binders; however, the reduction is not substantial when the concentration of Gilsonite is increased from 5% to 13%.

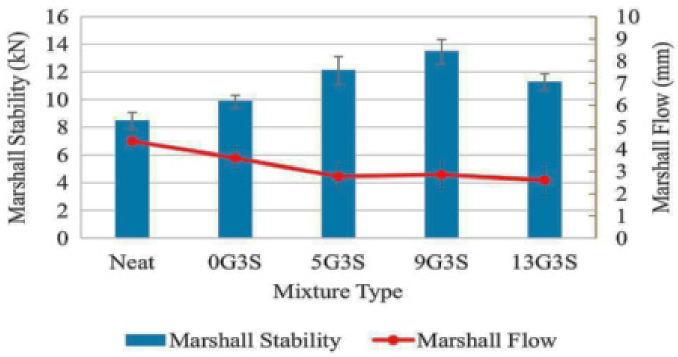


FIGURE 28. Marshall Stability of Asphalt Mixtures (Sobhi et al. 2020)

Zhou, L., et al. 2020 employed a terminal blend (TB) of CR and HDPE, SBS (with sulfur stabilizer), CR, and varying weight percentages of gilsonite (4, 8, 12, 20, 24). AC and gilsonite were combined at 180 degrees Celsius. It is unknown what the modification process involves. The modified asphalt binder was subjected to BBS and FTIR tests, while the modified asphalt was subjected to two investigations. A healing fatigue test using a four-point beam (4PB) combination at 25 °C was performed on modified asphalt mixes. There is no clarity concerning the way the mixtures were manufactured. The design of the asphalt pavement was done using a Superpave method, which was modified in light of the previous work. Optimal dosages of 4,5% SBS-modified asphalt, 15% TB-modified asphalt, 24% gilsonite-modified asphalt, 8% HDPE-modified asphalt, and 18% CR-modified asphalt were used to test the combinations in fatigue testing. Other than gilsonite, all of the modifiers had a detrimental effect on the asphalt's initial binding strength. The bond performance of the asphalt binder may be enhanced by adding the appropriate quantity of gilsonite. The proper amount of gilsonite may improve asphalt's ability to repair itself. The optimal amount of gilsonite was found to be between 12 and 20 percent.

Ameli et al. 2021 considered the possibility of using Gilsonite as a binder to provide a better moisture resistance in stone matrix asphalt (SMA) mixes with Crumb rubber (CR) addition. As per the findings, use of Gilsonite enhances the resilient modulus (Mr) and indirect tensile strength (ITS) of the asphalt mixtures. The results also revealed that CR is associated with the improvement of the ITS of the asphalt mixtures. However, when 10% CR is used, the MR values increase, but when 15% and 20% CR is used, the MR values decrease. The mixes with the highest ITS values among the different specimens created contain 30% Gilsonite and 20% of CR. The results further indicate that the specimens with the lowest TSR values incorporate 30% of Gilsonite with 20% of CR, which suggests that they have better resistance towards water susceptibility.

Mahmoudi Nehrani et al. 2022 added volumetric fillers of 5 weight percent, 7 weight percent, and 9 weight percent gilsonite to their concrete cement. Ten, fifteen, and twenty-weight percent Rice Husk Ash (RHA) were added to the cement to further hybridize it. Concrete samples were subjected to abrasion tests, flexural strength, compressive strength, and tensile splitting strength measurements. These two additives work together to reduce the cement mixture's compressive strength. However, the addition of RHA and gilsonite improves the abrasion results of concrete, increasing the flexural strength and tensile cracking by 4-7% in certain percentages of the concrete.

