International Journal of Multidisciplinary Research and Growth Evaluation

International Journal of Multidisciplinary Research and Growth Evaluation
ISSN: 2582-7138
Received: 26-07-2020; Accepted: 28-08-2020
www.allmultidisciplinaryjournal.com
Volume 1; Issue 3; July-August 2020; Page No. 38-44

Influence of ageing on temperature susceptibility of asphalt concrete

Saad Issa Sarsam
Professor, Sarsam and Associates Consult Bureau (SACB), Baghdad, Iraq

Corresponding Author: **Saad Issa Sarsam**

Abstract

Asphalt cement is supplied by multiple different refineries in Iraq. The wide variation in environmental condition all over the country had led the flexible pavement to practice a considerable variation in surface temperature, ranging from -15°C to more than 65°C. Ageing potential of the asphalt binder is variable. An attempt has been made in the present investigation to assess the influence of short and long term ageing on temperature susceptibility of asphalt concrete prepared by using dense graded aggregate and three types of asphalt binder obtained from Daura, Erbil, and Nasiriyah refineries located at middle, north and south regions of the country. Asphalt cement samples were subjected to the classical physical properties' determination, stiffness modulus, penetration index, and creep stiffness. Asphalt concrete specimens of 102 mm in diameter and 63.5 mm in height were prepared using the prementioned binders and subjected to temperature susceptibility determination. It was concluded that implementation of asphalt binder of the same penetration grade but from varied asphalt sources from (Erbil, Doura, and Nasiriya) have produced different behavior under ageing. Erbil binder exhibit the lowest temperature susceptibility of 50 kPa/°C after long term ageing and highest creep stiffness of 270 MPa after practicing 7 hours ageing among Daura and Nasiriya binders regardless of ageing periods. However, Erbil binder exhibit the lowest stiffness modulus of 140 kN/ m^2 and penetration index of (-0.64) before ageing as compared to other refineries' binder regardless of ageing period. It is recommended that the selection of a proper asphalt cement for paving must be based on evaluation of rheological properties such as temperature susceptibility and environmental conditions rather than the present practice of considering the physical properties only.

Keywords: Asphalt Concrete, Temperature Susceptibility, Creep Stiffness, Ageing, stiffness Modulus

1. Introduction

The climatic condition in Iraq is a continental one, with high summer pavement temperature reaching 65°C and low pavement temperature of -15°C during the winters. This is a critical issue for the flexible pavement's performance, causing rutting at summer and thermal low temperature cracking at winter. However, many oil refineries produce asphalt binder of the same penetration grade but with different chemical constituents. This may render the suitability of a specific binder to the environmental condition as reported by Sarsam [1]. Sirin *et al*, [2] stated that aging is the change in rheological properties of asphalt binders due to changes in chemical composition during construction and its service life period. Aging causes the asphalt material to stiffen and embrittle, which affects the durability and leads to a high potential for distress. Jing *et al*, [3] utilizes dynamic mechanical tests (frequency sweep, fatigue, and relaxation) to investigate the effect of ageing on the viscoelastic characteristics of bitumen. The stress relaxation test was found to be more suitable to characterize ageing of bitumen. Aged bitumen had higher residual stresses and longer relaxation times. Hence, aged bitumen was found to be more susceptible to stress accumulation and thus cracking. Glover *et al*, [4] addresses that ageing of asphalt binders occurs during the production of asphalt mixtures and while in service when exposed to the surrounding environment. As demonstrated in Figure 1, the first stage of aging occurs at a very fast rate when asphalt mixture is produced at a very high temperature. This stage is often referred to as short-term aging. During this stage, a very thin film of asphalt is exposed to air at elevated temperatures, leading to a significant change in the rheological properties of the asphalt binders. Such changes are presented in high viscosity and increased stiffness. The second stage of aging occurs when the asphalt is exposed to the environment as in-service pavement at a relatively lower temperature for a long duration. The rate of hardening depends on the in-place air void content and surrounding environment.

