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Research Article

Modeling the Influence of Additives on Deterioration of the Creep Stiffness of Asphalt Binder

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Keywords

Asphalt cement binder, Creep stiffness, Additives, Deterioration, Modeling, Bending beam Rheometer.

Abstract

Thermal cracking in asphalt concrete pavement represents a significant pavement distress in cold environment. As the temperature drops below freezing limit, thermal stress starts to increase in the restrained asphalt pavement layer. The flexural-creep stiffness of asphalt cement binder is considered as a good indicator of the resistance to cracking of the binder at low temperature which is measured with the aid of Bending Beam Rheometer (BBR). An attempt has been made in the present study to evaluate and model the influence of additives (hydrated lime, and coal fly ash) on the deterioration of the creep stiffness of asphalt cement binder with penetration grades (40-50) and (60-70). Conventional asphalt binders were found to be highly sensitive to stress at low temperatures. However, modification of the asphalt cement binder with additives can control the deterioration in the flexural-creep stiffness. It was concluded that the rate of decline in the creep stiffness throughout the loading period for (40-50) and (60-70) binders was (21.5, 22.2, and 14.5) % and (20, 19, and 16.6) % for control, coal fly ash modified, and hydrated lime modified asphalt binder respectively. For (40-50) and (60-70) binders at failure stage, there is a significant increase in the creep stiffness of (5 and 32.5) % and (6.2 and 25) % for coal fly ash and hydrated lime modified asphalt binder specimens respectively as compared with the control binder. The mathematical power models are recommended to predict the Influence of additives on deterioration of the creep stiffness of asphalt binder.

1. Introduction

Environmental condition plays a major role in traffic induced fatigue and low-temperature cracking. Pavement experiences various climatic conditions as well as high intensity traffic loading over its service life. When the climate temperature reaches a critical value below the freezing limit which is referred to as (critical cracking temperature), the thermal stresses start to exceed the strength of the material, and thermal cracking occurs. The traditional criteria for characterizing low temperature cracking behavior of asphalt cement binders is not appropriate for conventional binders. Thermal cracking 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. Saboo and Kumar, 2015, [1] investigated the asphalt cement binder's response to multiple stress creep and recovery test. It was revealed that modified binders exhibit delayed elastic response, and the conventional binders are not suitable for testing the creep stiffness at higher temperatures. It was concluded that when modeling the creep stiffness, power law model has been selected to simulate the measured response and incorporate non-linear viscoelastic response of the modified binders. Use of modified 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., 2012, [2]. The ENTPE transformation and Hirsch model are generally implemented for the prediction of asphalt mixture creep stiffness based on asphalt cement binder creep stiffness test data at low temperatures as addressed by Moon et al., 2014, [3]. To characterize viscoelastic behavior of asphalt materials, the creep test with the Bending Beam Rheometer was developed by AASHTO, 1993, [4]. In this test, stress is applied instantaneously to the asphalt binder specimen and maintained constant for the entire duration of the test. Lee, 1997, [5] stated that thermal cracking is one of the major types of distresses in asphalt pavement. Such distress is highly affected by the characteristics of asphalt cement binder or the modified binder (asphalt + additive). The properties of the binder exhibit a significant role in controlling low temperature cracking. The asphalt binder was modified with scrap tire rubber and carbon black. It was concluded that the inclusion of such additives increases the flexural creep stiffness of asphalt binder, and the testing results were within the limit value, maximum 300MPa at 60 second for BBR test. Büchner et al., 2022, [6] revealed that creep deformation can be verified through cyclic or static compression tests at elevated temperature. For asphalt cement binders, creep tests can usually be performed by means of a bending beam rheometer or dynamic Shear Rheometer (DSR). Creep properties of asphalt cement binders and asphalt mastics (binder + additive) were tested in the DSR on a set of 10 different asphalt binders and 18 corresponding asphalt mastics. Finally, the creep properties obtained from asphalt binder tests, and asphalt mastic tests were correlated. It was concluded that the asphalt binder has a significant impact on the creep behavior of the corresponding asphalt mixture. Zeiada et al., 2024, [7] stated that the BBR test has received growing concerns due to the long time-consuming beam preparation and testing process and large amount of long-term aged asphalt binder used in preparing asphalt binder beams. Frequency sweep tests were performed on asphalt binders at temperatures of 0 °C using the 8-mm parallel plate geometry to predict the flexural creep stiffness and m-value of asphalt binder while conversion from shear loading to bending loading was conducted. It was concluded that the predicted values of S (60) and m (60) value, which evaluates the ability of asphalt binder to relieve the thermal stress accumulated due to a drop in temperature and were comparable to those measured by the BBR, which well demonstrated the feasibility of the proposed DSR-BBR conversion method. Lu et al., 2017, [8] reported that thermal cracking of asphalt concrete is considered a major failure mode of flexible

