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Comparative Assessment of Ageing Impact on Strength and Rheological Properties of Asphalt Concrete

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ABSTRACT
The flexibility of asphalt concrete pavement declines with ageing, the mixture exhibits stiff behavior, and the durability degrades due to the changes in rheological properties. In the present investigation, three types of asphalt binder with similar penetration grade have been implemented in the preparation of asphalt concrete mixture for wearing course. Marshall Specimen was prepared after subjecting the loose mixture to short-term ageing. The specimens were subjected to long-term ageing before testing for indirect tensile strength. The temperature susceptibility was determined after testing the specimens at (20 and 40)°C. The variations in volumetric properties were determined throughout the ageing process. It was observed that Erbil binder exhibits the lowest temperature susceptibility of 35.6 kPa/°C and lowest indirect tensile strength of 1100.1 kPa and highest degradation in the flexibility of asphalt concrete as compared with Nasiriyah and Dourah binders.However, the rate of increase in voids content and voids in mineral aggregates VMA with ageing period is gentle in case of Nasiriyah binder while the rate is sharper in case of Erbil and Dourah binders. Nasiriyah binder exhibit the highest VMA of 15.3 % and lowest voids filled with asphalt binder Vfb of 70.6 % while Erbil and Dourah binders shows lower VMA of (15.1 and 14.8) % and higher Vfb of (71.3 and 73.2) % respectively.

Keywords: *Tensile Strength, Asphalt Concrete, Temperature Susceptibility, Voids, Ageing*

INTRODUCTION
The influence of ageing on asphalt concrete properties was investigated by many research works,Sirin et al., [1]revealed that ageingprocess is the change in rheological properties of asphalt bindersdue to the changes in chemical composition during constructionand throughout its service life period. Aging causes the asphalt material to stiffen and getting brittle, which affects the durability of asphalt concrete and leads to a highpotential for distress.Glover et al.,[2]addresses that ageing process of asphalt binders occurs during the production ofasphalt concrete mixtures and while it is in service when exposed to thesurrounding environment. The first stage of aging is referred to as short-termaging occurs ata fast rate when asphalt mixture is produced at a veryhigh temperature. During this stage, changes are presented in high viscosity andincreased stiffness which occurs due to significantchange in the rheological properties of the asphalt binders. The second stage of aging occurswhen the asphalt is exposed to the environment as in-servicepavement at a relatively lower temperature for a long duration. The rate of hardening depends on the in-place airvoid content and surrounding environment.Rahmani et al.,[3] stated that the stiffness modulusincreases up to four times due to aging process depending on the type of asphalt binder. This may cause the mixture to become excessively hard andbrittle and susceptible to

disintegration and fatigue crackingat low temperatures.Miró et al. [4]reported that rheological characterization of bitumen includes testing forage hardening, temperature susceptibility, shear susceptibility,stiffness, and viscosity.Molenaar et al., [5] assessed the effects of ageingon the mechanical characteristics of bituminous binders in asphalt concrete. The results showed that ageing process increases the tensile strength of the bituminous binders but decreased the strain at break. Fernandez-Gomez et al., [6] Revealed that volatilization of asphalt binder is another important mechanism that can occur during hot mixing and constructionof asphalt concrete. At high temperatures, lighter molecularweight component of the binder can vaporize and escape into the atmosphere.When thin asphalt film encounters aggregate at high temperatures, aromaticfractions rapidly evaporate and asphaltene fractions generallyincrease between 1 and 4%. Fumes and steams are generated because of this reaction depending on thecontact surface area between the asphalt film and the aggregates. As a result of weight loss, asphalt flowproperties are reduced, and viscosity is affected by volatilization. Swiertz, [7] stated that steric hardening, occurs over time when asphalt cementis exposed to low temperature. In this process, molecularstructure of asphalt is reorganized, affecting its asphaltenefractions.The effects of test type, asphalt cement typeand content, on temperaturesusceptibility of asphalt binder were investigated by Abed and Al-Haddad,[8]. The results showed that using activation energy, which is the slope of asphalt binders dynamic shear viscosity and the test temperature, for flowallowed discernment of asphalt cement’s susceptibility to temperature variation. Gao et al., [9] Revealed that degradation in asphalt mixture elastic modulus increases with the increase in agingperiod.Islam et al., [10] prepared cylindrical samples in the laboratory, and the specimens were aged in the laboratory and field, and then loaded diametrically to determine indirect tensile strengthITS valueof compacted samples after subjecting them to (1, 5, 10, 15, 20, and 25) days of oven aging at 85 °C in the laboratory. The ITS tests were also performed on samples prepared after the loose mixes were subjected to (8, 16, 32, 48, 72 and 100) hours oven aging at 135 °C. It was concluded that ITS increase with the aging period. It was found that one-day laboratory aging is close to approximately one-year of field aging measured in terms of ITS value. Results from loose mix aging show that the ITS value increases with the conditioning period, reaches a peak, and then decreases with the conditioning period.Omranian et al., [11]evaluated the effects of short-termaging on compactibility and volumetric properties of asphalt mixtures. Three different binders were utilized to prepare mixtures. Aging temperature, and aging duration, was considered as independent variables, while compactibility andvolumetric properties were regarded as dependent variables. The findings revealed significantimpacts of aging temperature and duration on compactibility, air voids, voids in mineral aggregate, and voids filled with asphalt.