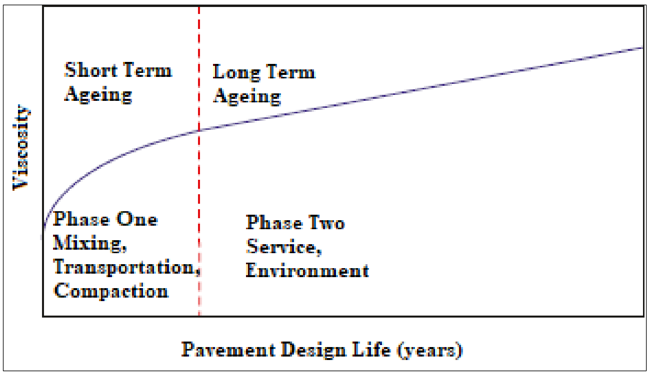

Fig 1: Typical Ageing response of Asphalt Binder

Wang *et al*, [5] reported that the thermal susceptibility of asphalt binder is considered as an important rheological property, being related to its ability to resist permanent deformation. Temperature susceptibility reflects how rapidly the properties of asphalt binders change with temperature in terms of indices such as activation energy, penetration index, and viscosity-temperature susceptibility. Cholewińska *et al*, [6] tested modified asphalt parameters after short-term and long-term ageing and the complex modulus and phase angle were measured. It was stated that because of ageing, the modified bitumen with fatty amines becomes a material sensitive to loading time and consequently shows a viscous response. The aging process causes an increase in complex modulus results in case of fatty amines modified bitumen. However, in case of wax modified bitumen a decrease in results was observed. The chemical and mechanical properties of asphalt mortar evolve with time because of bitumen ageing as reported by Ling *et al*, [7]. The mortar becomes more brittle and prone to cracking, thus leading to inferior pavement performance. It was concluded that both the chemical and mechanical properties of mortars significantly changed with ageing. Specifically, the carbonyl index, stiffness, and strength of the mortar increased. Lv *et al*, [8] demonstrated that ductility and penetration of bitumen diminish because of ageing, while softening point and ignition temperature increase in the process. Moreover, the viscosity increases, and bitumen becomes stiffer. Rahmani *et al*.,[9] stated that the stiffness modulus increases due to aging, and this increase can be up to 4 times depending on the type of asphalt. This may cause the mixture to become excessively hard and brittle and susceptible to disintegration and fatigue cracking at low temperatures. Mechanisms causing binder aging include Oxidation, volatilization, and steric hardening of asphalt mixtures as reported by Anderson and Bonaquist, [10]. During production, laying, and compaction, asphalt mixture is subjected to higher temperature which causes aging due to oxidation and loss of volatile compounds. On the contrary, long-term aging during service periods takes place at lower temperature primarily due to oxidation mechanism. Fernandez-Gomez *et al*, [11] stated that Volatilization is another important mechanism that occurs during hot mixing and construction of asphalt cement. At high temperatures, lighter molecular weight can vaporize and escape into the atmosphere. When thin asphalt film encounters aggregate at high temperatures, aromatic fractions rapidly evaporate, and asphaltene fractions generally increase between 1 and 4%. Fumes and steams are generated because of this reaction depending on the contact surface area between the asphalt film and the aggregates. As a result of weight loss, asphalt flow properties are reduced, that is, viscosity is affected by volatilization, especially given the speed with which volatilization takes place. However, Steric hardening, occurs over time when asphalt cements are exposed to low temperature. In this process, molecular structure of asphalt is reorganized, affecting its asphaltene fractions as mentioned by Swiertz, [12]. Consequences of steric hardening are increased viscosity, slight volume contraction, and ultimately the hardening of asphalt. Steric hardening is more pronounced at temperatures close to 0°C and must be considered while testing asphalt at very low temperature. It was concluded that as this hardening is a result of structural reorganization of the molecule at low temperatures, it can be reversed through heat or mechanical work. Rheological characterization of bitumen includes testing for age hardening, temperature susceptibility, shear susceptibility, stiffness, and viscosity as reported by Miró *et al*. [13]. The effects of test type, asphalt cement type, modifier type, and content, on temperature susceptibility of asphalt binder were investigated by Abed and Al-Haddad, [14]. The results showed that using activation energy, which is the slope of asphalt binders dynamic shear viscosity and the test temperature, for flow allowed discernment of asphalt cement's susceptibility to temperature variation. Molenaar *et al*, [15] studied the effects of ageing on the mechanical characteristics of bituminous binders in asphalt concrete. The results showed that ageing increased the tensile strength of the bituminous binders but decreased the strain at break. In recent study by Sirin *et al*, [16] and Yin *et al*, [17] on asphalt mixtures, it was indicated that nonuniform field aging of asphalt mixtures over depth and the surface of the asphalt pavement is found to be aged faster than the bottom. Elwardany *et al*. [18] reported that brittleness increases with conditioning period under all aging modes, and over time in in-field service conditions. As a result, fatigue cracking resistance and durability of asphalt mixtures is affected, which would be more notable as the temperature increases. Gao *et al*, [19] showed that degradation in asphalt mixture elastic modulus increases with the increase in aging period.

