IJDI-ERET

INTERNATIONAL JOURNAL OF DARSHAN INSTITUTE ON ENGINEERING RESEARCH AND EMERGING TECHNOLOGIES
Vol. 13, No. 2, 2024
www.ijdieret.in

DOI 10.32692/IJDI-ERET/13.2.2024.2403

(Research Article)

Modeling the Impact of Binder Type and Nano Additives on Creep Stiffness of Green Asphalt Binder

S. I. Sarsam[1*]

[1]Sarsam and Associates Consult Bureau (SACB), Baghdad, IRAQ*

Abstract

When the environment temperature reaches a critical value below the freezing limit which is known as (critical cracking temperature), the thermal stresses exceed the stability of the material, and thermal cracking occurs. Thermal cracking is a serious distress type and exhibits a serious negative influence on the performance of flexible pavement, since rainwater may penetrate freely in the pavement structure and accelerate the deterioration process as the traffic loading proceeds through the service life of the pavement. The flexural-creep stiffness of asphalt cement binder is considered as a good indicator of the resistance to thermal cracking of the binder at low temperature. It is usually measured with the aid of Bending Beam Rheometer (BBR). In the present assessment, the influence of Nano additives (silica fumes and fumed silica) on creep stiffness was evaluated and modeled. Such additives were implicated to obtain the green binder. Conventional asphalt cement binder with penetration grades (40-50) and (60-70) were assessed. It was detected from the experimental program that modification of the conventional binders with Nano additives exhibit significant control on the creep stiffness and the developed power mathematical models gave the best experimental fit, exhibit a high coefficient of determination, and are recommended to predict the impact of Nano additives on the creep stiffness of asphalt binder. It was noted that the creep stiffness of (60-70) binder is harder than that of (40-50) binder by (21.5 and 20) % at the initial point of loading and at failure respectively. The creep stiffness of (40-50), and (60-70) green asphalt binders treated with fumed silica is higher than that of control binder by (25 and 12.5) % at failure respectively. While the creep stiffness of (40-50), and (60-70) green asphalt binders treated with silica fumes is higher than that of control binder by (35 and 17.8) % at failure respectively. It was concluded that Nano additives are recommended to control the creep stiffness of green asphalt binder regardless of the sol and gel types of the conventional (60-70) and (40-50) binders.

Keywords: Flexural creep stiffness, Nano additives, Asphalt cement binder, bending beam rheometer, modeling.

1. Introduction

Through the service life of flexible pavements, asphalt concrete mixture degrades due to repeated traffic loading and environmental conditions such as temperature, moisture, ultraviolet radiation from the sun, and oxidation. Such environmental factors exhibit adverse influence on the behavior of asphalt binder. Asphalt concrete pavement practices varying degrees of failure during the service life, such as cracking, rutting, and moisture damage, all of which are associated with the adhesion, rheology, cohesion, and durability of the asphalt binders used. Such rheological and physical properties are related to the chemical composition of the asphalt cement binder directly, and more specifically to the intramolecular interactions. Zhao and Yang, [1] reported that utilization of industrial solid by-product and waste such as fly ash, phospho-gypsum, and those with typical chemical components related to pozzolanic reaction, such as SiO_2 (silicate), CaO and Al_2O_3 (oxide), CaOH (carbonate), SO_4 (sulfate), and related solid wastes such as blast furnace slag, desulfurization ash, red mud, and steel slag, were globally used in the construction of green pavement. Raufi et al., [2] studied the influence of implication of Nano materials, including Nano-$CaCO_3$, Zyco Therm, and Nano-Bentonite on the asphalt concrete mixture performance. Such modification with Nano additives was evaluated through the testing of mechanical properties. It was reported that Nano additives can improve slightly the stability of Marshall and decrease the asphalt cement binder percentages after Nano modification. The effect of Nano silica addition on the behavior of asphalt concrete was investigated by Yao et al., [3]. It was stated that the flow number and the dynamic modulus of Nano silica modified asphalt mixtures had improved, while the susceptibility to rutting was reduced of Nano additive modified asphalt

[*]Corresponding Author: e-mail: saadisasarsam@coeng.uobaghdad.edu.iq
Tel-+00964-7901878167
ISSN 2320-7590 (Print) 2583-3863 (Online)