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pavement in cold climate regions. The low-temperature rheology of asphalt cement binder has been found to be the principal factor influencing the thermal cracking of asphalt pavements. Transverse cracks of asphalt pavement become visible when the thermal stress that builds up in the restrained asphalt pavement with decreasing temperature exceeds the asphalt binder tensile strength as stated by Kommidi and Kim, 2021, [9]. It was recommended to Improve the tensile strength and the stress relaxation ability of asphalt binder by implication of additives to reduce the risk of thermal cracking in asphalt pavements. Sun et al., 2016, [10] reported that all the studies on creep of the binder could provide satisfactory predictions of flexural creep stiffness and m-value. However, the use of empirical or approximate equations can reduce the prediction accuracy, and 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., 2018, [11] investigated the effects of freeze-thaw cycles on asphalt binder samples in the laboratory using bending beam rheometer. It was observed that the freeze-thaw cycles cause damage to the binder, which can be seen in the reduction of stiffness with increasing the cycles. It was concluded that reduction of asphalt creep stiffness with an increase in cycles was found to be higher compared to the flexural strength of the asphalt concrete beam. Cheng et al., 2023, [12] investigated the rheological property of asphalt binder and mastic under freeze-thaw cycles through the bending beam rheological test, linear amplitude sweep test, multiple stress creep recovery test. The results showed that as freeze-thaw cycle increased, the recovery of asphalt binder increased, and the non-recoverable creep compliance of asphalt binder decreased. The low-temperature stiffness of asphalt binder and mastic increased as freeze-thaw cycle increased. Chen et al., 2021, [13] investigated the effect of four types of freeze-thaw cycles on asphalt cement binders. The creep compliance, rutting factor, and fatigue life of binders after freeze-thaw cycles were evaluated, and then the chemical composition was analyzed. The test results showed that the freeze-thaw cycle caused the complex modulus of asphalt binders to decline while the creep recovery rate of modified asphalt binder was reduced. Sayadi and Hesami, 2017, [14] proposed that the asphalt cement binder would become hard after freeze-thaw cycles, while the filler can affect the self-healing capability and the fatigue property of asphalt mastic after freeze-thaw cycles. It was revealed that the asphalt binder-filler interaction is more prominent to affect the rheological property. It was concluded that the asphalt binder-filler interaction can be evaluated effectively by the interaction indexes. Wang, 2023, [15] assessed the interface models of asphalt binder and three mineral crystals additives through Molecular Dynamic simulation. The effect of temperature change on the interaction strength was analyzed based on the service temperature of asphalt mixture. It was concluded that due to the increase 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. Radovskiy, and Teltayev, 2018, [16] developed a mathematical model that expresses the asphalt binder stiffness modulus as a function of temperature, time, and the simple properties of asphalt cement. It was concluded 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. Huang et al., 2023, [17] evaluated the critical low and high temperature rheological properties of a modified asphalt binder using low-temperature creep stiffness properties by the bending beam rheometer test. Technical indexes such as the creep recovery rate and the unrecoverable creep compliance were measured and calculated, while the creep stiffness, and creep speed are used as technical indexes for low-temperature properties. The results exhibit that the incorporation of modifiers increases the creep recovery rate and reduces the unrecoverable creep compliance of the asphalt binder. At low temperatures, the relaxation time decreases. Wu et al., 2021, [18] reviewed existing research on asphalt-filler interaction mechanisms and models. From the numerous literatures, it was concluded that the asphalt-filler interaction is a very complex physicochemical interaction. The rheological theory was considered suitable for evaluating asphalt-filler interaction. It was revealed that the main factors influencing the asphalt-filler interaction are the properties of asphalt and filler. Lin et al., 2018, [19] used bending beam rheometer test, Fourier Transform Infrared test, Gel Permeation Chromatography test, and DSC Differential Scanning Calorimetry test for evaluating the chemical and rheological properties of rubber modified asphalt binder and to estimate the low temperature properties of mixture. The results indicated that crumb rubber improved low temperature properties. Wang et al., 2022, [20] assessed three different rheological behaviors, neat binder, modified binder, and complex modified binder, by visually identification among the interlaboratory results and based on a simple statistical analysis of variance. The use of waste polyethylene as a sustainable additive to asphalt binder was experimentally investigated with the DSR, and the three different rheological behaviors were observed and identified by using the Black Diagram. Abedali et al., 2022, [21] developed a modified apparatus to simulate the reality of asphalt binder in the asphalt mixture, measure the flexural-creep stiffness properties of asphalt binder, and measure the deflection values at different test temperatures. Hischke, 2019, [22] explained the necessity of conducting creep tests for asphalt concrete in the pavement design process for flexible pavement. It was stated that the creep properties in asphalt concrete are the cause of rutting in existing pavement structures, and it should be placed as a higher priority in the pavement design process so that the road may achieve a much higher life span. Many researchers have tried to model the creep and recovery behavior of asphalt binder using different mathematical and rheological models. Numerous modifications to these models have also been attempted, to include various viscoelastic and visco-plastic characteristics, mostly for modified binder.