The aim of the present investigation is to assess the influence of ageing on rheological properties of asphalt binder and temperature susceptibility of asphalt concrete prepared by using dense graded aggregate and three types of asphalt binder having similar penetration grade obtained from Daura, Erbil, and Nasiriyah refineries located at middle, north and south regions of the country.

2. Materials Characteristics

2.1. Asphalt cement

Asphalt cement produced from three different oil refineries at the middle, north and south regions of Iraq (Dura, Erbil, and Nasiriya) have been implemented in the present investigation. Table 1 exhibit the physical properties of asphalt cement samples. It can be noted that the asphalt binders are of penetration grade (40-50) but with variable physical and rheological properties.

Table 1: Physical properties of asphalt binder

Physical property as per ASTM, [20]	Unit	Asphalt cement source			SCRB,[21] Specifications
		Doura	Erbil	Nasiriya	
Penetration (ASTM D-5)	0.1mm	41	45	43	40-50
Softening Point (ASTM D-36)	°C	49.4	48.2	53.8	------
Ductility (ASTM D-113)	Cm	144	132	117	+100
Flash Point (ASTM D-92)	°C	275	268	265	>232
Penetration Index	---	-1.77	-0.64	-1.88	------
Stiffness Modulus	(kN/m^2)	78	140	80	------
After Thin Film Oven Test (ASTM D-1754)					
Retained Penetration	%	66	64	61	>55 %
Ductility	Cm	87	79	65	>25 %
Loss in weight on Heating	%	0.3	0.27	0.35	< 0.75

2.2. Coarse and Fine Aggregates

The aggregate used in this work was obtained from AL-Nibaie quarry; it consists of crushed quartz, hard, tough, grains, free from deleterious substances. The aggregates are widely used in Baghdad for asphalt concrete pavement construction. The coarse and fine aggregates used in this work were separated to different sizes by sieving, then recombined in the proper proportions to meet the wearing course gradation as required by specification SCRB, R/9 [21]. The physical properties for the aggregates are presented in Table 2.

Table 2: Physical properties of aggregates

Property	Coarse aggregates	ASTM [20] Designation No.	Fine Aggregates	ASTM [20] Designation No.
Bulk Specific Gravity	2.584	ASTM C-127	2.604	ASTM C-128
Apparent Specific Gravity	2.608	ASTM C-127	2.664	ASTM C-128
Water Absorption %	0.57	ASTM C-127	1.42	ASTM C-128
Los Angeles Abrasion %	13	ASTM C-131	------	-------

2.3. Mineral Filler

Ordinary Portland cement obtained from Tasluga plant was implemented as mineral filler. The physical properties of the filler are presented in Table 3.

Table 3: Properties of Mineral filler

Property	Test Result
% Passing Sieve No. 200	96
Specific Gravity	3.140
Specific Surface Area (m^2/kg)	312.5

3. Testing Methods

3.1. Bending Beam Rheometer (BBR) Test

The BBR is designed to characterize the low-temperature behavior of bituminous binders. The bending beam rheometer as per ASTM D 6648, [20] was implemented to determine the flexural creep stiffness of bituminous binders. The tested beam specimen of 125mm length and 12.5 mm width and 6.25 mm height was seated as simply supported beam in the three point bending beam apparatus shown in Figure 1 and practices a constant creep load of 980 mN (100 gm) applied to the beam center for 240 seconds. Meanwhile, the vertical deflection was measured as a function of time. A low temperature bath (deep freeze) is used to control the temperature (at approximately -18 °C). The creep stiffness of the test specimen for the specific loading times is calculated from the bending stress and strain. The super pave specifications require that the creep stiffness does not exceed 300 MPa at 60 seconds.