The aim of the present work is to assessthe influence of ageing on the tensile strength and rheological property in terms of temperature susceptibility and volumetric properties of asphalt concrete by implementing 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. Models of the ageing process will be presented.

MATERIALS AND METHODS

Asphalt Cement

The asphalt cement implemented in the present investigation was obtained from three different oil refineries at the middle, north and south regions of Iraq (Dourah, Erbil, and

Nasiriyah). Table 1 exhibits the physical properties of asphalt cement binders. It can be noted that the all the asphalt binders have the same penetration grade (40-50) but with variable physical and rheological properties.

Table 1. Physical Properties of Asphalt Binder

Physical Property as Per ASTM, [12]	Unit	Asphalt Cement Source			SCRB, [13]Specifications
		Dourah	**Erbil**	**Nasiriyah**	
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

Coarse and Fine Aggregates

Coarse and fine aggregates were obtained from Al-Nibaee quarry and implemented in the present investigation; Table 2 presents their physical properties.

Table 2. Physical Properties of Al-Nibaee Coarse and fine Aggregates

Property as per ASTM, [12]	Course Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128)	2.610	2.631
Apparent Specific Gravity (ASTM C 127 and C 128)	2.641	2.6802
Percent Water Absorption (ASTM C 127 and C 128)	0.423	0.542
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	20.10	-

Mineral Filler

Ordinary Portland cement was implemented as mineral filler for the asphalt concrete mixture; the physical properties of Portland cement are presented in Table 3.

Table 3. Physical Properties of Portland Cement

Physical Properties	Test Value
% Passing Sieve No.200 (0.075mm)	98
Apparent Specific Gravity	3.1
Specific Surface Area (m^2/kg)	355

Selection of Asphalt Concrete Gradation

Dense graded asphalt concrete usually used for wearing course as per SCRB specification, [13] with 12.5 mm nominal maximum size of aggregates has been implemented. Figure 1 shows the selected aggregate gradation and the specification limits.