The aim of the present work is to model the influence of two types of additives (coal fly ash and hydrated lime) on deterioration of the creep stiffness of two types of asphalt binder with penetration grade of (40-50, and 60-70). The bending beam rheometer test will be implemented to measure the creep stiffness of asphalt cement binder.

2. Materials and Methods

The implemented additives (coal fly ash and hydrated lime) are locally available; Figure 1 demonstrates the implemented additives.

Figure 1. The implemented additives

2.1. Hydrated Lime

Hydrated lime is a derivative of burnt lime which is produced by reacting burnt lime with water in a continuous hydrator. Hydrated lime is light and fluffy with a chemical formula of $Ca(OH)_2$ and has 4404 m²/kg specific surface area and a specific gravity of 2.211. This material is obtained from the local market and the portion used is 75-micron maximum size. Its chemical compositions are listed in Table 1.

2.2. Coal Fly Ash

The fly ash class F was obtained as a by-product of coal combustion from local market, this fly ash has specific surface area of 600 m²/Kg and a specific gravity of 2.016. The portion used is 75-micron maximum size. Chemical components of fly ash are listed in Table 1.

Table 1. Chemical Components of additives

Additives	Oxides percentages					Loss on Ignition
	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	

Hydrated lime	0.74	0.19	0.5	64.23	1.17	29.94
Coal fly ash	61.95	2.67	28.82	0.88	0.34	0.86

2.3. Asphalt Cement Binder

Two types of Asphalt cement binder of penetration grade (40-50) and (60-70) were obtained from Dourah oil refinery. Such types of binder are usually implemented in asphalt pavement construction in Iraq. Table 2 presents the physical properties of asphalt binders.

Table 2. Physical Properties of Asphalt Cement Binders

Property	ASTM, 2016, [23] specification	Asphalt cement (40-50) Test results	Asphalt cement (60-70) Test results
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 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

2.4. Preparation of Modified Asphalt Binder

A modified asphalt binder was prepared by using the wet process. In the wet process, asphalt cement was heated to a 150 °C and then blended with the additives with the specified percentage. The blending was conducted at a blending speed of 1300 rpm and constant for 30 minutes to promote the possible chemical and physical bonding of the components. The degree of dispersion of the additives was controlled by the blending duration and blending speed. Similar precautions were followed by Li et al., 2017, [24]. The range of treatment with additives was (5-20) % with a 3 % increment. The optimum additive content was selected based on the significant change in physical and rheological properties of the modified binder. Details of mixing and obtaining the optimum additive could be referred to Sarsam and Lafta, 2014, [25]. The summary of the optimum additive content is listed in Table 3. Beam specimens of 12.5 mm in width, 125 mm in length, and 6.25 mm in height were prepared.