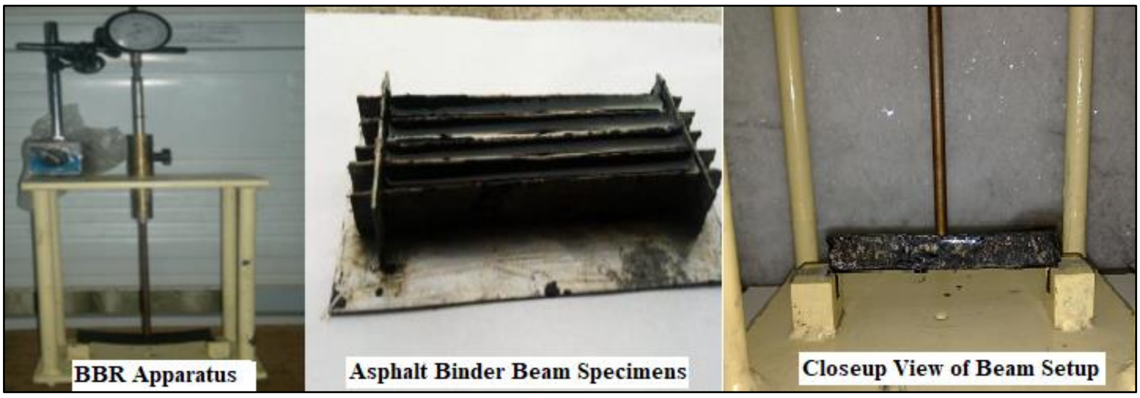

Fig 1: BBR Beams and Test Apparatus

3.2. Thin Film Oven Test (TFOT)

The thin film oven test as per ASTM D 1754 [20] is implemented to evaluate the changes in physical properties of asphalt cement because of its exposure to heat and air (short-term aging process) during conventional hot mixing in asphalt plants. A 50-gm sample of asphalt binder is placed in a flat container (140 mm diameter) resulting in a film thickness of 3.2 mm. Two or more of these containers are then positioned on a shelf rotating at 5 rpm to 6 rpm in an oven for 5 h at 163 °C. The mass loss (%) in sample after and before test is determined and the penetration, softening point and ductility after thin film oven test are determined.

3.3. Ageing of Asphalt Cement

Asphalt cement has been aged by using the thin film oven test device with various aging periods of (2, 3, 5 and 7) hours to verify its impact on physical and rheological properties of asphalt binders. Penetration, softening point, ductility, and bending beam rheometer were determined after each of the aging periods.

3.4. Preparation of Asphalt Concrete Mixture

The aggregates were washed, dried to a constant weight at 110 ºC, and then sieved. The combined aggregates mixture was heated to a temperature of (160 ºC) before mixing with asphalt cement. The asphalt cement was heated to a temperature of (150 ºC) to produce a kinematic viscosity of (170±20) centistokes. Then, asphalt cement was added to the heated aggregate to achieve the desired amount and mixed thoroughly by hand for 2 minutes until all aggregate particles are coated with thin film of asphalt cement.

3.5. Ageing of Asphalt Concrete Mixture

Aging of mixture was conducted in accordance with AASHTO, R30, [22]. The short-term conditioning of the mixture simulates the plant-mixing, transportation, laying and compaction in the field. The long-term conditioning of the asphalt concrete specimens simulates the ageing of the compacted mixture that will undergo during seven to ten years of service.

3.6. Short-Term Aging

According to SHRP, [23] the loose mixture was placed in a pan, and spread to an even thickness ranging between 25 and 50 mm. the mixture in pan was placed in the conditioning oven for four hours at a temperature of 135 °C. Stirring the loose mix every 60 minutes to maintain uniform conditioning was conducted. After aging process, the loose mix was removed from the forced-draft oven. Figure 2 exhibit the short-term ageing process.

Fig 2: Mixtures Under Short-Term Ageing

3.7. Preparation of Asphalt Concrete Specimens

The Marshall Mold assembly were (101.6 mm) in diameter and (63.5 mm) in height. Spatula and compaction hammer were heated on a hot plate to a temperature between (90-150 °C). The short-term aged asphalt mixture was transferred to the preheated mold and it was then spaded vigorously with the heated spatula 15 times around the perimeter and 10 times in the interior. The temperature of the mixture immediately prior to compaction was between 150°C. Then, 75 blows on the top and bottom of the specimen were applied with a compaction hammer of 4.535-kg sliding weight, and a free fall of (457.2 mm). The specimen in mold was left to cool at room temperature for 24 hours and then it was removed from mold by using sample extractor. The asphalt concrete specimens were prepared as per ASTM, [20] procedure.