mixtures. However, the performance in fatigue cracking of the treated asphaltic mixture was enhanced. Malarvizhi et al., [4] conducted comparative physical tests on asphalt concrete mixtures treated with Nano-clay as modifier and control binders. The major benefits of using Nano clay powder were assessed. It was stated that Nano-clay additive will improve stability, indirect tensile strength, and resilient modulus of asphalt concrete. The change of the rheological behavior of asphalt cement binder after digestion with Nano additives was investigated by Sarsam, [5]. The modified asphalt cement binders were subjected to the verification of the rheological properties. It was noticed that the penetration viscosity number declined while the viscosity increased. It was revealed that implementation of Nano additives exhibits lower temperature susceptibility when compared with the control binder. Fusco et al., [6] reported a review of the most popular Nano additives for implication into asphalt concrete mixtures; Nano-calcium oxide, Nano-clay, and Nano-silica have been investigated. The physical behavior of the modified mixture with additives was evaluated. It was detected that the resistance of the modified mixture to rutting, and permanent deformation was achieved and improved because of the increment in the viscosity of the binder after treatment with Nano additives. It was stated that the Nano additives were able to increase the service life of asphalt concrete mixture due to various interdependent physical-chemical mechanisms which can control the resistance of the mixture to failure due to fatigue. Li et al., [7] stated that implication of the Nano material additives exhibit specific positive characteristics when it is compared with the common material, while exhibits some novel properties which make it possible to be applied in the field of paving as an additive to asphalt binder due to its large surface area and small size. It was noted that the implication of Nano materials may dramatically enhance some of the properties of asphalt material such as resistance to aging, visco-elasticity, fatigue, high temperature properties, and moisture susceptibility. Nano particle type and content, binder type, and particle size must be considered to explore the mechanism of modification. Wu et al., [8] investigated existing research on filler-asphalt interaction mechanisms and models. It was stated that such interaction is a very complex physicochemical interaction. The rheological theory was selected to be suitable for evaluating filler-asphalt interaction. It was reported that the main factors that influence the filler-asphalt interaction are the chemical composition and the physical properties of filler and asphalt. Wang, [9] studied the interface models of three mineral crystals additives and asphalt binder through molecular dynamic simulation process. The influence of temperature change on the interaction strength was analyzed based on the service temperature of asphalt concrete mixture. It was concluded that due to the increment of model temperature, the non-polar components moved away from their surface, particularly saturate molecules while the polar components of asphalt moved toward the surface of Al_2O_3 and CaO crystals. Azarhoosh, et al. [10] investigated the influence of implication of Nano zinc oxide in various percentages as additive on the cracking due to fatigue of asphalt concrete mixtures. It was stated that the mechanism which influences the adhesive and cohesive bonds between the binder and the aggregates may be evaluated with the aid of surface free energy concept. The test results declared that the implication of Nano Zink oxide exhibits decline in the acid component of surface free energy, however, it shows an increment of the basic component of the binder which control the adhesion between the binder and aggregate. Sayadi and Hesami, [11] stated that the asphalt cement binder becomes hard after the process of freeze-thaw cycles, however, the additive can influence the self-healing capability and the fatigue property of the treated asphalt binder with additives after freeze-thaw cycles. It was addressed that the asphalt binder-additive interaction is more prominent to influence the rheological property. It was revealed that the asphalt binder-additive interaction may be evaluated effectively by the interaction indexes. Several studies were conducted on the capability of Nano-sized particles for improving the asphalt binder in its rheological characteristics as reported by Steyn, [12]. However, scared work has focused on the influence on fatigue life to enhance the healing property and mechanical characteristics of asphalt concrete. Hamedi and Esmaeili, [13] investigated the effect of implicating two types of Nano anti-stripping additives (Nano aluminum oxide and Nano iron oxide) on the susceptibility to the damage by moisture of hot mix asphalt concrete mixtures. Testing results exhibited that the implementation of Nano materials was able to improve the adhesive forces between the aggregates and asphalt binder by increasing the basic properties and lowering the acidic property of the treated asphalt binder. Lotfi-Eghlim and Karimi, [14] assessed the major benefits of implementation of Nano particles to modify the asphalt concrete mixtures. It was stated that Nano Al_2O_3 was able to improve the dynamic characteristics of the mixture of asphalt concrete. The test results exhibited that the fatigue life of Nano-modified asphalt-concrete mixtures is significantly extended as compared with control asphalt mixture. A new model is presented to characterize and predict the behavior of asphalt concrete mixtures in fatigue, which were modified with nano Al_2O_3 under dynamic loading conditions. The impact of the implication of Nano-SiO_2 on the ability to crack in asphalt concrete mixtures was experimentally investigated by Shafabakhsh et al., [15]. Yao and You, [16] assessed the use of Nano materials (Nanomer material, carbon microfiber, Nano clay, and Nano silica,) for modification and evaluation of the asphalt concrete mixture. The test results presented significant improvement of the dynamic modulus of Nano treated asphalt concrete and reduction of the rutting susceptibility. Mechanical tests were conducted by Ghaffarpour et al. [17] on asphalt concrete mixtures containing untreated binder and Nano-clay treated binder. The testing results exhibited that implementation of Nano-clay for modification of asphalt binder can improve the resilient modulus, stability, and indirect tensile strength of asphalt concrete. Sarsam, [18] assessed the influence of Nano additive material (silica fumes) on the energy dissipation of asphalt concrete mixture through the resistance of the mixture to the fatigue process. It was stated that implementation of Nano material for modification of asphalt binder exhibits lower energy dissipation using variable micro strain levels. The implication of Silica fumes exhibited minimal influence on energy dissipation and showed shorter fatigue life. Wang et al., [19] stated that the rheology of asphalt cement binder is an important consideration for selecting the proper binder for pavement design. It is related to its chemical composition and microstructures. The predominant forms of molecular interactions between asphalt cement molecules on the bases of the chemical functionality of the asphalt cement binder was described and the behavior of asphalt cement binder in terms of molecular interactions was explained. It was revealed that asphalt cement binder mainly comprises hydrogen (8–12%), carbon (80–88%), and few heteroatoms including oxygen (0–2%), sulfur (0–9%), nitrogen (0–2%), and traces of nickel vanadium as well as manganese. Nahar, [20] stated that Innovative solutions with a focus on better asphalt binder properties such as implementing additives into the binder may improve the binder performance by making the rate of deterioration slower and may offer efficient, fast, and cost-effective repair methods. It was stated that the chemical composition of asphalt binder is the key parameter which influences the microstructure properties. The asphaltene fraction of the binder is responsible for most of the structuring observed, while the wax component of the binder has been found to induce the phase separation of asphalt materials. Temperature during construction of the pavement and its variation throughout the service life may influence the properties of asphalt binder to a great extent. Sarsam, [21] reported that implementing Nano materials into the binder exhibit positive influence on asphalt cement by reducing its temperature susceptibility, increasing the softening point and viscosity. Büchner et al., [22] reported that creep deformation of asphalt binder can be verified through static or cyclic compression tests at freezing temperature. Creep tests can be performed by means of a dynamic Shear Rheometer (DSR) or bending beam rheometer. Asphalt mastics (binder + additive) and conventional asphalt cement binders were tested and the creep properties obtained from asphalt binder tests, and asphalt mastic tests were correlated. It was stated that the additive has a significant influence on the creep property of the asphalt mixture. Kommidi and Kim, [23] stated that formation of transverse cracks in asphalt pavement become visible when the thermal stress which was built up in the restrained asphalt pavement with decreasing temperature exceeds the asphalt cement binder tensile strength. Improving the tensile strength and stress relaxation ability of asphalt cement binder is recommended by implication of additives to reduce the risk of thermal cracking in asphalt pavements. Zeiada et al., [24] reported that the BBR test has received growing concerns since the preparation and testing process of the beam specimens are long-time-consuming beams. Frequency sweep tests were conducted on asphalt binders at temperatures of 0 °C to predict the flexural creep stiffness and m-value of asphalt binder while conversion from shear loading to bending loading was conducted. It was addressed that the predicted values of m (60) and S (60) values, which evaluates the ability of asphalt cement binder to relieve the thermal stress accumulated due to a drop in temperature were comparable to those measured by the BBR, which well demonstrated the feasibility of the proposed DSR-BBR conversion method. Cheng et al., [25] assessed the rheological property of asphalt cement binder and mastic under freeze-thaw cycles through the multiple stress creep recovery test, bending beam rheological test, and linear amplitude sweep test. The results exhibited that as freeze-thaw cycle increased, the recovery of asphalt cement binder increased, and the non-recoverable creep compliance of asphalt binder declined. The low-temperature creep stiffness of asphalt binder and mastic increased as the freeze-thaw cycle increased. Abedali et al., [26] developed a modified apparatus for simulating the reality of asphalt binder in the asphalt mixture, measuring the deflection values at different test temperatures, and measuring the flexural-creep stiffness properties of asphalt binder. Huang et al., [27] evaluated the critical high and low temperature rheological behavior of a modified asphalt binder using low-temperature creep stiffness properties by the BBR test. Technical indexes such as the creep recovery rate and the unrecoverable creep compliance were measured and calculated, while the creep speed and creep stiffness are used as technical indexes for low-temperature properties. The results exhibit that the implication of modifiers into asphalt binder increases the creep recovery rate and reduces the unrecoverable creep compliance of the asphalt binder. At low temperatures, relaxation time decreases. Saboo and Kumar, [28] assessed the asphalt cement binder's response to multiple stress creep and recovery test. It was reported that modified binders exhibit delayed elastic response. It was concluded that when modeling creep stiffness, power law models may be selected to simulate the measured response and incorporate non-linear viscoelastic response of the modified binders. Implementation of modified asphalt binder is among the most common techniques employed to improve the strength characteristics and performance of asphalt concrete mixtures at low temperature as revealed by Celauro et al., [29]. Lu et al., [30] stated that thermal cracking of asphalt concrete is a major mode of failure of asphalt pavement in cold climate regions. The rheology at low temperature of asphalt cement binder has been found to be the principal factor influencing the thermal cracking of asphalt pavements. Sun et al., [31] stated that studies on creep of asphalt cement binder provides satisfactory predictions of flexural creep stiffness and m-value. However, using empirical equations may decline the accuracy of prediction, while the nonlinear regressions are required for converting the dynamic shear modulus of the binder or dynamic shear compliance to shear creep compliance. Tarefder et al., [32] assessed the influence of freeze-thaw cycles on asphalt binder samples in the laboratory with the aid of bending beam rheometer. It was noted that the freeze-thaw cycles cause damage to the binder, which is exhibited in the reduction of stiffness with increasing the cycles. Radovskiy, and Teltayev, [33] presented a mathematical model that expresses the asphalt binder stiffness modulus as a function of time, temperature, and the simple properties of asphalt cement. It was addressed that the developed model can be implemented in assessing the stiffness modulus of asphalt binder which can be easily calculated in a wide range of loading time and temperatures. Hischke, [34] stated that the creep properties in asphalt concrete are the cause of rutting in existing pavement structures. Many researchers have modeled the creep and recovery behavior of asphalt binder using different mathematical and rheological models. Numerous modifications to those models have also been attempted, to include various viscoelastic and visco-plastic characteristics, mostly for modified binders. The aim of the present investigation is to model the influence of two types of Nano additives (fumed silica and silica fumes) on the flexural creep stiffness of two types of asphalt cement binder with penetration grade of (60-70, and 40-50). The bending beam rheometer (BBR) test will be implemented to measure the creep stiffness of the prepared green asphalt cement binder.

