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Influence of Ageing on Volumetric Properties of Rubber Modified Asphalt Concrete

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ABSTRACT

The rubber modified binder is implemented to reserve the flexibility of asphalt concrete pavement under ageing process. In the present assessment, asphalt binder of 40-50 penetration grade was obtained from (Nasiriyah, Erbil, and Dourah) oil refineries and practices rubber modification with (8 and 16)% crumb rubber powder. The control and modified have been implemented in the preparation of asphalt concrete mixture for wearing course. Marshall Specimens were prepared after subjecting the loose mixture to short-term ageing. The specimens were subjected to long-term ageing before evaluation of volumetric properties. The variations in volumetric properties were determined throughout the ageing process. It was observed that after ageing process, the bulk density of asphalt concrete declines by (2.5, 3.2, and 3.1) %, the voids content increases by (37.6, 47.4 and 52) %, Vfb decline after ageing process by (9.3, 10.6, and 10.3) %, and VMA increase after ageing process by (13.8, 18, and 14) % for Nasiriyah, Erbil, and Dourah binders respectively. When (8 and 16) % of crumb rubber was implemented, the bulk density declines before ageing by (0.4, 0.7, and 0.8) % and (0.9, 1.6, and 2) %, the volume of voids increased by (4.1, 14, and 14.2) % and (10.5, 26.7, and 10.3) %, the Vfb decreased by (1.2, 4.3, and 1.3) % and (2.7, 6.4, and 2.3) %, and the VMA increased by (2.6, 3.3, and 7.3) % and (5.1, 9.2, and 8.6) % for Nasiriyah, Erbil, and Dourah binders respectively. It was concluded that the obtained mathematical models fit into the experimental observation with high accuracy. Hence, the models are practical to be used to predict the influence of ageing process on the volumetric properties of asphalt concrete.

Keywords: Rubber Modified Binder, Asphalt Concrete, Volumetric Properties, Voids, Ageing Process.

1. INTRODUCTION

The implementation of crumb rubber into asphalt concrete mixture can enhance the volumetric properties and the quality of the mixture throughout the ageing process. Molenaar et al., [1] studied the influence of the ageing process on the mechanical characteristics of asphalt binders in asphalt concrete. The results showed that the ageing process had increased the indirect tensile strength of the asphalt binders while decreases the strain at break. Omranian et al., [2] evaluated the influence of short-term ageing process on compactibility and volumetric properties of asphalt concrete mixtures. Three different binders were utilized to prepare asphalt concrete mixtures. Ageing temperatures, and ageing duration, are recognized as an independent variable, while compactibility and volumetric properties are considered as dependent variable. The findings revealed significant impacts of ageing temperature and duration on compactibility, air voids, voids in mineral aggregate, and voids filled with asphalt. Sarsam, [3] prepared Marshall Specimens after practicing the loose asphalt concrete mixture to the short-term ageing process. The prepared Marshall specimens have practiced the long-term ageing before determination of its indirect tensile strength. Temperature susceptibility of asphalt concrete specimens was evaluated through the testing of the asphalt concrete specimens at (20 and 40)°C. The volumetric properties variations of the asphalt concrete specimens were determined throughout the short- and long-term ageing process. It was concluded that the binder from Erbil shows low value of indirect tensile strength of 1100.1 kPa and low value of temperature susceptibility of 35.6 kPa/°C while it exhibits the highest degradation in asphalt concrete flexibility when compared with Dourah and Nasiriyah binders. Rahmani et al., [4] stated that the stiffness modulus of asphalt concrete increases by four folds after the aging process based on the asphalt binder type. This may cause the mixture to become brittle and excessively hard so that it will be susceptible to fatigue cracking at low temperatures and disintegration. Hamzah and Omranian, [5] investigated the effects of short-term aging on binder viscosity at high temperature. The test results showed that aging process had increased the asphalt binder's viscosity, however, increasing the test temperature had decreased the corresponding value of viscosity. It was concluded that aging process impact differs and depend on test temperatures, binder types, and aging process conditions. Sirin et al., [6] stated that ageing process is the change in rheological properties of asphalt binders due to the changes in chemical composition during construction and throughout its service life period. Ageing causes the asphalt material to stiffen and getting brittle, which affects the durability of asphalt concrete and leads to a high potential for distress. Fernandez-Gomez et al., [7] revealed that volatilization of asphalt binder during ageing is an important mechanism that can occur during hot mixing and construction of asphalt concrete. At high temperatures, lighter molecular weight component of the binder can change to vapor and leave into the atmosphere. When thin asphalt film encounters aggregate at high temperatures, aromatic fractions can rapidly evaporate from the binder, and the asphaltene fractions may generally increases between (1 and 4) %. Steams and fumes are generated into the binder because of such reaction based on the contact surface area between the aggregates and asphalt film. As a result of the loss in weight, asphalt flow properties are reduced, and viscosity is affected by volatilization. There is a widespread recognition that a systematic measurement of the asphalt concrete mixtures volumetric properties is vital. Huner and Brown, [8] revealed that the demand for accurate measurement of the mixtures' volumetric properties has gained attention due to their significant impacts on the design of mixtures and evaluation of the final product. Hand and Epps, [9] stated that to certify the mixtures' adequate field performance, the assessment of asphalt concrete mixtures can be indirectly estimated by their volumetric properties. However, understanding the potentially detrimental influence of aging process on the volumetric properties is considered as the utmost important as revealed by Sadek et al. [10]. It was concluded that an equivalent level of volumetric properties of plant-produced mixtures can be captured using corresponding lab-produced mixtures. Abed and Al-Haddad, [11] investigated the effects of test type, asphalt cement type and content, and temperature susceptibility of asphalt binder. The testing results exhibited that implementation of activation energy, which is the slope of the test temperature for flow and dynamic shear viscosity of the asphalt binders that allows discernment of asphalt cement's susceptibility to temperature variation. Islam et al., [12] prepared at the laboratory a cylindrical specimens of asphalt concrete, and the specimens have practiced ageing process at the field and in the laboratory, and then the specimens were subjected for indirect tensile strength ITS value determination of the specimens after practicing (1, 5, 10, 15, 20, and 25) days of oven ageing process at 85 °C environment in the laboratory. The indirect tensile strength test was also performed on asphalt concrete specimens prepared after their loose mixtures have practiced (8, 16, 32, 48, 72 and 100) hours of oven ageing process at 135 °C. It was concluded that ITS increases with the ageing period.