Table 3. Optimum Additives Content

Additives	
Coal fly Ash	Hydrated Lime
5 %	10 %

2.5. Testing of Modified Binder

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, 2016, [4]. 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 total time of 240 seconds, at the meantime, the vertical deflection is monitored and measured. The creep stiffness at time 60 seconds can be calculated using the following equation:

$$S(t) = PL^3 / (4bh^3 \delta(t)) \quad (1)$$

Where:

S (t) = creep stiffness at time, t = 60 seconds
P = applied constant load, 100 gm
L = distance between beam supports = (102 mm)
b = beam width = (12.5 mm)
h = beam thickness = (6.25 mm)
δ (t) = deflection at time, t = 60 seconds

Superpave specification, AASHTO M320, [26] 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.

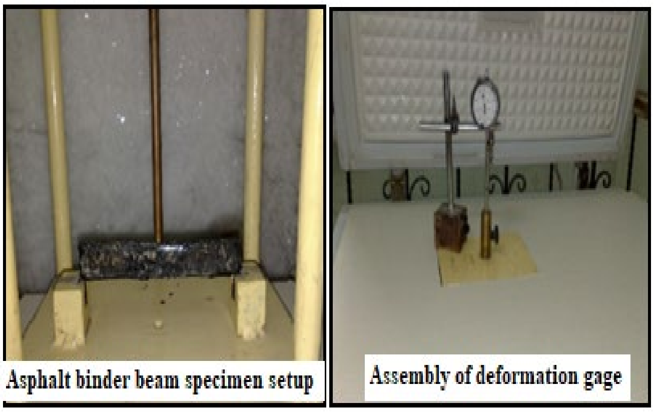

Figure 2. Bending beam rheometer (BBR) test apparatus

3. Results and Discussions

3.1. Behavior of hard asphalt binder

The low temperature cracking susceptibility of control and modified asphalt binders was studied using flexure-creep stiffness test. Figure 3 exhibits the deterioration of creep stiffness of asphalt cement binder as the loading proceeds for 40-50 penetration grade binder. Sharp decline in the creep stiffness at early stages of loading could be noticed for control and modified binder specimens. After 30 seconds of loading, the trend of decline in the creep stiffness is gentle for the tested specimens. It can be observed that implementation of additives (coal fly ash and hydrated lime) increased the creep stiffness by (5.8 and 21.5) % for fly ash and hydrated lime modified asphalt binder specimens respectively after 10 seconds of loading as compared with the control binder. However, after 250 seconds of loading (at failure stage), a significant increase in the creep stiffness of (5 and 32.5) % for fly ash and hydrated lime modified asphalt binder specimens respectively as compared with the control binder. On the other hand, the rate of decline in the creep stiffness throughout the loading period was (21.5, 22.2, and 14.5) % for control, coal fly ash modified, and hydrated lime modified asphalt binder respectively. Similar behavior of the rheological properties of binder was observed by Sarsam, 2024, [27]; and Lu et al., 2017, [8].

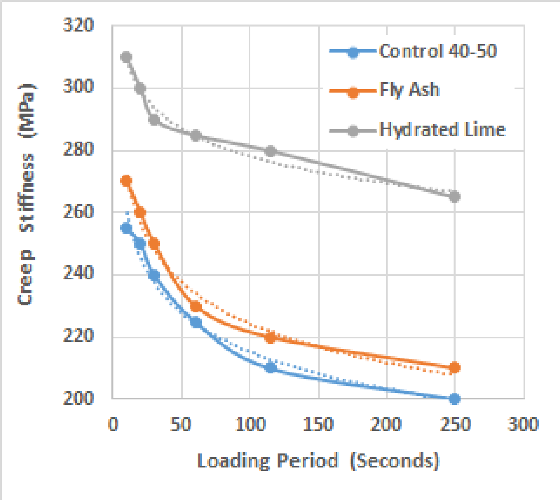

Figure 3. deterioration of creep stiffness for 40-50 binder

It can be revealed that the implication of additives into the asphalt cement binder exhibit lower flexibility at lower temperatures and increased the creep stiffness of the binder at such low testing temperature. It was found that the conventional binder is highly sensitive to stresses at low temperatures and is not suitable at locations with extremely cold environments. Such behavior is further supported by the mathematical power models exhibited in Table 4 which shows a high coefficient of determination. The intercept represents the creep stiffness of asphalt binder at the start point of loading, while the slope represents the rate of deterioration of the creep stiffness of the asphalt binder.