2. The Materials and Methods of Testing

2.1 Nano additives: Two types of Nano additives have been implemented in the present investigation using different percentages for modification of asphalt cement binder and preparation of the green asphalt binder, Silica fumes and fumed silica.

2.2 Silica fumes: Silica fumes are an ultra-fine powder, densified, gray colored which has a high content of amorphous silicon dioxide and consists of very fine spherical particles around 100 times smaller than a grain of cement. The specific surface area of silica fumes is 200000 m2/kg, while the specific gravity is 2.134. It is considered to have a Nano size. It was obtained from the local market. Details of chemical composition and physical properties of the silica fumes are listed in Table 1, while Table 2 exhibits the chemical composition of silica fumes. Figure 1 exhibits the Silica Fumes.

2.3 Fumed silica: Fumed silica is supplied as a fluffy, white powder. It has a specific surface area of 100000 m2/kg and is considered to have a Nano size. The physical properties of fumed silica are shown in

Table 1, while the chemical compositions of fumed silica are presented in Table 1, while Table 2 exhibits the chemical composition of fumed silica. Figure 1 exhibits the fumed silica.

Figure 1. The implemented nano additives

Table 1. The physical properties of fumed silica as supplied by the manufacturing plant

Physical properties	Test results	
	Fumed silica	Silica fumes
Color	White	Gray
Specific surface area m²/kg	200000	100000
Density kg/m³	202	213
PH	4.1	4.5
% Retained on 40 µm sieve	< 0.04	-----
Moisture %	0.82	Non

Table 2. Chemical components of nano size additives

Oxide type	Percentage	
	Fumed silica	Silica fumes
SiO_2	99.1	90
Fe_2O_3	35.0 ppm	1.0
Al_2O_3	< 0.035	3.0
CaO	0.03	1.2
MgO	52.0 ppm	< 6%
Loss on ignition	0.7	1.0

2.4 Asphalt cement binder: Asphalt cement binder of two penetration grades of (40-50) and (60-70) were obtained from Durah oil refinery. Such types of binder are usually implemented in asphalt paving work in Iraq. Table 3 presents the physical properties of asphalt binders, and Table 4 exhibit the rheological properties of the tested asphalt binders.

Table 3. The physical properties of asphalt cement binders

Property	ASTM, [35] specification	Asphalt cement (40-50)	Asphalt cement (60-70)
Penetration at 25˚C, 100gm, 5sec, (0.1mm)	D-5	44	66
Softening point, ˚C	D-36	50	48
Ductility at 25 ˚C, 5cm/min, (cm)	D-113	+100	+100
Resilience (ball strain recovery) %	D-5329	98	99
Specific gravity	D-70	1.042	1.030
After conducting the thin film oven test			
Penetration at 25°C, 100gm, 5sec, (0.1mm)	D-5	33	51
Loss in weight	D-1754	0.17	0.24
Ductility at 25 °C, 5cm/min, (cm)	D-113	73	90

Softening point, ˚C	D-36	54	51

Table 4. Rheological properties of asphalt cement binders

Asphalt cement type	Penetration grade (40-50)	Penetration grade (60-70)
Penetration-index (PI)	-1.474	-1.370
Penetration viscosity number (PVN)	6.09	6.204
Temperature of equivalent stiffness (TES)	-22	-25
Viscosity (poises)	3690	2123
Stiffness modulus (N/m²)	2000 x10^3	1000×10^3

2.5 Preparation of green asphalt cement binder: The green asphalt binders were prepared in the laboratory by implementing the wet process. In the wet process, asphalt cement was heated to 150 °C and then blended with the Nano additives (fumed silica or silica fumes) with variable specified percentages. The blending speed of 1300 rpm was retained for 30 minutes to furnish the possible chemical and physical bonding of the binder components with the Nano additives. It was noticed through the blending process that the asphalt cement softens, swells and exhibits bubbles as an indicator of possible chemical reaction. The degree of dispersion of the Nano additives was controlled by the blending speed, blending duration, and mixing temperature. Beam specimens of 12.5 mm in width, 125 mm in length, and 6.25 mm in height were prepared. The range of Nano additives was (1 to 5) % of the binder weight with 1 % increment. The optimum additives content was selected based on the significant change in the physical and rheological properties of the prepared green binder specimens. Details of mixing and obtaining the optimum additives can be found in Sarsam and Lafta, [36]. The summary of the optimum Nano additives content is shown in Table 5.