3.8. Long-Term Aging

The compacted asphalt concrete specimens prepared from mixtures exposed to short-term aging were placed in a forced-draft oven at 85°C for 120 hours as per the requirements of SHRP, [24], and AASHTO R30, [22]. At the end of the aging periods, the oven is switched off and left to cool to room temperature before removing the specimens. The specimens were tested after 24 hours after removal from the oven.

3.9. Indirect Tensile Strength Test and Temperature Susceptibility of Asphalt Concrete

Specimens were tested for indirect tensile strength according to ASTM D 4123 [20]. The prepared specimens were conditioned at different testing temperatures of (25 and 40 ˚C) for 30 minutes. Then they were tested by Versa-Tester using a 1/2 in. (12.5 mm) wide curved, stainless steel loading strip on both the top and bottom, running parallel to the axis of the cylindrical specimen which was loaded diametrically at a constant rate of 2 in/min. (50.8 mm/min.) until reaching the ultimate loading resistance. Temperature susceptibility was calculated according to the procedure by ASTM, 2015 [19].

4. Results and Discussions

4.1. Influence of Ageing on Rheological Properties of Binder

The penetration index, (PI) is a measure of the temperature susceptibility of bitumen that can be derived mathematically from the penetration and softening point test values. Temperature susceptibility is the rate at which the consistency of asphalt cement changes with a change in temperature. Asphalt cements with penetration index (PI) above (+2) have less temperature susceptibility and are less brittle at low temperature. Large negative values of (PI) indicate greater temperature susceptibility. Typical paving asphalts have (PI) values between (+2 and -2) which exhibits normal susceptibility to temperature. In addition, the negative sign of (PI) means that asphalt cement is more susceptible to temperature as reported by Woods *et al*, [25].

Figure 3 demonstrates the influence of ageing period on penetration index (PI) of asphalt binders. The penetration index values of various control and aged asphalt cement binders are within normal limits of (+2 and -2) and their temperature susceptibility is mostly normal. However, it can be noticed that Erbil binder exhibit the lowest penetration index as compared to other binders regardless of the ageing periods. For control binder (before ageing), the (PI) of Erbil binder is (- 0.64) which is lower than that of Daura and Nasiriya binders by (63.8 and 66) % respectively. Such observation can indicate lower temperature susceptibility of Erbil binder and more suitability for use in paving work when compared to other binders. However, as the ageing period increases, the penetration index increases for Erbil and Daura binders while it decreases for Nasiriya binder. This could be attributed to the lower ductility of Nasiriya binder before and after ageing (117 and 65) cm which indicate lower volatiles and higher asphaltene content as compared to Daura (144 and 87) cm and Erbil (132 and 79) cm respectively. On the other hand, the rate of increase in negative (PI) value is (0.09, and 0.48) % for Daura and Erbil respectively, while (PI) negative values decreases by 0.18 %. Such finding indicate improvement in the resistance to temperature variation after ageing for Nasiriya binder, while the quality of Erbil and Daura binder decline after ageing. Such findings agree with Sarsam, [26] work.

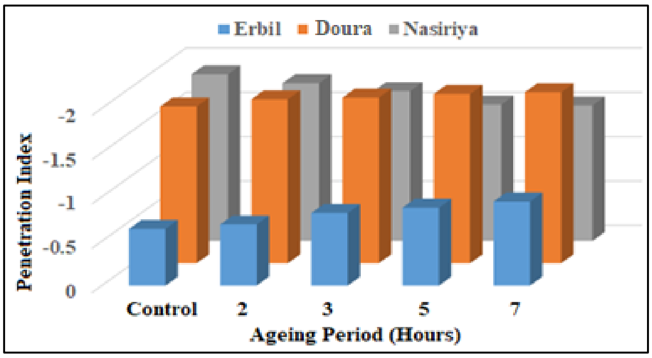

Fig 3: Influence of Ageing on Penetration Index of Asphalt Binder

The shell nomograph, Van der Poel, [27] is applied to determine the stiffness modulus of asphalt cement based on the test temperature, the time of loading, ring and ball softening point and temperature susceptibility (penetration index) for asphalt cement. The stiffness modulus of various asphalt binders was determined at temperature of 60 º C, using a single loading time of 0.02 second. The time of loading is approximately 0.02 second which t is related to the typical traffic speed (50–60 kph) according to Strategic Highway Research Program (SHRP) as cited by Hunter *et al*, [28]. As demonstrated in Figure 4, although the binders have the same penetration grade of (40-50), they exhibit various stiffness modulus values of (78, 80 and 140) kN/m^2 for Daura, Nasiriya, and Erbil binders respectively before ageing. It can be noted that the stiffness modulus increases throughout the ageing process. This may be attributed to the stiffening of binder after continuous loss of volatiles. The stiffness modulus increases by (118, 112.5, and 193) % after seven hours of ageing for Daura, Nasiriya, and Erbil binders respectively. Similar findings were reported by Sarsam and Lafta [29].