Table 4. Deterioration models of creep stiffness for 40-50 binder

Additive type	Intercept (MPa)	Slope	Mathematical power model	R^2
Control (40-50)	313.66	0.082	$Y = 313.66 x^{0.082}$	0.976
Coal fly ash	329.06	0.083	$Y = 329.06 x^{0.083}$	0.984
Hydrated lime	343.23	0.046	$Y = 343.23 x^{0.046}$	0.973

3.2. Behavior of soft asphalt binder

Figure 4 exhibits the deterioration of creep stiffness of asphalt cement binder as the loading proceeds for 60-70 penetration grade binder which is considered as a softer binder than that of 40-50 penetration grade binder. Gentle decline in the creep stiffness at early stages of loading could be noticed for control and modified binder specimens. After 50 seconds of loading, the trend of decline in the creep stiffness is steady for the tested specimens. It can be observed that implementation of additives (coal fly ash and hydrated lime) increased the creep stiffness by (5 and 20) % for fly ash and hydrated lime modified asphalt binder specimens respectively after 10 seconds of loading as compared with the control binder. However, after 250 seconds of loading (at failure stage), a significant increase in the creep stiffness of (6.2 and 25) % for coal fly ash and hydrated lime modified asphalt binder specimens respectively as compared with the control binder. On the other hand, the rate of decline in the creep stiffness throughout the loading period was (20, 19, and 16.6) % for control, coal fly ash modified, and hydrated lime modified asphalt binder respectively through the loading period. It can be revealed that the implication of additives into the asphalt cement binder exhibit lower flexibility at lower temperatures and increased the creep stiffness of the binder at such low testing temperature. It was found that the conventional binder exhibits lower sensitivity to stresses at low temperatures as compared with the 40-50 penetration grade binder and is more suitable at locations with extremely cold environments. Implication of additives tends to increase the viscoelastic response of binder and reduces its temperature susceptibility. Such behavior agrees with the work reported by Sarsam, 2023, [28]; and Lee, 1997, [5].

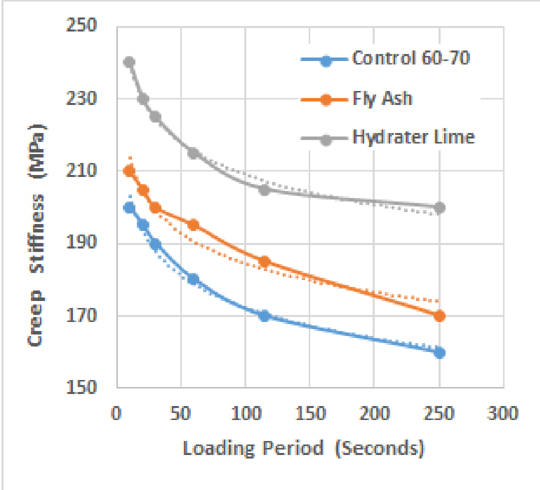

Figure 4. deterioration of creep stiffness for 60-70 binder

Such behavior is further supported by the mathematical power models exhibited in Table 5 which shows a high coefficient of determination. The intercept represents the creep stiffness of asphalt binder at the start point of loading, while the slope represents the rate of deterioration of the creep stiffness of the asphalt binder.

Table 5. Deterioration models of creep stiffness for 60-70 binder

Additive type	Intercept (MPa)	Slope	Mathematical power model	R^2
Control (60-70)	240.05	0.072	$Y = 240.05 x^{0.072}$	0.981
Coal fly ash	247.54	0.064	$Y = 247.54 x^{0.064}$	0.949
Hydrated lime	274.28	0.059	$Y = 274.28 x^{0.059}$	0.991

When the properties of both penetration grades binders are compared, the low temperature cracking susceptibility of different control and modified asphalt binders was indicated by using flexure-creep stiffness test.