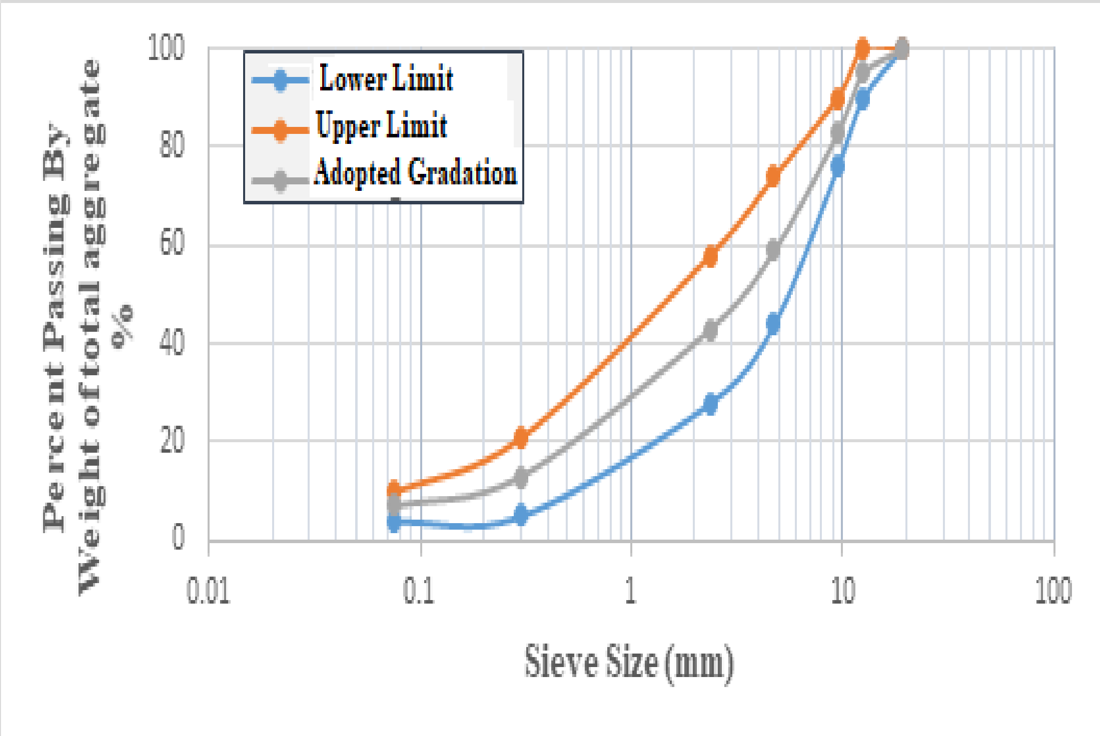

Fig.1. Specification Limits and Mid-Point Gradation of SCRB,[13] for Wearing Course.

Preparation of Hot Mix Asphalt Concrete Specimens

Coarse and fine aggregates were separated to different sizes by sieving, then were combined with mineral filler to meet the specified gradation. The combined aggregate mixture was heated to 150 ºC before mixing with asphalt cement, while the asphalt cement was heated to 140ºC. Then, the required amount of asphalt cement was added to the heated aggregate and mixed thoroughly using mechanical mixer for 2 min until all aggregate particles were coated with thin film of asphalt cement.

Asphalt concrete mixtures were subjected to the short-term ageing process as per SHRP, [14].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.Marshall specimens were prepared in accordance with ASTM D1559, [12] using 75 blows of Marshall hammer on each face of the specimen.

The optimum asphalt content was determined as percent by weight of aggregates for each binder type. The prepared Marshall specimens were subjected to the long-term ageing process according to SHRP, [15].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.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.Asphalt concrete specimens were tested in duplicate, and the average value was considered for analysis. Details of obtaining the optimum asphalt content and the strength properties of asphalt concrete could be found in Sarsam and AL-Sadiq, [16].

Testing of Asphalt Concrete Specimens for Indirect Tensile Strength

Specimens were tested for indirect tensile strength according toASTM D 4123, [12].The prepared specimens were conditioned at different testing temperatures of (25 and 40°C) for 30 minutes. Thenthey were tested by Versa-Tester using a 1/2 in. (12.5 mm) wide curved, stainless steel loadingstrip on both the top and bottom, running parallel to the axis of the cylindrical specimen whichwas loaded diametrically at a constant rate of (50.8 mm/min.) until reaching the ultimateloading resistance. Temperature susceptibility was calculated according to the procedure by ASTM, [12].

RESULTS AND DISCUSSIONS

Determination of Optimum Asphalt Binder Content

Four different percentages of asphalt cement (4, 4.5, 5, 5.5) % of each source from different refineries (Dourah, Erbil and Nasiriyah) were implemented to determine the optimum asphaltcontent for asphalt concrete mixtures using Marshalltest method as per ASTM, 2015.Table 4exhibit a summary of the properties of the Marshall mixture at theoptimum binder for all asphalt cement types according to thespecification Requirements (SCRB, R/9 2003). The optimum asphalt content for different types of asphalt (Dourah, Erbil, and Nasiriyah) are found to be (4.7, 5 and 5.1) % respectively.