The aim of the present work is to assess the influence of ageing impact on the volumetric property of asphalt concrete that is modified with rubber by implementing asphalt binder of three types having similar penetration grade obtained from Daura, Erbil, and Nasiriyah refineries located at middle, north and south regions of the country. Models to predict the ageing impact on volumetric properties will be presented.

2. MATERIALS AND METHODS

Asphalt cement

The asphalt cement used in this investigation was obtained from three different refineries at the north, middle, and south environmental regions of Iraq (Erbil, Dourah, and Nasiriyah). Table 1 demonstrates the asphalt cement binders' physical properties.

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It can be noted that the all the asphalt binders have the same penetration grade (40-50) while their physical and rheological properties are variable.

Table 1. The physical properties of asphalt binders

Physical Property as Per ASTM, [13]	Unit	Asphalt Cement Source			SCRB, [14] 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 Conducting the ageing as per (ASTM D-1754) (thin-film oven test)					
The 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

Fine and Coarse aggregates have been brought from Al-Nibaee quarry and implemented in the present investigation; Table 2 presents their physical properties.

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

Property as per ASTM, [13]	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

The Portland cement was implemented as mineral filler for the asphalt concrete mixtures; the physical properties of Portland cement are listed in Table 3.

Table 3. The 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

Crumb rubber

Crumb rubber powder used in the present investigation was brought from tires factory in AL-Najaf governorate. This type of crumb rubber powder was recycled from scrap used tires. The specific gravity is 1.130 while the specific surface area of crumb rubber powder is 80 m^2/kg. Table 4 exhibits the gradation of the implemented crumb rubber particles.

Table 4. The grain sizes distribution of crumb rubber

Sieves Size (mm)	4.75	2.36	2.1	1.18	0.6	0.3	0.075
% Passing	100	100	97.4	52	20	8	0

Preparation of Modified Asphalt Cement Binder

Asphalt cement of penetration grade (40-50) was heated to a temperature of 160°C, and then crumb rubber powder was added and mixed thoroughly using manual stirring on the hot plate for 60 minutes as a constant blending time. Eight and sixteen percentages

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of crumb rubber by weight of asphalt binder were implemented for the present investigation. Details of the rubber content selection process can be referred in Sarsam and Al-Sadik, [15].