4. Conclusions

- The following conclusions can be addressed based on the limited testing program and limitations of tested materials.
- For (40-50) and (60-70) binders, the rate of decline in the creep stiffness throughout the loading period was (21.5, 22.2, and 14.5) % and (20, 19, and 16.6) % for control, coal fly ash modified, and hydrated lime modified asphalt binder respectively.
- The conventional binder (40-50) is highly sensitive to stresses at low temperatures and is not suitable for paving work at locations with extremely cold environments.
- The conventional binder (60-70) exhibits lower sensitivity to stresses at low temperatures as compared with the (40-50) penetration grade binder and is more suitable for paving at locations with extremely cold environments.
- For (40-50) and (60-70) binders and after 250 seconds of loading (at failure stage), a significant increase in the creep stiffness of (5 and 32.5) % and (6.2 and 25) % for coal fly ash and hydrated lime modified asphalt binder specimens respectively as compared with the control binder.
- The mathematical models exhibit a high coefficient of determination and are recommended to predict the Influence of additives on deterioration of the creep stiffness of asphalt binder.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. He has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1.] Saboo N., Kumar P. A study on creep and recovery behavior of asphalt binders. Elsevier Construction and Building Materials. Volume 96, 15 October 2015, Pages 632-640 https://doi.org/10.1016/j.conbuildmat.2015.08.078.

[2.] Celauro C., Fecarotti C., Pirrotta A., Collop A. Experimental validation of a fractional model for creep/recovery testing of asphalt mixtures Elsevier Construction and Building Materials. Volume 36, November 2012, P. 458-466. https://doi.org/10.1016/j.conbuildmat.2012.04.028.

[3.] Moon K., Falchetto A., Hu J. Investigation of asphalt binder and asphalt mixture low temperature creep properties using semi mechanical and analogical models. Elsevier Construction and Building Materials. Volume 53, 28 February 2014, P. 568-583 https://doi.org/10.1016/j.conbuildmat.2013.12.022

[4.] AASHTO. T-313, 2016. 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.

[5.] Lee, K. The determination of the flexural creep stiffness of asphalt binder using bending beam rheometer. KSCE J Civ Eng 1, P. 49–57. 1997. https://doi.org/10.1007/BF02830463.

[6.] Büchner, J., Wistuba, M.P., Hilmer, T. Creep Properties of Asphalt Binder, Asphalt Mastic and Asphalt Mixture. In: Di Benedetto, H., Baaj, H., Chailleux, E., Tebaldi, G., Sauzéat, C., Mangiafico, S. (eds) Proceedings of the RILEM International Symposium on Bituminous Materials. ISBM 2020. RILEM Book series, vol 27. 2022. Springer, Cham. https://doi.org/10.1007/978-3-030-46455-4_65.

[7.] Zeiada W., Liu H., Alani M., Ezzat H. Al-Khateeb G. An efficient and robust method for evaluating the low-temperature performance of asphalt binder based on DSR testing. Elsevier Construction and Building Materials. Volume 448, 18 October 2024, 138196 https://doi.org/10.1016/j.conbuildmat.2024.138196.

[8.] Lu X., Uhlback P., Soenen H. Investigation of bitumen low temperature properties using a dynamic shear rheometer with 4 mm parallel plates. International Journal of Pavement Research and Technology. Volume 10, Issue 1, January 2017, P. 15-22. https://doi.org/10.1016/j.ijprt.2016.08.010.

[9.] Kommidi S., Kim Y. Dynamic shear rheometer testing and mechanistic conversion to predict bending beam rheometer low temperature behavior of bituminous binder. Elsevier Construction and Building Materials. Volume 267, 18 January 2021, 120563. https://doi.org/10.1016/j.conbuildmat.2020.120563.

[10.] Sun Y., Huang B., Chen J., Jia X., Ding Y. Characterizing rheological behavior of asphalt binder over a complete range of pavement service loading frequency and temperature. Elsevier Construction and Building Materials. Volume 123, 1 October 2016, P 661-672. https://doi.org/10.1016/j.conbuildmat.2016.07.047.

[11.] Tarefder R., Faisal H., Barlas G. Freeze-thaw effects on fatigue LIFE of hot mix asphalt and creep stiffness of asphalt binder. Elsevier Cold Regions Science and Technology. Volume 153, September 2018, Pages 197-204. https://doi.org/10.1016/j.coldregions.2018.02.011.

[12.] Cheng y., Wang H., Wang W., Liang J. Rheological evolution mechanisms of asphalt binder and mastic under freeze-thaw cycles. Elsevier Construction and Building Materials. Volume 372, 3 April 2023, 130780. https://doi.org/10.1016/j.conbuildmat.2023.130780.