Sobhi et al. 2022 stated that gilsonite (5, 9, 13 weight percent) fusions with Sasobit (3 weight percent) were used to modify an AC 62 pen. For 30 minutes, the AC and gilsonite were mixed at high shear (2400 rpm) and 140 degrees Celsius. After increasing the temperature to 160 degrees Celsius, mixing was carried out for 30 minutes, but at a higher Shear rate (4000 rpm). Mixing continued for 15 minutes at the same speed, but at a higher temperature of 180 degrees Celsius. Sasobit was incorporated into the mixture at 140 degrees Celsius and blended at a slow speed (200 rpm) for 20 minutes. These procedures seem quite standard for modifying ACs, and they are followed by the standard characterization tests on the modified asphalts, such as FTIR, storage stability, shear fatigue testing, and DSR rheology studies. It was discovered that the addition of gilsonite and Sasobit to the modified asphalt increased the binder asphalt's stiffness, guaranteeing improved performance against rutting and high temperatures. Additionally, both additions made sure that stable modified asphalt would form that would not separate while kept in storage. Sasobit enhances the workability of asphalt treated with gilsonite. When used with Sasobit, gilsonite may help with moisture susceptibility in HMA and WMA applications, even though it does not chemically link with the underlying asphalt. Sasobit-containing asphalt is thought to lessen its resistance to moisture damage, although gilsonite helps to increase it.

## CHALLENGES IN IMPLEMENTATION

The integration of natural asphalts into HMA systems faces several hurdles, including variability in the properties of NAs depending on their geographic origin. Additionally, compatibility with existing refinery processes and the high cost of sourcing and processing these materials could limit their scalability.

## RESEARCH GAPS

There is a lack of long-term field performance data for NA-modified asphalt mixtures, particularly in varying environmental conditions. Furthermore, comprehensive cost-benefit analyses comparing NA-based and conventional petroleum asphalts are scarce, limiting the economic feasibility of widespread adoption.

## PROMISING NATURAL ASPHALTS

Gilsonite and TLA, in particular, show the most promise due to their excellent performance in enhancing asphalt properties and their potential for reducing the environmental impact of asphalt production. Their use in high-traffic roadways and pavements in hot climates could offer significant benefits.

## CONCLUSION

Figure (29) presents a summary of a group of studies that utilized different materials at various proportions with the aim of improving asphalt properties. Table (4) also provides an overview of the most prominent of these studies, highlighting the types of additives used, the tests conducted, and the effects of these additives on asphalt properties. The results of these studies varied, with some showing significant improvements in the physical and mechanical properties of asphalt.

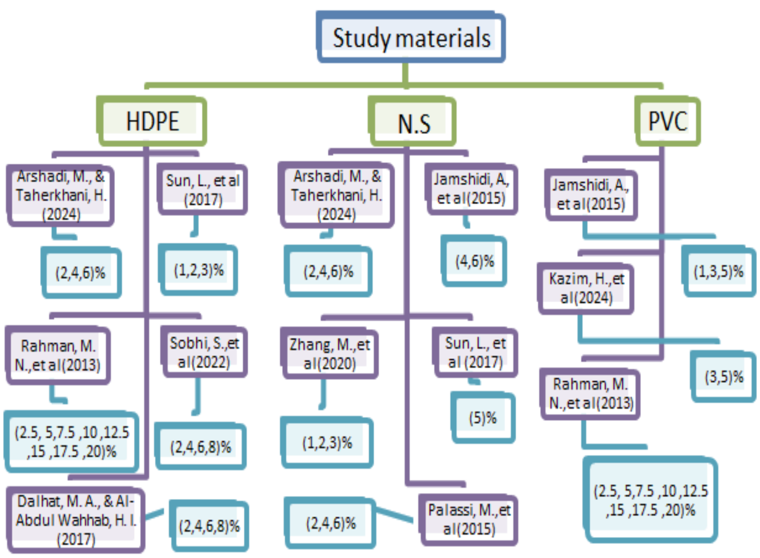


FIGURE 29. Use Ratios Of Additives For Some Studies

TABLE 4. Details the addition of materials to asphalt during the various tests conducted in the mentioned sources.