Selection of Asphalt Concrete Combined Gradation

Dense gradation of asphalt concrete is usually implemented for wearing course layer according to SCRB specification, [14]. The nominal maximum size of aggregates is 12.5 mm. Figure 1 demonstrates the selected aggregate gradation and the specification limits.

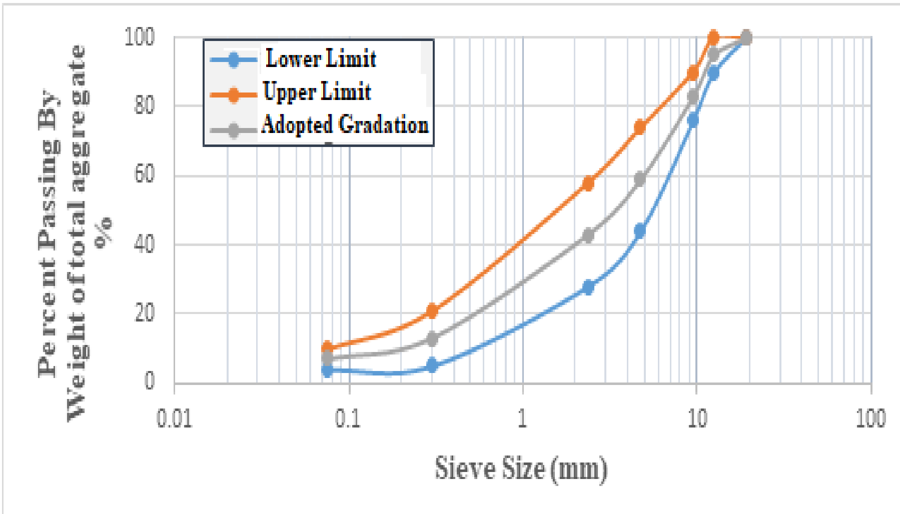

Figure 1. Specification Limits and Mid-Point Gradation of SCRB, 2003 for Wearing Course.

Preparation of Hot Mix Asphalt Concrete Specimens

Fine and coarse aggregates were sieved to different sizes, then the mineral filler was combined with the aggregates so that the specified gradation could be met. The combined aggregates mixture was subjected to heating to 150 ºC before it was mixed with asphalt cement, while the asphalt cement binder was heated to 140ºC. Then, implication of the required amount of asphalt cement binder was conducted into the heated aggregate and mixed thoroughly for two minutes with the aid of mechanical mixer. All of the aggregate particles were checked visually to be coated with thin film of asphalt cement. Asphalt concrete mixtures were subjected to the short-term ageing process as per SHRP, [16]. The loose mixture was placed in an open pan, spread, while thickness of the mixture was ranging between 25 and 50 mm. The pan was placed in the ageing oven at a temperature of 135 °C for four hours. Stirring of the loose mixture was conducted every 600 seconds so that to maintain uniform ageing. After aging process, the loose mixture was removed from the ageing oven. Marshall specimens have been prepared according to the ASTM D1559, [13] using 75 blows of Marshall hammer acting on each face of the asphalt concrete specimen. The optimum asphalt content was evaluated 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, [17]. The compacted asphalt concrete specimens prepared from mixtures which were exposed to the short-term ageing process were placed in a forced-draft oven at 85°C for 120 hours to practice the long-term ageing process. At the end of the ageing periods, the asphalt concrete specimens were left to cool at room temperature. The specimens were tested after 24 hours after removal from the oven. Asphalt concrete specimens have been tested in duplicate. The average indirect tensile strength value was considered for analysis. Details of evaluating the optimum asphalt binder content and the indirect tensile strength properties of asphalt concrete can be referred at Sarsam and Adbulmajeed, [18].

3. 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 asphalt content for asphalt concrete mixtures using Marshall test method as per ASTM, [13]. Table 5 exhibit a summary of the properties of the Marshall mixture at the optimum binder for all asphalt cement types according to the specification Requirements SCRB, R/9 [14]. The optimum asphalt binder content for different types of asphalt

(Dourah, Erbil, and Nasiriyah) are found to be (4.7, 5 and 5.1) % respectively. Specimens were subjected to volumetric properties determination as per ASTM, [13].