Table 5. Optimum additives content

Nano size additive	
Silica fumes	Fumed silica
2 %	3 %

2.6 Testing of green asphalt cement binder: To characterize viscoelastic behavior of asphalt materials, the creep test with the Bending Beam Rheometer was implemented. In this test, stress is applied instantaneously to the prepared asphalt cement binder specimen and maintained constantly for the entire duration of the test. The prepared asphalt binder samples were subjected to the creep stiffness determination with the aid of bending beam rheometer apparatus which follows the recommended testing procedures by AASHTO, [37]. Figure 2 exhibits the bending beam rheometer test apparatus.

To characterize the low temperature stiffness properties of binders. A simply supported small asphalt binder beam of 12.5 mm in width, 125 mm in length, and 6.25 mm in height was subjected to a constant creep load at the mid-point of the beam, and the subsequent mid-point deflection was measured. The prepared specimens were maintained at low temperature (approximately -18°C) using a deep freezer. After seating the asphalt binder specimen in the apparatus, the test starts at (-18°C) by applying a 100-gm load to the beam center for a total time of 240 seconds, at the meantime, the vertical deflection is monitored and measured. Superpave specification, AASHTO M320, [38] requires that the creep stiffness must be less than or equal to 300 MPa at 60 seconds and creep rate (m-value) greater than or equal to 0.300 at 60 seconds.

Figure 2. Bending beam rheometer (BBR) test apparatus

3. Test Results and Discussions

3.1 Modeling the influence of conventional binder penetration grade on the creep stiffness: Asphalt cement binders can be divided into two major fractions on the basis of the chemical composition: asphaltenes and maltenes as reported by Farhan et al., [39]. The asphaltenes fraction controls the physical characteristics of the binder which are highly affected by the asphaltene content. Higher asphaltene content exhibits stiffer and more sticky asphalt cement binder. While maltenes consist of aromatics, saturates, and resins. Based on the percentages of the four fractions, Saturates, Aromatics, Resins, and Asphaltene (SARA), asphalt cement is divided into gel and a sol type as stated by Siroma et al., [40]. The sol type has an adequate quantity of aromatics and resins of sufficient solvating power, while the asphaltenes are completely peptized and the subsequent micelles have free movements inside the asphalt cement. However, for the gel type, the aromatic and resin fractions are not presented in adequate amounts to peptize the micelles, or have not sufficient solvating power, whereas the asphaltenes associate and form irregular structures as presented in Figure 3. Gel type asphalt cement binder is less ductile and more elastic than the sol type. Most asphalt cements have intermediate character between sol and gel types as revealed by Lesueur et al., [41].

The assessed conventional Asphalt cement binder's composition can be divided into four parts as demonstrated in Table 6. It shows that the asphaltene ratio represents (19, and 8.7) % of the overall asphalt composition for (40-50, and 60-70) grade binders respectively. Gastel index is defined as the dispersing capability of maltene to asphaltene and noted as the peptizing power, the growth of the Gastel index leads to decline in colloidal stability. The decline in Gastel index indicates a growing of sol character of the asphalt cement. Oyekunle [42] demonstrated that such an index is implemented in addition to (SARA) in distinguishing the variation in asphalt binder behavior on the basis of the chemical composition. Another indicator of asphalt binder behavior is the ratio of aromatic to asphaltene, which exhibits an assessment of the solvation capacity of the asphalt cement. The lower ratio indicates fewer peptized asphaltenes, and results in increasing the gel character and the softening point of the asphalt cement as reported by Weigel and Stephan [43]. Hermadi, and Pravianto, [44] revealed that the rise of saturates lead to the decline in the rheological properties of the asphalt cement binder, and the asphalt exhibit viscous, less elastic, more resistant to fatigue cracking, and to plastic failure. It can be noticed that the chemical composition of the asphalt cement binders is variable among the penetration grade which will have an influence on the rheological and physical properties. Higher asphaltene content cause reduction in penetration, which is a measure of the consistency of asphalt cement and exhibits stiffer structure and higher viscosity and change the physical and rheological properties.

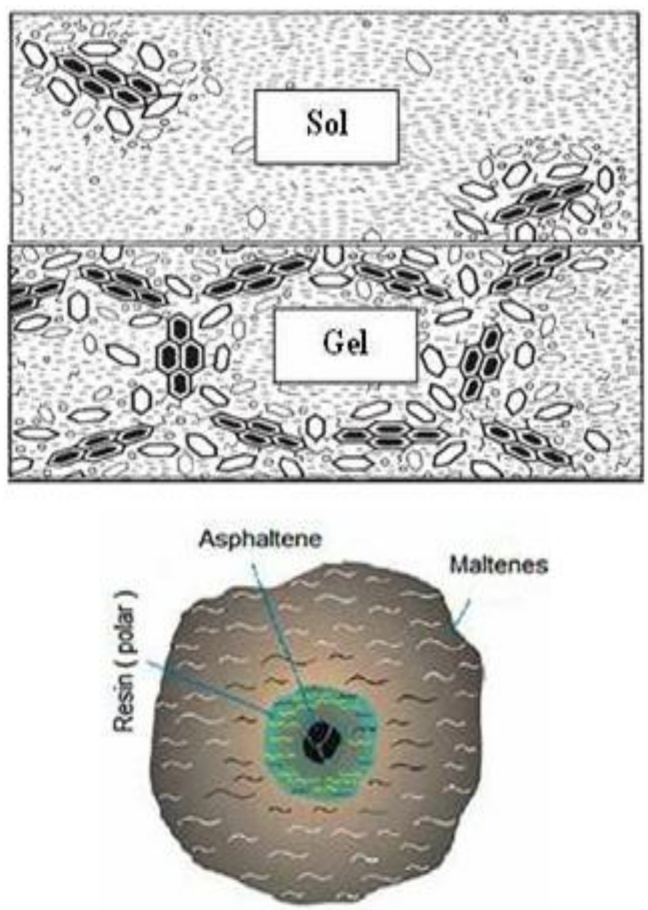

Figure 3. Variation between sol and gel types of asphalt binder, Lesueur et al., [41]