Table 4. Properties of Asphalt Concrete Mixtures

Property	Asphalt Binder Source			SCRB, [13] Specifications
	Dourah	Erbil	Nasiriyah	
Optimum asphalt content (%)	4.7	5	5.1	------
Marshall stability (kN)	10.8	11.1	10.4	8 kN (minimum)
Marshall flow (mm)	3.2	3.1	3.2	2-4 (mm)
Bulk density (gm/cm^3)	2.351	2.341	2.347	-------
Volume of voids (%)	3.5	4.2	4.1	3-5 (%)
Voids in mineral aggregates (%)	14.7	14.9	14.8	14 (%) (minimum)
Voids filled with asphalt binder (%)	73.8	71.5	74.4	-------

Influence of Ageing on Temperature Susceptibility of Asphalt Concrete

Figure 2 exhibit the influence of ageing period on temperature susceptibility of asphalt concrete mixtures when implementing different asphalt binder sources. It can be noted that the temperature susceptibility increases with ageing period. However, as shown in Table 5, Erbil binder exhibit the lowest susceptibility to temperature variation of 35.6 kPa/°C among Nasiriyah and Dourah asphalt binders with (49.8 and 54.6) kPa/°C respectively. On the other hand, the rate of increment in the temperature susceptibility as indicated by the slope of Erbil binder is the lowest as compared with other binders implemented. Table 5 also demonstrates the mathematical models of ageing in terms of increment in the susceptibility to temperature variations with their coefficients of determination. Such behavior agrees with Miró et al. [4] work.

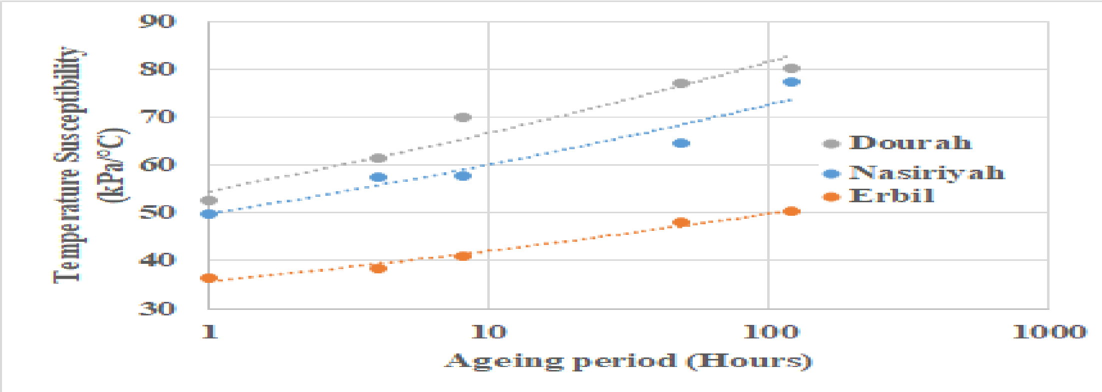

Fig. 2. Influence of Ageing on Temperature Susceptibility of Asphalt Binder

Table 5. Temperature Susceptibility Parameters

Binder origin	Intercept	Slope	Ageing model	R^2
Dourah	54.6	0.0873	$Y = 54.6\ X^{0.0873}$	0.941
Nasiriyah	49.8	0.0820	$Y = 49.8\ X^{0.082}$	0.932
Erbil	35.6	0.0730	$Y = 35.6\ X^{0.073}$	0.983

Influence of Ageing on Indirect Tensile Strength of Asphalt Concrete

Figure 3 demonstrates the degradation in the flexibility of asphalt concrete as the ageing process proceeds. It can be observed that the indirect tensile strength increases with the increment of ageing period. This could be attributed to the increment in the stiffness due to hardening of asphalt concrete.Dourah binder exhibit the highest tensile strength of 1509.3 kPa as compared to that of Nasiriyah and Erbil binders with (1352.7 and 1100.1) kPa respectively. Table 6 exhibits the slope which refers to the rate of ageing of the binders in terms of the increment of tensile strength. Dourah binder exhibits the lowest rate of increment in tensile strength with ageing (slope) as compared with Nasiriyah and Erbil binders. The ageing mathematical models are also demonstrated in Table 6 with their high coefficients of determination.Such finding agrees well with Sirin et al., [1] and Rahmani et al., [3].