| References | Tests | Explanation |
|---|---|---|
| Dalhat, M. A., & Al-Abdul Wahhab, H. I. (2017) HDPE | Penetration | Decreased → Higher stiffness )↓30–50% at 6–8% HDPE( |
| | Softening Point | Increased → Better high-temp resistance |
| | Viscosity | Increased → Improved flow resistance |
| | Ductility | Slightly decreased → Less stretchable |
| | G* (DSR) | Increased → Better rutting resistance |
| | Phase Angle (δ) | Decreased → More elastic behavior |
| Jamshidi, A., et al. (2015) PVC – N.S | Viscosity | (↑ High (40–80%) – N.S) , ( ↑ Medium (30–50%) – PVC) |
| | Dynamic Shear Rheometer (G* ) | (↑ Strong – N.S) , (↑ Good – PVC) |
| | Dynamic Shear Rheometer (δ Angle ) | (↓ Higher → Higher Elasticity - N.S) , (↓ Slightly Lower - PVC) |
| | Time Stability | )Excellent - N.S) , (Good - PVC) |
| Arshadi, M., & Taherkhani, H. (2024) HDPE-N.S | Penetration Test | Decreased significantly → binder became stiffer (by 25–45% with 4–6%) |
| | Softening Point Test | Increased → improved thermal resistance (b y 10–20% (e.g., from 45°C to 54°C) |
| | Rotational Viscosity Test | Increased → better high-temp performance (↑ by 50–150%, depending on HDPE %) |
| | Dynamic Shear Rheometer (DSR) | better resistance to rutting. |
| | Bending Beam Rheometer (BBR) | Enhanced low-temperature performance |
| Sun, L., et al. (2017) HDPE-N.S | Penetration Test | Significant decrease |
| | Softening Point Test | Increase |
| | Rotational Viscosity Test | Significant increase |
| | DSR | Clear increase |
| | BBR | Slight increase |
| Kazim, H.,et al. (2024) PVC | Rotational Viscosity Test | Increase |
| | Wheel Tracking | I got better |
| Rahman, M. N.,et al. (2013) PVC - HDPE | Stability | Increased significantly up to 10% PE and 7.5% PVC → Improved deformation resistance |
| | Unit Weight | Increased up to optimal levels, then decreased with higher percentages |
| | Flow | Increased with higher percentages → Indicates better flexibility, but very high values may mean too much softness |
| | Air Voids | Decreased up to 10% PE and 12.5% PVC → Then increased at higher dosages |
| | VMA | Reached minimum at 7.5% for both PE and PVC → Indicates better aggregate-binder bonding |
| Palassi, M.,et al. (2015) N.S | Penetration Test | Increased with increasing ratio → improved heat resistance. |
| | Softening Point Test | Decreased → indicates increased stiffness. |
| | Ductility | Decreased with increasing ratio → improved heat resistance. |
| | Shear modulus G* | Increased → improved resistance to deformation under load. |
| | Phase angle δ | Decreased → indicates higher elasticity at optimum ratios (4–6%). |
| | Screw resistance (MSCR) | Improved significantly with increasing ratio up to 6% → excellent performance in hot and high-pressure regions. |

## CONCLUSION

This review highlights the promising role of natural asphalts (NA) such as Gilsonite, Trinidad Lake Asphalt, and rock asphalt in modifying hot mix asphalt (HMA) for flexible pavement construction. The inclusion of NAs has been shown to improve key performance characteristics, including resistance to rutting, tensile strength, and moisture susceptibility. These enhancements suggest that NAs could be a sustainable alternative to petroleum-based asphalts, offering both environmental and performance benefits.

However, despite the positive findings, several challenges must be addressed for the practical implementation of NA-modified asphalt. These challenges include the variability of NA sources, their compatibility with existing refinery processes, and the need for further validation through long-term field performance studies. Additionally, comprehensive cost analyses are necessary to assess the economic viability of using NAs in large-scale asphalt production.

Policymakers and engineers should consider piloting the use of NA-modified asphalts in high-traffic areas, particularly in regions with hot climates, where the enhanced rutting resistance and durability of these materials could provide significant cost savings in pavement maintenance. Furthermore, industry standards for the use of natural asphalts should be developed to ensure consistency in performance and quality.

## FUTURE DIRECTIONS

Further studies are needed to explore the long-term durability of NA-modified asphalts in field conditions, as well as their cost-effectiveness in comparison to petroleum-based products. Additionally, research should focus on optimizing the processing and blending of NAs to enhance their compatibility with modern asphalt production techniques.

## ACKNOWLEDGEMENT

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## DECLARATION OF COMPETING INTEREST

None

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