Table 6. Major chemical composition SARA of Durah (40-50) asphalt binder, as per Saad and Ahmed, [45]; Al Jafari and Ismael, [46]

SARA Fractions	Content (%) by weight	
	Penetration grade 40-50	Penetration grade 60-70
Saturates	19.53	6.5
Aromatics	26.8	58.5
Resins	29.47	26.4
Asphaltenes	19.0	8.7
Gastel index	0.684	0.179
Aromatic/asphaltenes	1.41	6.72

It can be stated that the penetration grade (60-70) asphalt cement is of sol type while the penetration grade (40-50) asphalt cement binder is of gel type. Figure 4 exhibits the impact of binder penetration grade on creep stiffness of conventional asphalt cement. Higher creep stiffness is noticed for (40-50) binder throughout the testing period when compared with the (60-70) binder. This could be attributed to the gel type of (40-50) binder when compared to the sol type of (60-70) binder. The creep stiffness of (60-70) binder is lower than that of (40-50) binder by (21.5 and 20) % at the initial point of loading and at failure respectively. However, the decline in creep stiffness throughout the testing period is (21.5 and 20) % for (40-50) and (60-70) binders respectively. A similar trend of decline in the creep stiffness is observed through the loading period regardless of the binder penetration grade. Such behavior could be attributed to the higher asphaltenes and saturates and lower aromatics content in the composition of (40-50) binder. Such behavior is further supported by the obtained models. Similar findings were reported by Raufi et al., [2]; Wang et al., [19]; Nahar, [20]; and Moon et al., [47].

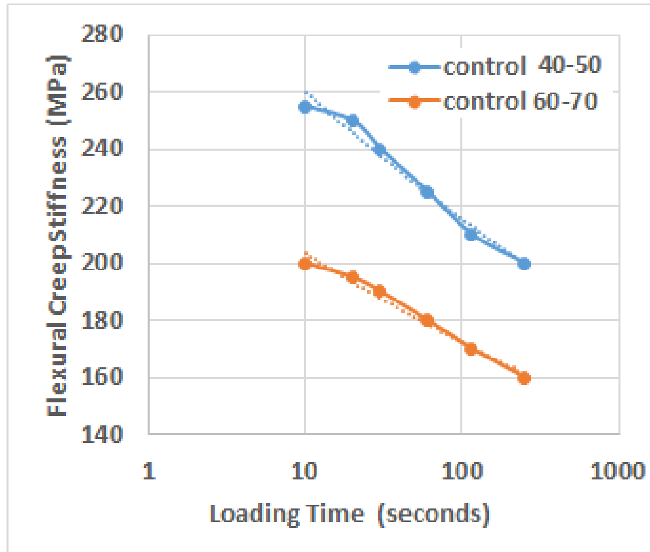

Figure 4. Influence of binder penetration grade on creep stiffness

Table 7. Deterioration models of creep stiffness for conventional binders

Additive type	Intercept (MPa)	Slope	Mathematical power model	R^2
Control (40-50), gel type binder	313.66	- 0.082	$Y = 313.66\ X^{-0.082}$	97.64
Control (60-70), sol type binder	240.05	- 0.072	$Y = 240.05\ X^{-0.072}$	98.19
Y= Flexural creep stiffness (MPa) X= Rate of decline in the creep stiffness through loading				

Table 7 demonstrates the obtained mathematical power models which represent the deterioration in the creep stiffness of conventional binder throughout the testing period. The models show a high coefficient of determination for both binders. The intercept represents creep stiffness at early stage of loading while the negative slope represents the deterioration rate in the flexural creep stiffness.

3.2 Modeling the impact of implicating Nano additives on the creep stiffness of green asphalt binder: Figure 5 exhibits the impact of implicating Nano additives on the creep stiffness of green asphalt binder. Higher flexural creep stiffness is noticed when the asphalt cement was treated with silica fumes as compared with the case of modification with fumed silica. A significant increment in the creep stiffness is detected when Nano additives were implicated into the (40-50) grade binder as compared with the control or the (60-70) grade binder. This is attributed to the chemical reaction with the binder ingredient which was possible to change the conventional asphalt binder to a stiffer green binder. The creep stiffness of (40-50) green asphalt binder treated with fumed silica is higher than that of (40-50) control binder by (17.6 and 25) % at the start point of loading and at failure respectively. When the binder was treated with silica fumes, the creep stiffness of (40-50) green asphalt binder treated with silica fumes is higher than that of (40-50) control binder by (25.5 and 35) % at the initial point of loading and at failure respectively. However, the creep stiffness of (60-70) green asphalt binder treated with fumed silica is higher than that of (60-70) control binder by (10 and 12.5) % at the initial point of loading and at failure respectively. When the binder was treated with silica fumes, the creep stiffness of (60-70) green asphalt binder treated with silica fumes is higher than that of (60-70) control binder by (15 and 18.7) % at the initial point of loading and at failure respectively. It can be revealed that a significant variation in the creep stiffness exists between the sol and gel type binders after modification with Nano additives. Such performance agrees well with the reported work by Sarsam, [48]; and Lin et al., [49].

Table 8 exhibits the creep stiffness models for green asphalt binder, it may be noticed that the obtained mathematical power models show high coefficients of determination regardless of the implicated Nano additives. The intercept represents the creep stiffness at initial stage of loading and shows significant hardening of the creep stiffness of the green binder as compared with the conventional binders, while the gentle negative slope represents the deterioration rate in the creep stiffness throughout the testing period.