Table 5. Properties of Asphalt Concrete Mixtures

Property	Asphalt Binder Source			SCRB, [14] Specifications
	Dourah	Erbil	Nasiriyah	
Optimum asphalt binder 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 cement (%)	73.8	71.5	74.4	-------

Influence of Ageing on Bulk Density

Figure 2 exhibit the variation of bulk density with ageing time. It could be noted that the density of asphalt concrete decline as the ageing proceed. Before ageing process, Dourah binder exhibit the highest bulk density of 2.354 gm/cm^3 as compared with (2.339 and 2.335) gm/cm^3 for Erbil and Nasiriyah binders respectively. After ageing process, the bulk density of asphalt concrete declines by (2.5, 3.2, and 3.1) % for Nasiriyah, Erbil, and Dourah binders respectively. This can be related to the evaporation of volatiles throughout the ageing process. However, the variation in the rate of decline in the density as represented by the slope of the (density-ageing) relationship is not significant among the binders implemented as demonstrated in Table 6. When crumb rubber powder was implemented in asphalt concrete mixtures, further reduction in bulk density could be observed regardless of the binder origin. This can be related to the higher voids content created after implication of crumb rubber. Molenaar et al., [1]; and Lee et al., [19] have reported similar behavior. It may be noticed that implication of (8 and 16) % of crumb rubber declines the bulk density of asphalt concrete before ageing by (0.4, 0.7, and 0.8) % and (0.9, 1.6, and 2) % for Nasiriyah, Erbil, and Dourah binders respectively. While the reduction in bulk density after ageing was (2.4, 3.2, and 2.8) % and (2.4, 2.8, and 1.8) % for Nasiriyah, Erbil, and Dourah binders respectively. Such behavior agreed with the work reported by Ali et al., [20]. The mathematical models presented in Table 6 can be implemented to predict the impact of ageing on bulk density of asphalt concrete.

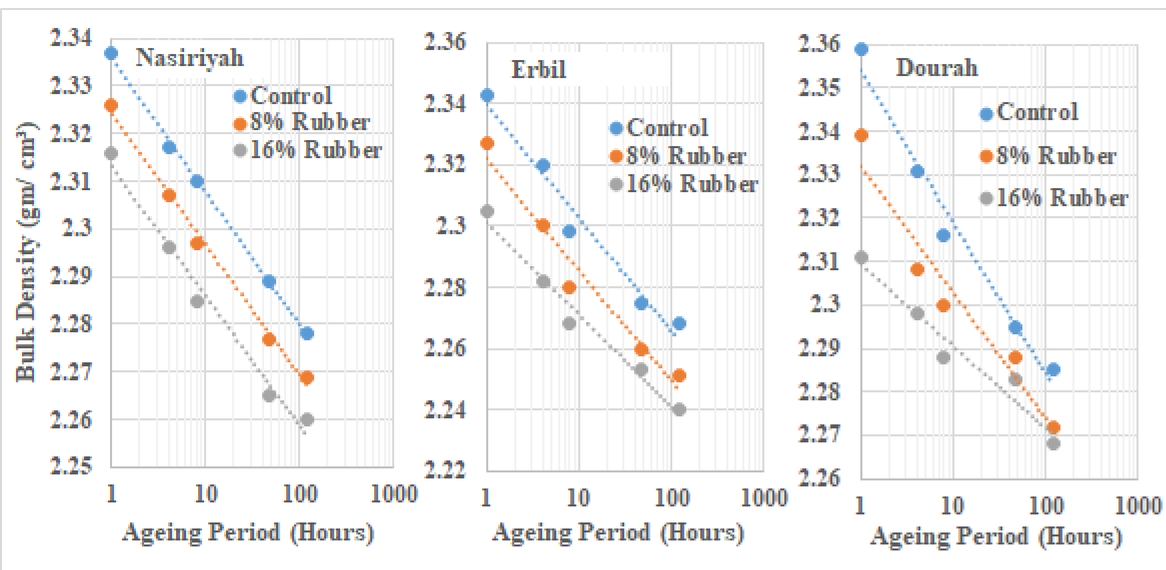

Figure 2. Influence of Ageing on Bulk Density of Asphalt Concrete

Table 6. Bulk Density Parameters

Binder origin	Binder Type	Intercept	Slope	Ageing model	R^2
Nasiriyah	Control	2.335	0.005	$Y = 2.335\ X^{-0.005}$	0.997