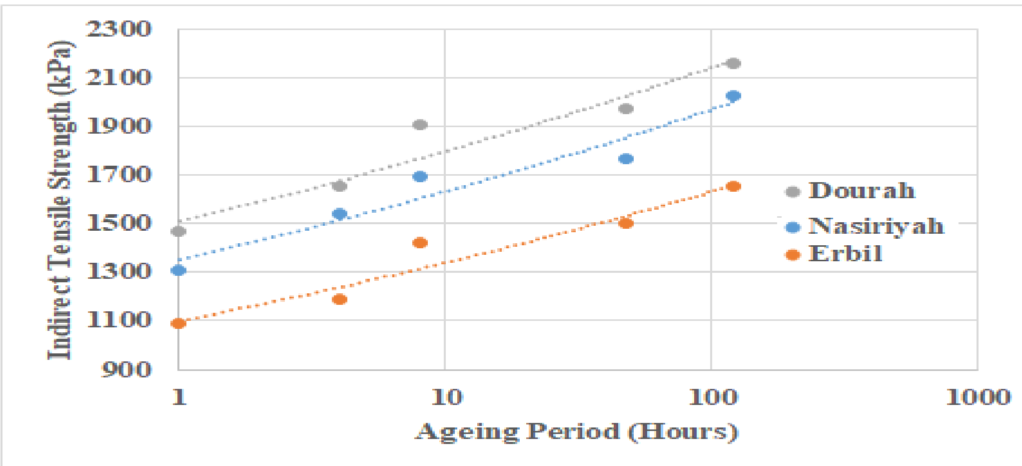

Fig. 3. Influence of Ageing on Tensile Strength of Asphalt Concrete

Table 6. Tensile Strength Parameters

Binder origin	Intercept	Slope	Ageing model	R^2
Dourah	1509.3	0.0716	$Y = 1509.3\ X^{0.0716}$	0.922
Nasiriyah	1352.7	0.0817	$Y = 1352.7\ X^{0.0817}$	0.930
Erbil	1100.1	0.0857	$Y = 1100.1\ X^{0.0857}$	0.928

Influence of Ageing on Volumetric Properties of Asphalt Concrete

As demonstrated in Figure 4, the voids content increases with ageing time regardless of the binder source. This may be attributed to the loss of volatiles from the binder structure. However, it can be noted from Table 7 that Nasiriyah binder exhibit the highest voids content in asphalt concrete mixture as indicated by the higher intercept value of 4.52 % as compared with the voids of Erbil and Dourah which exhibit (4.35 and 3.98) % of intercept respectively. On the other hand, the slope which represent the rate of increment in the voids content shows thatthe rate of increase in voids content is gentle in case of Nasiriyah binder while the rate is sharper in case of Erbil and Dourah binders.The ageing models of the binders are demonstrated in Table 7. A power mathematical model with high coefficients of determination could be noticed. Similar behavior was noticed byOmranian et al., [11].