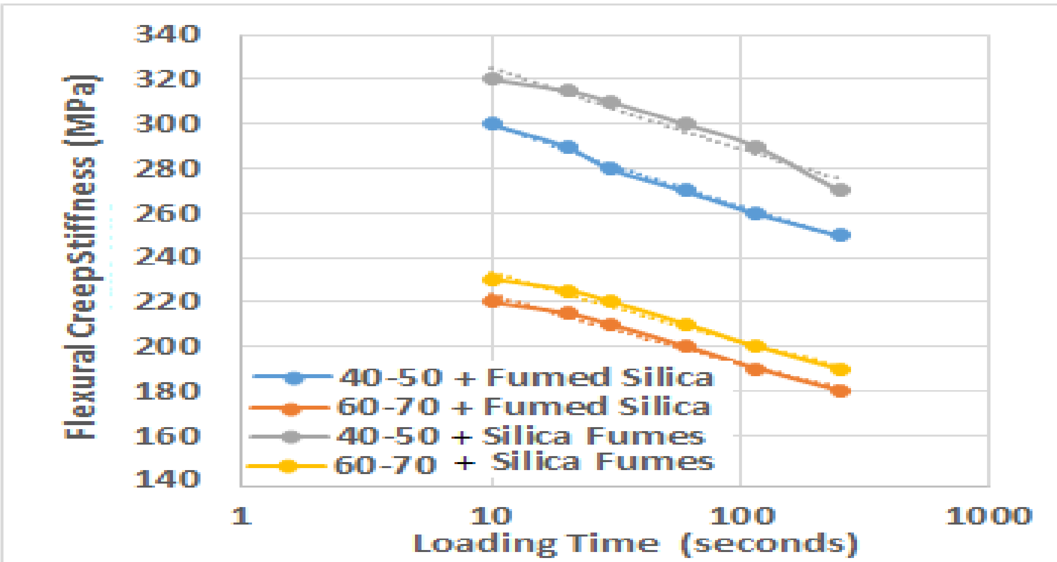

Figure 5. Influence of Nano additives on the creep stiffness of green asphalt binder

Table 8. Creep stiffness models for green asphalt binder

Binder type	Intercept (MPa)	Slope	Mathematical power model	R^2
(40-50) + Fumed silica	342.5	- 0.058	$Y=342.5X^{-0.058}$	99.61
(60-70) + Fumed silica	259.2	- 0.065	$Y=259.2X^{-0.065}$	98.27
(40-50) + Silica fumes	366.73	- 0.052	$Y=366.73X^{-0.052}$	94.84
(60-70) + Silica fumes	268.84	-.0.062	$Y=268.84X^{-0.062}$	98.30
Y= Flexural creep stiffness (MPa) X= Rate of decline in the creep stiffness through loading				

4. Concluding Remarks

Based on the limitations of materials and the conducted testing, the following concluding remarks may be addressed.

- The penetration grade (60-70) asphalt cement is of sol type while the penetration grade (40-50) asphalt cement binder is of gel type.
- The creep stiffness of (60-70) binder is less than that of (40-50) binder by (21.5 and 20) % at the initial point of loading and at failure respectively.
- The creep stiffness of (40-50), and (60-70) green asphalt binders treated with fumed silica is higher than that of control binder by (25 and 12.5) % at failure respectively. While the creep stiffness of (40-50), and (60-70) green asphalt binders treated with silica fumes is higher than that of control binder by (35 and 17.8) % at failure respectively.
- Nano additives are recommended to control the creep stiffness of green asphalt binder regardless of the sol and gel types of the conventional (60-70) and (40-50) binders.
- The developed power mathematical models gave the best experimental fit, exhibit a high coefficient of determination, and are recommended to predict the impact of implicating the Nano additives on the creep stiffness of asphalt cement binder.

References

[1] W. Zhao and Q. Yang, “Design and performance evaluation of a new green pavement: 100% recycled asphalt pavement and 100% industrial solid waste,” *Journal of Cleaner Production*, vol. 421, p. 138483,

Oct. 2023, doi: 10.1016/j.jclepro.2023.138483.

[2] H. Raufi, A. Topal, B. Sengoz, and D. Kaya, "Assessment of Asphalt Binders and Hot Mix Asphalt Modified with Nanomaterials," *Periodica Polytechnica Civil Engineering*, Dec. 2019, doi: 10.3311/PPci.14487.

[3] H. Yao *et al.*, "Rheological Properties and Chemical Bonding of Asphalt Modified with Nanosilica," *Journal of Materials in Civil Engineering*, vol. 25, no. 11, pp. 1619–1630, Nov. 2013, doi: 10.1061/(ASCE)MT.1943-5533.0000690.

[4] Ganapathi Malarvizhi, Sabermathi R, and Chidambaram Kamaraj, "Laboratory Study on Nano Clay Modified Asphalt Pavement," *International Journal of Applied Engineering Research (IJAER)*, vol. 10, no. 8, pp. 20175–20190, 2025, [Online]. Available: https://www.ripublication.com/ijaer10/ijaerv10n8_102.pdf

[5] S. I. Sarsam, "Monitoring the Rheological Properties of Asphalt Cement after Digestion with Micro and Nano Size Additives," *International Journal of Darshan Institute on Engineering Research and Emerging Technologies*, vol. 12, no. 1, pp. 5–12, Jun. 2023, doi: 10.32692/IJDI-ERET/12.1.2023.2302.

[6] R. Fusco, L. Moretti, N. Fiore, and A. D'Andrea, "Behavior Evaluation of Bituminous Mixtures Reinforced with Nano-Sized Additives: A Review," *Sustainability*, vol. 12, no. 19, p. 8044, Sep. 2020, doi: 10.3390/su12198044.

[7] R. Li, F. Xiao, S. Amirkhanian, Z. You, and J. Huang, "Developments of nano materials and technologies on asphalt materials – A review," *Construction and Building Materials*, vol. 143, pp. 633–648, Jul. 2017, doi: 10.1016/j.conbuildmat.2017.03.158.

[8] W. Wu *et al.*, "A review of asphalt-filler interaction: Mechanisms, evaluation methods, and influencing factors," *Construction and Building Materials*, vol. 299, p. 124279, Sep. 2021, doi: 10.1016/j.conbuildmat.2021.124279.

[9] D. Wang, "Investigation of Interfacial Interaction Effect of Asphalt Binder and Mineral Crystals Through MD Simulation," *International Journal of Pavement Research and Technology*, vol. 16, no. 6, pp. 1536–1554, Nov. 2023, doi: 10.1007/s42947-022-00212-8.

[10] A. R. Azarhoosh, F. M. Nejad, and A. Khodaii, "Nanomaterial and fatigue cracking of hot mix asphalt," *Road Materials and Pavement Design*, vol. 19, no. 2, pp. 353–366, Feb. 2018, doi: 10.1080/14680629.2016.1261724.

[11] M. Sayadi and S. Hesami, "Performance evaluation of using electric arc furnace dust in asphalt binder," *Journal of Cleaner Production*, vol. 143, pp. 1260–1267, Feb. 2017, doi: 10.1016/j.jclepro.2016.11.156.

[12] W. J. Steyn, "Potential Applications of Nanotechnology in Pavement Engineering," *Journal of Transportation Engineering*, vol. 135, no. 10, pp. 764–772, Oct. 2009, doi: 10.1061/(ASCE)0733-947X(2009)135:10(764).

[13] G. H. Hamedi and N. Esmaeili, "Investigating of the effects of nanomaterials on the moisture susceptibility of asphalt mixtures containing glass cullets," *AUT Journal of Civil Engineering*, no. Online First, Sep. 2018, doi: 10.22060/ajce.2018.14665.5492.