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	8 % Rubber	2.324	0.005	$Y = 2.324 X^{-0.005}$	0.993
	16 % Rubber	2.313	0.005	$Y = 2.313 X^{-0.005}$	0.982
Erbil	Control	2.339	0.007	$Y = 2.339 X^{-0.007}$	0.970
	8 % Rubber	2.322	0.007	$Y = 2.322 X^{-0.007}$	0.966
	16 % Rubber	2.301	0.006	$Y = 2.301 X^{-0.006}$	0.977
Dourah	Control	2.354	0.007	$Y = 2.354 X^{-0.007}$	0.977
	8 % Rubber	2.332	0.005	$Y = 2.332 X^{-0.005}$	0.942
	16 % Rubber	2.309	0.004	$Y = 2.309 X^{-0.004}$	0.947

Influence of Ageing on Voids Content in Asphalt Concrete

As demonstrated in Figure 3, the voids content increases with ageing time regardless of the binder origin. This can be related to the loss of volatiles from the binder structure throughout the ageing process. However, it can be noted from Table 7 that Nasiriyah asphalt cement binder exhibits the highest voids content of 4.52 % in asphalt concrete mixture as compared with (4.35 and 3.98) % voids of Erbil and Dourah respectively. On the other hand, the slope which represent the rate of increment in the voids content shows that the rate of increment in voids content of Dourah binder is 0.0876 which is higher when compared to that of Nasiriyah and Erbil binders. After ageing process, the voids content increases by (37.6, 47.4 and 52) % for Nasiriyah, Erbil and Dourah binders respectively. When the crumb rubber was implemented, further increments in the voids content could be noted, this may be related to the changes in the structure of the modified binder. After implementing (8 and 16) % of crumb rubber, the volume of voids increased before ageing process by (4.1, 14, and 14.2) % and (10.5, 26.7, and 10.3) % for Nasiriyah, Erbil and Dourah binders respectively. However, the volume of voids increased after ageing process by (15, 15, and 16.2) % and (21, 30, and 26.4) % for Nasiriyah, Erbil and Dourah binders respectively. The ageing models in terms of increment of voids with ageing period of the binders are demonstrated in Table 7. A power mathematical models with high coefficients of determination could be noticed. Similar behavior was noticed by Omranian et al., [2].