[13.] Chen H., Chen M., Geng J., He L., Xia C., Niu Y., Luo M. Effect of multiple freeze-thaw on rheological properties and chemical composition of asphalt binders. Elsevier Construction and Building Materials. Volume 308, 15 November 2021, 125086. https://doi.org/10.1016/j.conbuildmat.2021.125086.

[14.] Sayadi M. and Hesami S, Performance evaluation of using electric arc furnace dust in asphalt binder. Journal of Cleaner Production, vol. 143, P. 1260–1267, Feb. 2017, http://doi:10.1016/J.JCLEPRO.2016.11.156

[15.] Wang, D. Investigation of Interfacial Interaction Effect of Asphalt Binder and Mineral Crystals Through MD Simulation. Springer nature Int. J. Pavement Res. Technol. 16, 1536–1554. 2023. https://doi.org/10.1007/s42947-022-00212-8.

[16.] Radovskiy, B., Teltayev, B. Determining of Asphalt Stiffness Modulus. In: Viscoelastic Properties of Asphalts Based on Penetration and Softening Point. Structural Integrity, vol 2. Springer, Cham. 2018. P. 23-29. https://doi.org/10.1007/978-3-319-67214-4_2.

[17.] Huang Z., Ling X., Wang D., Li P., Li H., Wang X., Wang W., Wei R., Zhu W., Falchetto A. Research on High- and Low-Temperature Rheological Properties of High-Viscosity Modified Asphalt Binder. MDPI Building. 2023, 13, 1077. https://doi.org/10.3390/buildings13041077.

[18.] Wu W., Jiang W., Yuan D., Lu R., Shan J., Xiao J., Ogbon A. A review of asphalt-filler interaction: Mechanisms, evaluation methods, and influencing factors. Elsevier Construction and Building Materials. Volume 299, 13 September 2021, 124279. https://doi.org/10.1016/j.conbuildmat.2021.124279

[19.] Lin P., Huang W., Tang N., Xiao F., Li Y. Understanding the low temperature properties of Terminal Blend hybrid asphalt through chemical and thermal analysis methods. Elsevier Construction and Building Materials. Volume 169, 30 April 2018, Pages 543-552. https://doi.org/10.1016/j.conbuildmat.2018.02.060.

[20.] Wang D., Baliello A., Poulikakos L., Vasconcelos K., Kakar M., Giancontieri G., Pasquini E., Porot L., Tušar M., Riccardi C., Pasetto M., Presti D., Falchetto A. Rheological properties of asphalt binder modified with waste polyethylene: An interlaboratory research from the RILEM TC WMR. Elsevier Resources, Conservation and Recycling. Volume 186, November 2022, 106564. https://doi.org/10.1016/j.resconrec.2022.106564.

[21.] Abedali A., kareem Y., Jebur Y., Abed M., Almaali Y., Fahem F., Badri R. Flexural-Creep Stiffness of Asphalt Binders Measured by Simple Developed Apparatus. ICCEET 2020. IOP Conf. Series: Materials Science and Engineering 888. 2020. 012071. https://doi:10.1088/1757-899X/888/1/012071.

[22.] Hischke G. Understanding Creep in Asphalt Concrete. Bradley University Civil Engineering and Construction Department. Report Distributed February 1, 2019. Illinois Asphalt Paving Association (IAPA). Global web icon. https://www.il-asphalt.org.

[23.] 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.

[24.] Li R., Xiao F., Amirkhanian S., You Z., Huang J. Developments of nano materials and technologies on asphalt materials – a review Constr. Build. Mater., 143 2017,

P. 633-648, https://doi.org/10.1016/j.conbuildmat.2017.03.158.

[25.] Sarsam S. and Lafta I. Assessing Rheological Behavior of Modified Paving Asphalt Cement. American Journal of Civil and Structural Engineering. AJCSE 2014, 1(3): P. 47-54. Sciknow Publications Ltd. http://doi:10.12966/ajcse.07.02.2014

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

[27.] Sarsam S. I. "Influence of Additives on the Rheological Behavior of Asphalt Binder" HBRP Journal of Engineering Analysis and Design. Volume 6 Issue 2. 2024. P. 35-46. DOI: https://doi.org/10.5281/zenodo.12747625.

[28.] Sarsam S. I. "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, 2023 www.ijdieret.in.

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