[14] A. Lotfi and M. S. Karimi, "FATIGUE BEHAVIOR OF HOT MIX ASPHALT MODIFIED WITH NANO AL2O3 – AN EXPERIMENTAL STUDY," *Advances in Science and Technology Research Journal*, vol. 10, no. 31, pp. 58–63, 2016, doi: 10.12913/22998624/64011.

[15] G. Shafabakhsh, M. Sadeghnejad, and R. Ebrahimnia, "Fracture resistance of asphalt mixtures under mixed-mode I/II loading at low-temperature: Without and with nano SiO2," *Construction and Building Materials*, vol. 266, p. 120954, Jan. 2021, doi: 10.1016/j.conbuildmat.2020.120954.

[16] H. Yao and Z. You, "Effectiveness of Micro- and Nanomaterials in Asphalt Mixtures through Dynamic Modulus and Rutting Tests," *Journal of Nanomaterials*, vol. 2016, pp. 1–14, 2016, doi: 10.1155/2016/2645250.

[17] J. S. Ghaffarpour, A. Bihruz, and V. Shahram, "Engineering properties of nanoclay modified asphalt concrete mixtures," *The Arabian Journal for Science and Engineering. Section B, Engineering*, vol. 35, no. 1B, pp. 90–103, 2010.

[18] Saad Issa Sarsam, "Influence of Nano Material Additives on Dissipated Energy Through the Fatigue Process of Asphalt Concrete," *International Journal of Chemical Engineering and Analytical Science*, vol. 1, no. 1, pp. 53–59, 2016, [Online]. Available: http://www.aiscience.org/journal/ijceas

[19] Y. Wang, W. Wang, and L. Wang, "Understanding the relationships between rheology and chemistry of asphalt binders: A review," *Construction and Building Materials*, vol. 329, p. 127161, Apr. 2022, doi: 10.1016/j.conbuildmat.2022.127161.

[20] S. N. Nahar, "Phase-Separation Characteristics of Bitumen and their Relation to Damage-Healing," Delft University of Technology, 2016. doi: 10.4233/UUID:670C70FF-F9F0-4CDB-AA4D-B661E7117354.

[21] Saad Issa Sarsam, "Effect of Nano Materials on Asphalt Cement Properties," *International Journal of Scientific Research in Knowledge (IJSRK)*, vol. 1, no. 10, pp. 422–426, 2013, doi: 10.12983/IJSRK-2013-P422-426.

[22] J. Büchner, M. P. Wistuba, and T. Hilmer, "Creep Properties of Asphalt Binder, Asphalt Mastic and Asphalt Mixture," in *Proceedings of the RILEM International Symposium on Bituminous Materials*, vol. 27, H. Di Benedetto, H. Baaj, E. Chailleux, G. Tebaldi, C. Sauzéat, and S. Mangiafico, Eds., Cham: Springer International Publishing, 2022, pp. 513–519. doi: 10.1007/978-3-030-46455-4_65.

[23] S. R. Kommidi and Y.-R. Kim, "Dynamic shear rheometer testing and mechanistic conversion to predict bending beam rheometer low temperature behavior of bituminous binder," *Construction and Building*

Materials, vol. 267, p. 120563, Jan. 2021, doi: 10.1016/j.conbuildmat.2020.120563.

[24] W. Zeiada, H. Liu, M. W. Alani, H. Ezzat, and G. G. Al-Khateeb, "An efficient and robust method for evaluating the low-temperature performance of asphalt binder based on DSR testing," *Construction and Building Materials*, vol. 448, p. 138196, Oct. 2024, doi: 10.1016/j.conbuildmat.2024.138196.

[25] Y. Cheng, H. Wang, W. Wang, and J. Liang, "Rheological evolution mechanisms of asphalt binder and mastic under freeze-thaw cycles," *Construction and Building Materials*, vol. 372, p. 130780, Apr. 2023, doi: 10.1016/j.conbuildmat.2023.130780.

[26] A. H. Abedali *et al.*, "Flexural-Creep Stiffness of Asphalt Binders Measured by Simple Developed Apparatus," *IOP Conference Series: Materials Science and Engineering*, vol. 888, no. 1, p. 012071, Jul. 2020, doi: 10.1088/1757-899X/888/1/012071.

[27] Z. Huang *et al.*, "Research on High- and Low-Temperature Rheological Properties of High-Viscosity Modified Asphalt Binder," *Buildings*, vol. 13, no. 4, p. 1077, Apr. 2023, doi: 10.3390/buildings13041077.

[28] N. Saboo and P. Kumar, "A study on creep and recovery behavior of asphalt binders," *Construction and Building Materials*, vol. 96, pp. 632–640, Oct. 2015, doi: 10.1016/j.conbuildmat.2015.08.078.

[29] C. Celauro, C. Fecarotti, A. Pirrotta, and A. C. Collop, "Experimental validation of a fractional model for creep/recovery testing of asphalt mixtures," *Construction and Building Materials*, vol. 36, pp. 458–466, Nov. 2012, doi: 10.1016/j.conbuildmat.2012.04.028.

[30] X. Lu, P. Uhlback, and H. Soenen, "Investigation of bitumen low temperature properties using a dynamic shear rheometer with 4 mm parallel plates," *International Journal of Pavement Research and Technology*, vol. 10, no. 1, pp. 15–22, Jan. 2017, doi: 10.1016/j.ijprt.2016.08.010.

[31] Y. Sun, B. Huang, J. Chen, X. Jia, and Y. Ding, "Characterizing rheological behavior of asphalt binder over a complete range of pavement service loading frequency and temperature," *Construction and Building Materials*, vol. 123, pp. 661–672, Oct. 2016, doi: 10.1016/j.conbuildmat.2016.07.047.

[32] R. Tarefder, H. Faisal, and G. Barlas, "Freeze-thaw effects on fatigue LIFE of hot mix asphalt and creep stiffness of asphalt binder," *Cold Regions Science and Technology*, vol. 153, pp. 197–204, Sep. 2018, doi: 10.1016/j.coldregions.2018.02.011.

[33] B. Radovskiy and B. Teltayev, "Determining of Asphalt Stiffness Modulus," in *Viscoelastic Properties of Asphalts Based on Penetration and Softening Point*, vol. 2, Cham: Springer International Publishing, 2018, pp. 23–39. doi: 10.1007/978-3-319-67214-4_2.

[34] G. Hischke, "Understanding Creep in Asphalt Concrete," Civil Engineering and Construction Department, Bradley University, Illinois Asphalt Paving Association (IAPA), Feb. 2019.