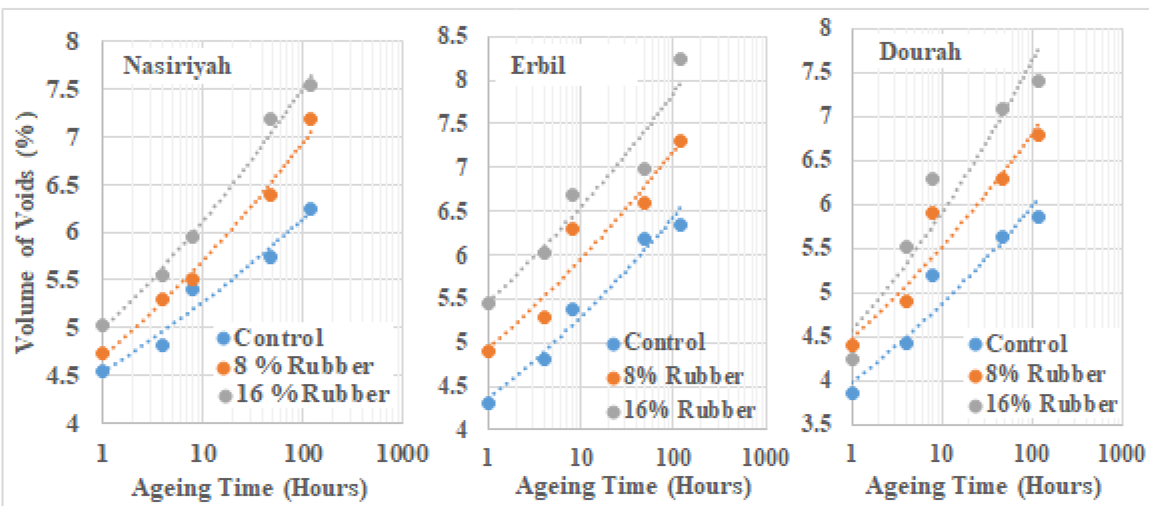

Figure 3. Influence of Ageing on Percent Voids of Asphalt Concrete

Table 7. Percent Voids Parameters

Binder origin	Binder Type	Intercept	Slope	Ageing model	R^2
Nasiriyah	Control	4.529	0.0657	$Y = 4.529 X^{0.0657}$	0.957
	8 % Rubber	4.684	0.0853	$Y = 4.648 X^{0.0853}$	0.990
	16 % Rubber	4.974	0.0895	$Y = 4.974 X^{0.0895}$	0.992
Erbil	Control	4.358	0.0846	$Y = 4.358 X^{0.0846}$	0.970
	8 % Rubber	4.935	0.0816	$Y = 4.935 X^{0.0816}$	0.924
	16 % Rubber	5.463	0.0787	$Y = 5.463 X^{0.0787}$	0.937
Dourah	Control	3.989	0.0876	$Y = 3.989 X^{0.0876}$	0.917
	8 % Rubber	4.487	0.0905	$Y = 4.487 X^{0.0905}$	0.926

	16 % Rubber	4.575	0.111	$Y = 4.575\ X^{0.111}$	0.915

Influence of Ageing on Voids Filled with Asphalt in Asphalt Concrete Mixture

Figure 4 exhibit the influence of ageing period on the voids that was filled with the asphalt binder Vfb, it can be noticed that Nasiriyah binder mixture shows the lowest voids that was filled with asphalt binder as compared with Dourah binder which exhibit the highest volume of voids filled with binder. On the other hand, it can be noticed that the volume of voids that was filled with the asphalt binder declines with ageing period. This can be related 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.

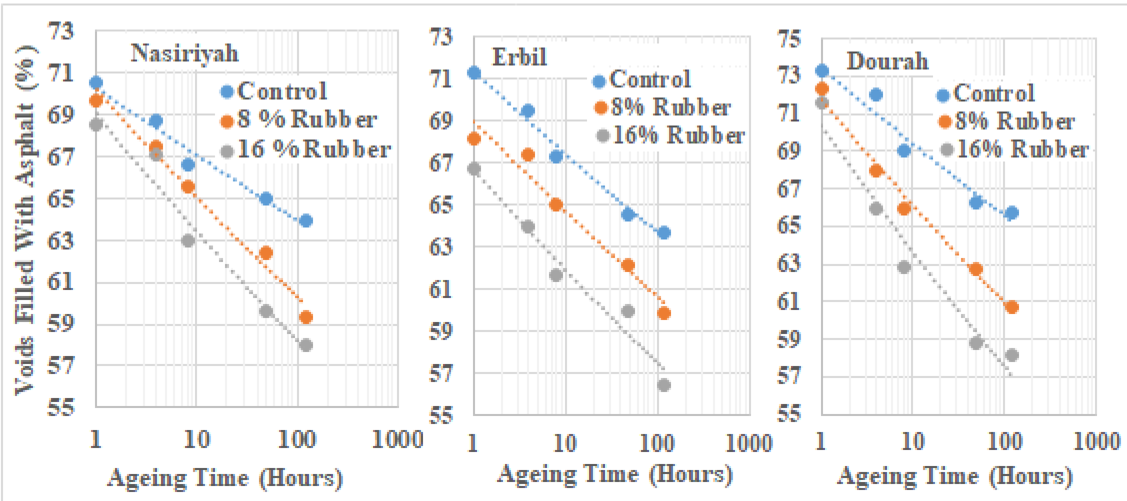

Figure 4. Influence of Ageing on Percent Voids Filled with Binder (Vfb) of Asphalt Concrete