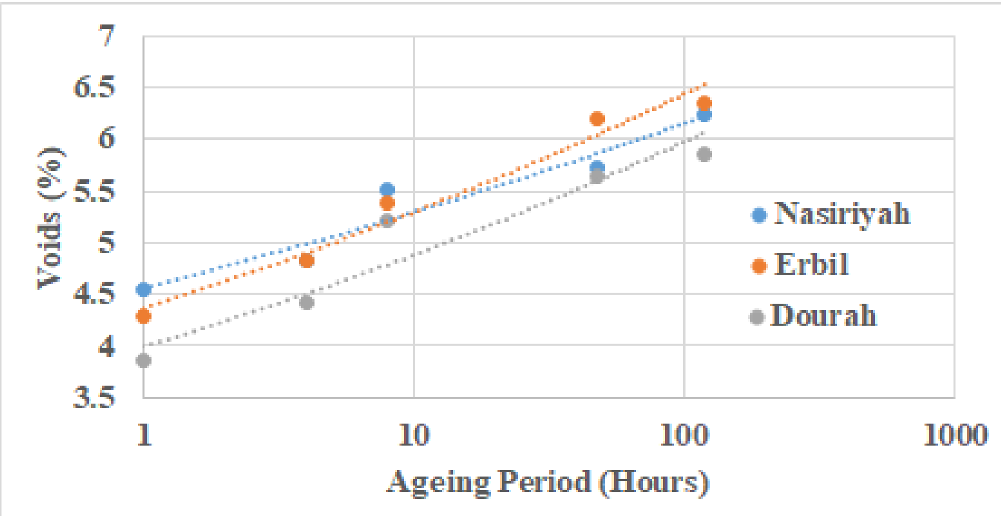

Fig. 4. Influence of Ageing on Percent Voids of Asphalt Concrete

Table 7. Percent Voids Parameters

Binder Origin	Intercept	Slope	Ageing model	R^2
Dourah	3.98	0.0876	$Y = 3.98\ X^{0.0876}$	0.917
Nasiriyah	4.52	0.0657	$Y = 4.52\ X^{0.0657}$	0.957
Erbil	4.35	0.0846	$Y = 4.35\ X^{0.0846}$	0.970

Figure 5 exhibits the influence of ageing period on the voids filled with binder, it can be noticed that Nasiriyah binder shows the lowest voids that was filled with asphalt binder while Dourah binder exhibit the highest volume of voids filled with binder. On the other hand, the volume of voids filled with asphalt binder declines with ageing period. This may be attributed to the fact that volume of asphalt binder decreases with increment of ageing period due to the loss of volatiles and the chemical changes in the binder structure. Table 8 demonstrates that Nasiriyah binder exhibit the lowest and gentler rate of decline in the voids filled with binder as compared with Erbil and Dourah binders. The ageing models in terms of declination in the voids filled with binder with ageing period are demonstrated in Table 8.

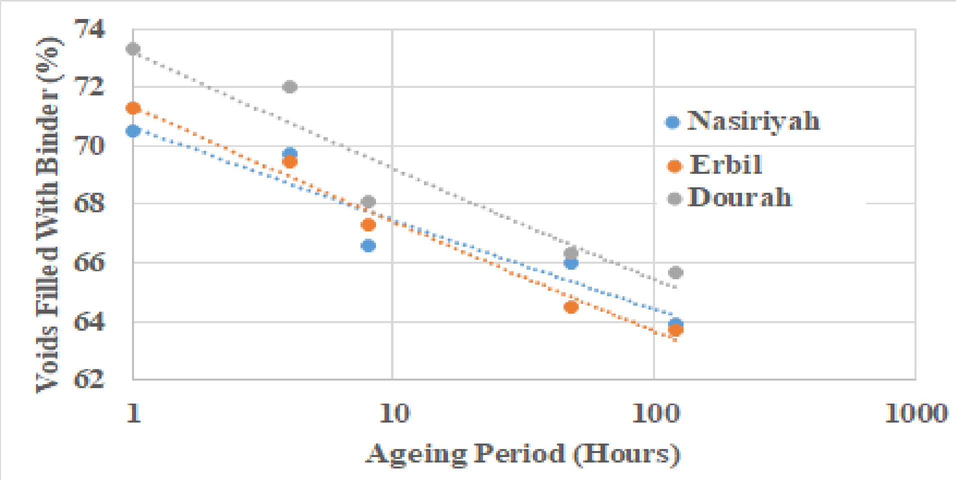

Fig. 5. Influence of Ageing on Voids Filled with Binder of Asphalt Concrete

Table 8. Percent Voids Filled with Binder Parameters

Binder Origin	Intercept	Slope	Ageing model	R^2
Dourah	73.21	0.024	$Y = 73.21\ X^{-0.024}$	0.910
Nasiriyah	70.65	0.020	$Y = 70.65\ X^{-0.020}$	0.905
Erbil	71.35	0.025	$Y = 71.35\ X^{-0.025}$	0.982