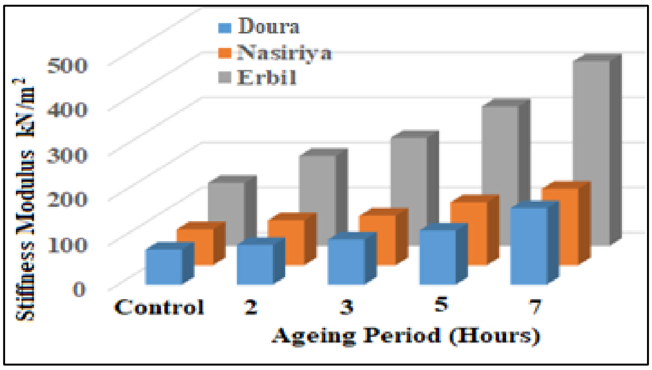

Fig 4: Influence of Ageing on Stiffness Modulus of Asphalt Binder

The low temperature behavior of asphalt binders has been characterized by the Bending Beam Rheometer (BBR) test. The BBR measures a binder's creep stiffness which is an indication of its resistance to thermal cracking. The creep stiffness behavior at various ageing periods is exhibited in Figure 5. It can be observed that creep stiffness values before and after ageing are within the limitations of Superpave. It can be noted that the creep stiffness increase with increasing the aging periods for all asphalt binders investigated in this study. The increasing in creep stiffness refers to the fact that aging process converts the asphalt consistency to very hard and brittle material. Erbil binder exhibit the highest creep stiffness of 145 MPa among Doura and Nasiriya binders with (136.8 and 125.4) MPa respectively before ageing. After practicing ageing, the creep stiffness increases by a rate of (81.8, 74.2, and 84.4) % for Doura, Erbil and Nasiriya respectively. This is further supporting the previous behavior of Erbil binder as superior quality at high and low temperature among other investigated binders. Sarsam and Al-Sadik, [30] reported similar behavior.

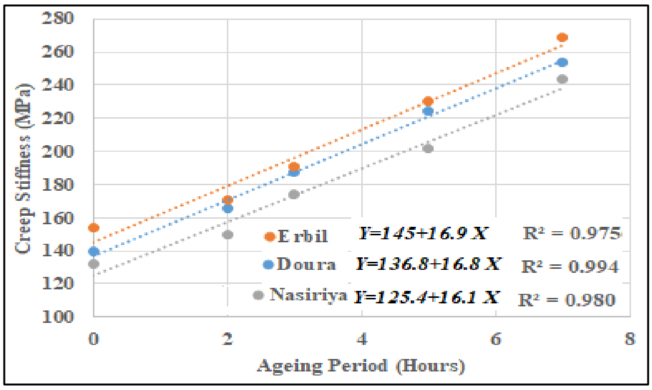

Fig 5: Influence of Ageing on Creep Stiffness of Asphalt Binder

4.2. Influence of Ageing on Rheological Properties for Asphalt Concrete

Figure 6 exhibit the influence of ageing (long term) on the rheological properties of asphalt concrete. A significant variation in temperature susceptibility of asphalt concrete mixture could be noted when implementing Erbil binder among the other binders. For control asphalt concrete specimens (before long term ageing), the temperature susceptibility was (39.4, 50.1, and 53.4) kPa/°C when Erbil, Nasiriya, and Doura binders were implemented respectively. On the other hand, the temperature susceptibility of asphalt concrete increase under long term ageing by a rate of (31, 52.4, and 55) % for Erbil, Doura, and Nasiriya binders respectively.