Table 8 demonstrates that Nasiriyah binder exhibit the lowest and gentler rate of decline in the voids filled with binder which is represented by the slope of (Vfb vise ageing) as compared with Erbil and Dourah binders. The Vfb decline after ageing process by (9.3, 10.6, and 10.3) % for Nasiriyah, Erbil and Dourah binders respectively. When crumb rubber was implemented, further decline in Vfb could be detected. This could be attributed to the increment in the modified binders' viscosity which control the absorption of binder inside the voids. After implementing (8 and 16) % of crumb rubber, the Vfb decreased before ageing process by (1.2, 4.3, and 1.3) % and (2.7, 6.4, and 2.3) % for Nasiriyah, Erbil and Dourah binders respectively. However, the Vfb decreased after ageing process by (7.2, 6, and 7.6) % and (9.1, 11.4, and 11.4) % for Nasiriyah, Erbil and Dourah binders respectively. The ageing models presented in Table 8 in terms of declination in the voids filled with binder with ageing period can be implemented with high coefficient of determinations to predict the decline in Vfb with ageing period. Such behavior agrees with Glover et al., [21].

Table 8. Percent Voids Filled with Binder Parameters

Binder origin	Binder Type	Intercept	Slope	Ageing model	R^2
Nasiriyah	Control	70.315	0.021	$Y = 70.315\ X^{-0.021}$	0.972
	8 % Rubber	70.164	0.033	$Y = 70.164\ X^{-0.033}$	0.981
	16 % Rubber	69.023	0.037	$Y = 69.023\ X^{-0.037}$	0.959
Erbil	Control	71.351	0.025	$Y = 71.351\ X^{-0.025}$	0.982
	8 % Rubber	68.968	0.028	$Y = 68.968\ X^{-0.028}$	0.962
	16 % Rubber	66.709	0.032	$Y = 66.709\ X^{-0.032}$	0.958
Dourah	Control	73.465	0.025	$Y = 73.465\ X^{-0.025}$	0.955
	8 % Rubber	71.737	0.036	$Y = 71.737\ X^{-0.036}$	0.990
	16 % Rubber	70.404	0.044	$Y = 70.404\ X^{-0.044}$	0.955

Influence of Ageing on Voids in Mineral Aggregates of Asphalt Concrete

Figure 5 demonstrates the influence of ageing period on the voids in the mineral aggregates. It can be observed that Nasiriyah asphalt cement binder shows the highest voids in mineral aggregates of 15.3 % while asphalt binders obtained from Erbil and

Dourah exhibits lower voids in the mineral aggregates of (15.1 and 14.8) % respectively. However, Table 9 present the rate of increment in the VMA for different binders, it can be noted that Dourah and Nasiriyah binders exhibits a gentle slope which represent the rate of increment in VMA of 0.025 and 0.026 as compared with Erbil binder. VMA increase after ageing process by (13.8, 18, and 14) % for Nasiriyah, Erbil and Dourah binders respectively. After implementing (8 and 16) % of crumb rubber, the VMA increased before ageing process by (2.6, 3.3, and 7.3) % and (5.1, 9.2, and 8.6) % for Nasiriyah, Erbil and Dourah binders respectively. However, the VMA increased after ageing process by (3.2, 3.3, and 2.3) % and (4, 6.7, and 3.5) % for Nasiriyah, Erbil and Dourah binders respectively. such finding agrees with the work reported by Hamzah and Omranian, [5]. The ageing models in terms of increment in VMA with ageing period are demonstrated in Table 9.