Figure 6 demonstrates the influence of ageing period on the voids in mineral aggregates (VMA). It can be observed that Nasiriyah binder exhibit the highest VMA of 15.3 % while Erbil and Dourah binders shows lower VMA of (15.1 and 14.8) % respectively. However, Table 9 present the rate of increase in the VMA for different binders, it can be noted that Nasiriyah binder exhibit the gentlest slope of 0.026 as compared with other binders. The ageing models in terms of increment in VMA with ageing period are demonstrated in Table 9.

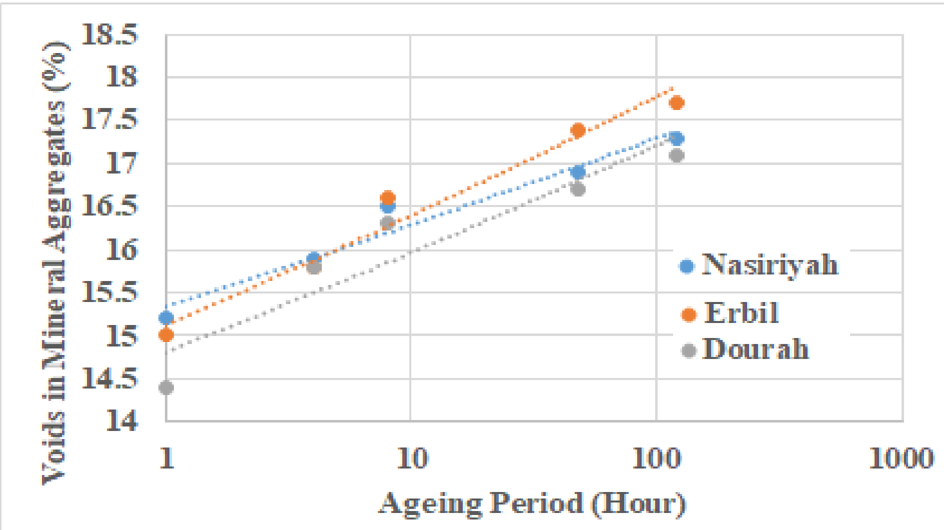

Fig. 6. Influence of Ageing on Voids in Mineral Aggregates (VMA) of Asphalt Concrete

Table 9. VMA Parameters

Binder Origin	Intercept	Slope	Ageing model	R^2
Dourah	14.81	0.0326	$Y = 14.81\ X^{0.0326}$	0.879
Nasiriyah	15.34	0.0260	$Y = 15.34\ X^{0.0260}$	0.955
Erbil	15.12	0.0350	$Y = 15.12\ X^{0.0350}$	0.966

CONCLUSIONS

In accordance with the limitations in materials properties and the testing program, the following conclusions may be addressed.

1) Erbil binder exhibit the lowest susceptibility to temperature variation of 35.6 kPa/°C among Nasiriyah and Dourah asphalt binders with (49.8 and 54.6) kPa/°C respectively.The rate of increment in the temperature susceptibility with ageing is the lowest as compared with other binders.
2) Dourah binder exhibit the highest indirect tensile strength of 1509.3 kPa as compared to that of Nasiriyah and Erbil binders with (1352.7 and 1100.1) kPa respectively.Dourah binder exhibit the lowest rate of increment in tensile strength with ageing as compared with other binders.
3) Nasiriyah binder exhibit the highest voids content in asphalt concrete mixture of 4.52 % as compared with the voids of Erbil and Dourah which exhibit (4.35 and 3.98) % respectively.The rate of increase in voids content is gentle in case of Nasiriyah binder while the rate is sharper in case of Erbil and Dourah binders.
4) Nasiriyah binder shows the lowest voids filled with asphalt binder of 70.65 % while Dourah binder exhibit the highest volume of voids filled with binder of 73.2 %.It exhibits the lowest and gentler rate of decline in the voids filled with binder as compared with Erbil and Dourah binders.
5) Nasiriyah binder exhibit the highest VMA of 15.3 % while Erbil and Dourah binders shows lower VMA of (15.1 and 14.8) % respectively. However, the rate of increase in the VMA for Nasiriyah binder exhibits gentlest slope among other binders.