[35] ASTM. Road and Paving Materials, Annual Book of ASTM Standards, Volume 04.03, *American Society for Testing and Materials*, West Conshohocken, 2016. USA. www.astm.org

[36] S. I. Sarsam and I. M. Lafta, "Assessing Rheological Behavior of Modified Paving Asphalt Cement," *American Journal of Civil and Structural Engineering-AJCSE*, vol. 1, no. 3, pp. 47–54, 2014, doi: 10.12966/ajcse.07.02.2014.

[37] AASHTO. T-313, Standard method of test for determining the flexural creep stiffness of asphalt mixtures using the bending beam rheometer (BBR). *American Association of State Highway and Transportation Officials*. Washington, DC: AASHTO. 2016.

[38] AASHTO M 320, Standard Specification for Performance-Graded Asphalt Binder. *American Association of State Highway and Transportation Officials*. Washington, DC: AASHTO. 2017.

[39] M. M. Farhan, M. A. Rabeea, R. F. Muslim, and T. A. Zidan, "Chemical composition (saturate fraction) of western Iraq natural bitumen," *Materials Today: Proceedings*, vol. 42, pp. 2527–2533, 2021, doi: 10.1016/j.matpr.2020.12.574.

[40] R. S. Siroma *et al.*, "Asphaltene agglomeration through physical-chemical and rheological testing," *Road Materials and Pavement Design*, vol. 25, no. sup1, pp. 248–261, Jun. 2024, doi: 10.1080/14680629.2023.2221744.

[41] D. Lesueur, M. D. Elwardany, J.-P. Planche, D. Christensen, and G. N. King, "Impact of the asphalt binder rheological behavior on the value of the ΔTc parameter," *Construction and Building Materials*, vol. 293, p. 123464, Jul. 2021, doi: 10.1016/j.conbuildmat.2021.123464.

[42] L. O. Oyekunle, "Certain Relationships between Chemical Composition and Properties of Petroleum Asphalts from Different Origin," *Oil & Gas Science and Technology - Revue de l'IFP*, vol. 61, no. 3, pp. 433–441, May 2006, doi: 10.2516/ogst:2006043a.

[43] S. Weigel and D. Stephan, "Relationships between the chemistry and the physical properties of bitumen," *Road Materials and Pavement Design*, vol. 19, no. 7, pp. 1636–1650, Oct. 2018, doi: 10.1080/14680629.2017.1338189.

[44] M. Hermadi and W. Pravianto, "The Effect of Resins on Rheological and ageing Characteristics of Bitumen for Pavement," *MATEC Web of Conferences*, vol. 258, p. 01004, 2019, doi: 10.1051/matecconf/201925801004.

[45] D. N. Saad and E. İ. Ahmed, "Rheology of Iraqi Asphalt Modified with SBS, Polyphosphoric Acid and Sulfur," *The Eurasia Proceedings of Science Technology Engineering and Mathematics*, no. 4, pp. 277–280, Dec. 2018, [Online]. Available: http://www.epstem.net/en/pub/epstem/issue/40805/498145

[46] Z. Aljaafari and M. Q. Ismael, "The influence of chemical composition of asphalt cement on the physical and rheological properties," *Journal of Engineering Science and Technology (JESTEC)*, vol. 15, no. 6, pp. 4303–4319, Dec. 2020, [Online]. Available: https://jestec.taylors.edu.my/Vol%2015%20issue%206%20December%202020/15_6_53.pdf

[47] K. H. Moon, A. Cannone Falchetto, and J. W. Hu, "Investigation of asphalt binder and asphalt mixture low temperature creep properties using semi mechanical and analogical models," *Construction and Building Materials*, vol. 53, pp. 568–583, Feb. 2014, doi: 10.1016/j.conbuildmat.2013.12.022.

[48] Saad Issa Sarsam, "Influence of Additives on the Rheological Behavior of Asphalt Binder," *Journal of Engineering Analysis and Design*, vol. 6, no. 2, pp. 35–46, Jul. 2024, doi: 10.5281/ZENODO.12747625.

[49] P. Lin, W. Huang, N. Tang, F. Xiao, and Y. Li, "Understanding the low temperature properties of Terminal Blend hybrid asphalt through chemical and thermal analysis methods," *Construction and Building Materials*, vol. 169, pp. 543–552, Apr. 2018, doi: 10.1016/j.conbuildmat.2018.02.060.

Biographical notes

Prof. Saad Issa Sarsam was born in Baghdad (1955), got his B. Sc. Degree in Civil Engineering (1977); Post graduate Diploma in Transportation Engineering (1978); M. Sc. in Transportation Engineering (1980). Worked as senior material Engineer for NCCL (National center for construction laboratories) (1982-1988); Served as Director of NCCL- Mosul, (1988-1992). Joined the academic staff at University of Mosul (1992-2005) and at University of Baghdad (2005-2020) and got the Professor degree at (2007). Head of the Department of Civil Engineering, University of Baghdad, (2016-2018). He published four books, and 422 research papers. He is a Member of the editorial board, and scientific reviewer of nine international scientific journals. Supervised 45 M. Sc. Thesis and participated in 53 national and international scientific conferences. He worked as consultant engineer for quality assurance, Ministry of Industry and Military Manufacturing, FAW General Directory- Badoosh dam Project (1989-1990), and project 555, and wax plant project, (1990-1991). He was a consultant engineer for Mosul Municipality on urban road resurfacing and construction (2001-2003). He was a consultant engineer for quality control on rehabilitation of Mosul International Hotel (2004), and consultant engineer for middle Euphrates international airport (2011-2013), consultant engineer for the state company for implementation of transportation facilities, Ministry of transportation (2011-2014), consultant engineer for NCCLR, Baghdad (2011-2015). He was a consultant engineer for AFM Group-Switzerland, Baghdad international airport runway rehabilitation (2014), and Consultant engineer for ministry of transport (2017). He was a consultant engineer for evaluation of a taxi lane pavement condition at Basra international airport, (2017), and Consultant Engineer for Triple S GMBH, Germany for Diwaniya poultry project, Pavement Design, (2020), and Consultant Engineer for Abraj Al-Bilad Company, Mall of Iraq Project, (Traffic impact assessment), (2022). Director of Sarsam and Associates Consult Bureau SACB, Baghdad-Iraq (2020). Areas of specialization and interest (Environmental impact, Safety issues in roadway operation, Airport Engineering; Nano materials in asphalt pavement, Roller compacted concrete; Modified asphalt concrete; Asphalt stabilized embankment models; Road user characteristics).