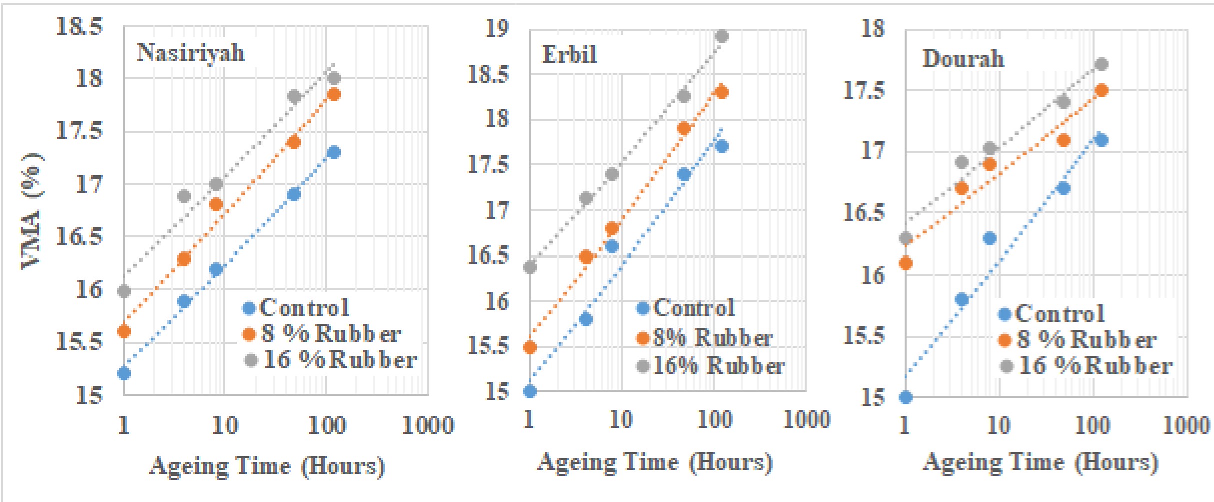

Figure 5. Influence of Ageing on Percent Voids in Mineral Aggregates (VMA) of Asphalt Concrete

Table 9. Percent Voids in the Mineral Aggregates Parameters

Binder origin	Binder Type	Intercept	Slope	Ageing model	R^2
Nasiriyah	Control	15.271	0.0265	$Y = 15.271\ X^{0.0265}$	0.994
	8 % Rubber	15.695	0.0274	$Y = 15.695\ X^{0.0274}$	0.985
	16 % Rubber	16.133	0.0246	$Y = 16.133\ X^{0.0246}$	0.967
Erbil	Control	15.128	0.0350	$Y = 4.358\ X^{0.0846}$	0.966
	8 % Rubber	15.611	0.0344	$Y = 4.935\ X^{0.0816}$	0.990
	16 % Rubber	16.395	0.0291	$Y = 5.463\ X^{0.0787}$	0.995
Dourah	Control	15.179	0.0259	$Y = 3.989\ X^{0.0876}$	0.951
	8 % Rubber	16.230	0.0156	$Y = 4.487\ X^{0.0905}$	0.936
	16 % Rubber	16.413	0.0161	$Y = 4.575\ X^{0.111}$	0.964

4. CONCLUSIONS

According to the limitations in the laboratory testing and materials properties and the testing program, the following conclusions can be addressed.

1- After ageing process, the bulk density of asphalt concrete declines by (2.5, 3.2, and 3.1) % for Nasiriyah, Erbil, and Dourah binders respectively. When (8 and 16) % of crumb rubber was implemented, the bulk density declines before ageing by (0.4, 0.7, and 0.8) % and (0.9, 1.6, and 2) %, while after ageing process, the reduction in bulk density was (2.4, 3.2, and 2.8) % and (2.4, 2.8, and 1.8) % for Nasiriyah, Erbil, and Dourah binders respectively.

2- After ageing process, the voids content increases by (37.6, 47.4 and 52) % for Nasiriyah, Erbil and Dourah binders respectively. After implementing (8 and 16) % of crumb rubber, the volume of voids increased before ageing process by (4.1, 14, and 14.2) % and (10.5, 26.7, and 10.3) %, while it increases after ageing by (15, 15, and 16.2) % and (21, 30, and 26.4) % for Nasiriyah, Erbil and Dourah binders respectively.

3- The Vfb decline after ageing process by (9.3, 10.6, and 10.3) % for Nasiriyah, Erbil and Dourah binders respectively. After implementing (8 and 16) % of crumb rubber, the Vfb decreased before ageing process by (1.2, 4.3, and 1.3) % and (2.7, 6.4, and 2.3) %

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and decreased after ageing process by (7.2, 6, and 7.6) % and (9.1, 11.4, and 11.4) % for Nasiriyah, Erbil and Dourah binders respectively.

4- VMA increase after ageing process by (13.8, 18, and 14) % for Nasiriyah, Erbil and Dourah binders respectively. After implementing (8 and 16) % of crumb rubber, the VMA increased before ageing process by (2.6, 3.3, and 7.3) % and (5.1, 9.2, and 8.6) % and increased after ageing process by (3.2, 3.3, and 2.3) % and (4, 6.7, and 3.5) % for Nasiriyah, Erbil and Dourah binders respectively.

5- The mathematical models obtained fits into the experimental observation with high accuracy. Hence, the models are practical to be used to predict the changes in volumetric properties of asphalt concrete throughout the ageing process.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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