REFERENCES

1) Sirin O., Paul D., and Kassem E. *State of the art study on aging of asphalt mixtures and use of antioxidant additives.*HindawiAdvances in Civil Engineering. Volume 2018, Article ID 3428961, 2018. 18 pages. https://doi.org/10.1155/2018/3428961
2) Glover C. J., Martin E., Chowdhury A. *Evaluation of binder aging and its influence in aging of hot mix asphalt concrete: literature review and experimental design*. ResearchReport No. FHWA/TX-08/0-6009-1. Texas TransportationInstitute, 2009. College Station, TX, USA.
3) Rahmani E., Darabi E., Little D., and Masad E. *Constitutive modeling of coupled aging-viscoelastic response of asphalt concrete.* Construction and BuildingMaterials, Vol. 131, 2017. P. 1–15.
4) Miró R., et al., *Effect of ageing and temperature on the fatigue behavior of bitumen*. Materials and Design, 86, 2015. P.129–137.
5) Molenaar, A.A.A.; Hagos, E.T.; Van de Ven, M.F.C. *Effects of aging on the mechanical characteristics of bituminous binders in PAC*. J. Mater. Civ. Eng., 22, 2010. P. 779–787.https://doi.org/10.1061/(ASCE)MT.1943-5533.0000021
6) Fernandez-GomezW., Quintana H., and Lizcano F.*A review of asphalt and asphalt mixture aging*. Ingenierıa e Investigacion, Vol. 33, No. 1, 2013. P. 5–12.

7) Swiertz D. *Asphalt Aging Characteristics, Rheological Implications and Laboratory Techniques*, University of Wisconsin, Madison, 2010. WI, USA.
8) Abed Y. and Al-Haddad A. *Temperature Susceptibility of Modified Asphalt Binders*. Proceedings, 3rd International Conference on Engineering Sciences IOP Conf. Ser.: Mater. Sci. Eng. 2020. 671 012121. Doi:10.1088/1757-899X/671/1/012121.
9) Gao Y., Geng D., Huang X., and Li G. *Degradation evaluation index of asphalt pavement based on mechanical performance of asphalt mixture.* Construction and Building Materials.Vol. 140, 2017. P. 75–81.
10) Islam R., Hossain M., Tarefder R. *A study of asphalt aging using Indirect Tensile Strength test*. Construction and Building Materials, Volume 95, 1 October2015. Pages 218-223. https://doi.org/10.1016/j.conbuildmat.2015.07.159.
11) Omranian S., Hamzah M., Pipintakos G., bergh W., Vuye C., and Hasan M. *Effects of Short-Term Aging on the Compactibility and Volumetric Properties of Asphalt Mixtures Using the Response Surface Method*. Sustainability 2020, 12, 6181; MDPI. doi:10.3390/su12156181.www.mdpi.com/journal/sustainability
12) ASTM. *Road and Paving Materials*, Annual Book of ASTM Standards, Volume 04.03, American Society for Testing and Materials, West Conshohocken, 2015. USA.
13) SCRB. State Commission of Roads and Bridges SCRB, 2003. *Standard Specification for Roads & Bridges*, Ministry of Housing & Construction, Iraq.
14) SHRP.*Standard Practice for Simulating the Short-Term Ageing of Bituminous Mixtures Using A Forced Draft Oven*. SHRP No. 1025, 1992. Strategic Highway Research Program. National Research Council, Washington, D.C.
15) SHRP.*Test Method for Predicting the Long-Term Ageing of Bituminous Mixtures Using A Forced Draft Oven.* SHRP No. 1030, 1992. Strategic Highway ResearchProgram, National Research Council, Washington, D.C.
16) Sarsam S. I., Al-Sadik S. M. *Modeling Aging Impact on Physical Properties of Asphalt Cement*. Research Journal of Modeling and Simulation, RJMS, May, Vol. 1(2) 2014. (P20-29). Sciknow Publications Ltd. USA.