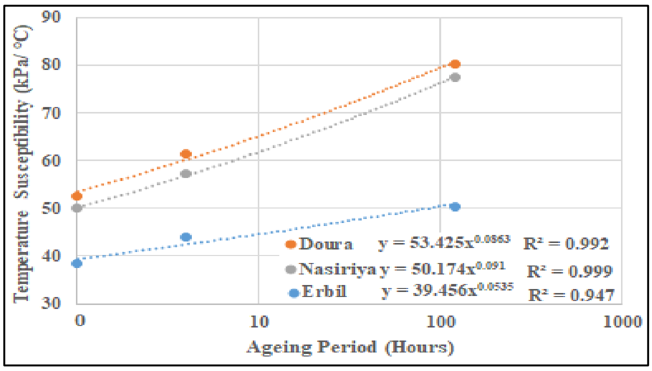

Fig 6: Influence of Ageing on Temperature Susceptibility of Asphalt Concrete

5. Conclusion

Based on the limitations of implemented materials and the testing program, the following conclusions may be addressed.

1. Implementation of asphalt binder of the same penetration

grade but from varied asphalt sources from the north, middle and south regions of Iraq (Erbil, Doura, and Nasiriya) have produced different behavior under ageing. This appears to be related to the crude from which the asphalt is produced.
2. Erbil binder exhibit the lowest penetration index (PI) as compared to other binders regardless of the ageing periods. The rate of increase in negative (PI) value is after ageing (0.09, and 0.48) % for Daura and Erbil respectively, while (PI) negative values decreases by 0.18 %.
3. The stiffness modulus increases by (118, 112.5, and 193) % after seven hours of ageing for Daura, Nasiriya, and Erbil binders respectively.
4. Erbil binder exhibit the highest creep stiffness of 145 MPa among Doura and Nasiriya binders before ageing. After practicing ageing, the creep stiffness increases by a rate of (81.8, 74.2, and 84.4) % for Doura, Erbil and Nasiriya respectively.
5. The temperature susceptibility of asphalt concrete increase under long term ageing by a rate of (31, 52.4, and 55) % for Erbil, Doura, and Nasiriya binders respectively.
6. It is recommended that the selection of a proper asphalt cement for paving must be based on evaluation of rheological properties such as temperature susceptibility and environmental conditions rather than the present practice of considering the physical properties only.

6. References

1. Sarsam SI. Assessing rheological and physical characteristics of modified asphalt cement. Proceedings, 8TH International Conference on Material Sciences (CSM8-ISM5), UNESCO Palace, Beirut-Lebanon, 2012, 28-30.
2. Sirin O, Paul D, Kassem E. State of the art study on aging of asphalt mixtures and use of antioxidant additives. Hindawi Advances in Civil Engineering. Volume 2018, Article ID 3428961, 18 pages https://doi.org/10.1155/2018/3428961
3. Jing R, Varveria A, Liua X, Scarpasb A, Sandra Erkens S. Rheological, fatigue and relaxation properties of aged bitumen. International journal of pavement engineering. 2020; 8(21):1024-1033 https://doi.org/10.1080/10298436.2019.1654609
4. Glover CJ, Martin E, Chowdhury A. Evaluation of binder aging and its influence in aging of hot mix asphalt concrete: literature review and experimental design. Research Report No. FHWA/TX-08/0-6009-1. Texas Transportation Institute, College Station, TX, USA, 2009.
5. Wang L, Wei J, Zhang YJ. Pavement Res. Technol. 2009; 2(2):75.
6. Cholewińska M, Iwański M, Mazurek G. The impact of ageing on the bitumen stiffness modulus using the cam model. The Baltic Journal of Road and Bridge Engineering. 2018; 13(1):34-39. https://doi.org/10.3846/bjrbe.2018.386
7. Ling R, Liu X, Varveri A, Scarpas A, Erkens S. The Effect of Ageing on Chemical and Mechanical Properties of Asphalt Mortar. Appl. Sci. 2018; 8:2231. MDPI, Doi:10.3390/app8112231 www.mdpi.com/journal/applsci
8. Lv S, Wang S, Guo T, Xia C, Li J, Hou H. Laboratory evaluation on performance of compound-modified asphalt for rock asphalt/styrene-butadiene rubber (SBR) and rock asphalt/nano-caco3. Appl. Sci. 2018; 8:1009. https://doi.org/10.3390/app8061009
9. Rahmani E, Darabi E, Little D, Masad E. Constitutive modeling of coupled aging-viscoelastic response of asphalt concrete. Construction and Building Materials. 2017; 1-15:131.
10. Anderson D, Bonaquist R. Investigation of short-term laboratory aging of neat and modified asphalt Binders. Research Report NCHRP-709, Transportation Research Board. Washington, DC, USA, 2012.
11. Fernandez-Gomez W, Quintana H, Lizcano F. A review of asphalt and asphalt mixture aging. Ingenierıa e Investigacion. 2013; 33(1):5-12.
12. Swiertz D. Asphalt Aging Characteristics, Rheological Implications and Laboratory Techniques, University of Wisconsin, Madison. WI, USA, 2010.
13. Miró R, *et al*, Effect of ageing and temperature on the fatigue behavior of bitumen. Materials and Design. 2015; 86:129-137.
14. Abed Y, Al-Haddad A. Temperature Susceptibility of Modified Asphalt Binders. Proceedings, 3rd International Conference on Engineering Sciences IOP Conf. Ser.: Mater. Sci. Eng. 671 012121. 2020. Doi: 10.1088/1757-899X/671/1/012121.
15. Molenaar AAA. Hagos ET. Van de Ven MFC. Effects of aging on the mechanical characteristics of bituminous binders in PAC. J. Mater. Civ. Eng. 2010; 22:779-787. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000021
16. Sirin O, Paul D, Ohiduzzaman M, Kassem E. Effect of ageing on asphalt binders in the State of Qatar: a case study. Road Materials and Pavement Design. 2017; 18(4):165-184.
17. Yin F, Martin A, Arambula-Mercado E, Newcomb D. Characterization of non-uniform field aging in asphalt pavements. Construction and Building Materials. 2017; 153:607-615.
18. Elwardany M, Rad F, Castorena C, Kim Y. Evaluation of asphalt mixture laboratory long-term ageing methods for performance testing and prediction. Road Materials and Pavement Design. 2017; 18(1):28-61.
19. Gao Y, Geng D, Huang X, Li G. Degradation evaluation index of asphalt pavement based on mechanical performance of asphalt mixture. Construction and Building Materials. 2017; 140:75-81.
20. ASTM. Road and Paving Materials, Annual Book of ASTM Standards, Volume 04.03. Standard test method for pulse velocity through concrete. American Society for Testing and Materials, West Conshohocken, USA, 2015.
21. SCRB. State Commission of Roads and Bridges SCRB. Standard Specification for Roads & Bridges, Ministry of Housing & Construction, Iraq, 2003.
22. AASHTO. Standard Practice for Mixture Conditioning of Hot Mix Asphalt (HMA). AASHTO R30. Washington, D.C., USA, 2015.
23. SHRP. Standard Practice for Simulating the Short-Term Ageing of Bituminous Mixtures Using A Forced Draft Oven. SHRP No. 1025. Strategic Highway Research Program. National Research Council, Washington, DC, 1992.
24. SHRP. Test Method for Predicting the Long-Term Ageing of Bituminous Mixtures Using A Forced Draft

Oven. SHRP No. 1030. Strategic Highway Research Program, National Research Council, Washington, DC, 1992.
25. Woods KB, Berry DS, Goetz WH. Highway Engineering Handbook, 1982. Mc Graw-Hill Book Company, Inc. London, 1992, 18-21.
26. Sarsam S. Assessing rheological and physical characteristics of modified asphalt cement. Proceedings, 8TH International Conference on Material Sciences (CSM8-ISM5), UNESCO Palace. Beirut–Lebanon, 2012, 28-30.
27. Van der Poel CA. General System Describing the Visco-Elastic Properties of Bituminous and Its Relation to Routine Test Data. Shell Bitumine Reprint. Shell Laboratorium-Koninklijike, 1954, 9.
28. Hunter R, Self A. and Read J. The Shell Bitumen Handbook, Sixth edition.. Shell International Petroleum Company Ltd. ICE Publishing, 2015. www.icevirtuallibrary.com
29. Sarsam SI, Lafta IM. Assessing Rheological Behavior of Modified Paving Asphalt Cement. American Journal of Civil and Structural Engineering, (AJCSE), Sciknow Publications Ltd. USA. 2014; 1(3):47-54.
30. Sarsam SI, Al-Sadik SM. Modeling Aging Impact on Physical Properties of Asphalt Cement. Research Journal of Modeling and Simulation, RJMS. 2014; 1(2):20-29. Sciknow Publications Ltd. USA.