International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 2 (2019) pp. 560-570

Evaluation the Effect of Asphalt Film Thickness on Stripping Resistance

Nabil AlKofahi [1)] and Taisir Khedaywi, [2)]

[1] *Civil Engineering Department, Faculty of Engineering, Jadara University, P.O.Box 733, Irbid 22110, Jordan.*
**Corresponding Author*
Orcid: 0000-0003-4295-1560

[2] *Civil Engineering Department, Faculty of Engineering, Jordan University of Science and Technology, P.O.Box 3030, Irbid 22110 Jordan.*
Orcid: 0000-0003-1077-5144

Abstract

Stripping is the separation of the asphalt binder film from the aggregate surface due to the action of water. To evaluate the effect of asphalt film thickness on stripping resistance for loose and asphalt concrete mixtures, Texas boiling test and ASTM tests were used. Three types of aggregate: limestone, valley gravel, and basalt, asphalt binder (60/70), hydrated lime and a liquid additive called (Morelife) were used. The results showed that retained asphalt film thickness depended on many factors such as asphalt content, type of aggregate, the total surface area of the aggregate in the mixture, and the degree and period of moisture. A loose mixture can be used to predict effecting of asphalt film thickness on stripping potential. The effective percent of asphalt content have (3.65, 3.95, and 4.38%) and the optimum asphalt content (4.2, 5.2, and 5.4%) for valley gravel, limestone, and basalt respectively. The results showed an average film thickness of asphalt mixtures is about 9-11 micron for all aggregates. It is recommended to decreasing the total surface area of the mixture by decreasing the percentage of very fine particles, which would achieve a larger asphalt film thickness and higher stripping resistance. Besides this, using additives could resist the moisture damage. Test results showed that the optimum dosage for lime additive (1.5 -2% by weight of aggregate) and morelife (0.75 to 1% by weight of AC), might be restored the retained asphalt against the stripping action, and lime is the best. Also, that aggregate type was the most significant variable affecting stripping.

Keywords: Asphalt, Film thickness, Stripping, Additives, Boiling test, Visual assessment, VMA

1. INTRODUCTION

Stripping is the breaking of the bond between the asphalt and the aggregate by the action of water. This bond failure is due to the separation of asphalt cement film from the aggregate surface. Adhesion of bitumen to aggregate is a surface phenomenon.

Aggregates have unbalanced surfaces charges that result in surface tension or surface energy. These mineral surfaces, when covered by a liquid of opposite polarity, will satisfy their energy demands and establish an adhesive bond. The liquid that satisfies the greater energy demand will adhere more tenaciously. When the adhesion of two liquids like water and asphalt is compared, the one that can satisfy the greater energy demand can replace the film of the other [1].

Maupin [2] reported that stripping could involve two mechanisms, adhesion, and cohesion. Adhesive failure is caused by intruded water between asphalt film and aggregate surface, where cohesion failure results from stiffness reduction due to the combination between water and asphalt. Most of the studies concentrated on adhesive failure.

Asphalt cement contributes to the stripping potential, there are three factors related to stripping potential, which are:

1- Binders viscosity: binders of high viscosity have better water displacement resistance than those of low viscosity [3]. Many researchers reported that AC (60/70) has better resistance for water damage than AC (80/100) [4, 5].

2- Asphalt source: asphalt cement source has shown different stripping potentials rather than asphalt cement grades. The hydrocracked residues were found enriched in total nitrogen and basic nitrogen, the increase of nitrogen basicity enhances anti-stripping properties of the hydrocracked residues [6, 7].

3- Asphalt film thickness: the higher asphalt content-to-surface ratios give higher tensile strength ratios (TSRs), which means that the film thickness has a significant effect on tensile strength retention Gharaybeh and Parker [6, 8]. There was a strong correlation between asphalt binder film thickness and the tensile strength, it was recommended using an average film thickness of 9 to 10 µm for specimens have 8% air voids [8].

Kennedy et al. [9] concluded that Texas boiling test provides valuable information, which means that this test can be used to detect moisture-susceptible mixtures. They recommended that asphalt retained 70% after boiling can be used as pass-fail criteria between stripping and non-stripping aggregates.

Elseifi et al. [10] investigated the concept of asphalt binder film thickness experimentally. To achieve this, they used image analysis techniques, reflective light microscopy, and scanning electron microscopy (SEM). The results indicated that asphalt mastic films were asphalt binder films surrounding large aggregates in hot-mix asphalt, which had a thickness greater than 100 µm in the mixture and appeared a highly irregular in shape. A thickness of 2 µm was observed for some fine aggregates, which was only part of a blend with and mineral fillers. Additional results by microscopic analysis showed that air voids usually appear near the boundary between large aggregates and asphalt mastic not in the asphalt mastic itself.

Radovskiy [11] suggested a surface area factor of 160 m^2 /kg is assumed for fine particle sizes, filler particles may have a surface area as large as 1,000 m^2 /kg. In general, suggesting of an average film thickness between 8 and 15 µm would provide acceptable pavement performance. Roberts et al. [12] calculated the average film thickness on the basis of the following equation [13]:

$$T_F = 1000\{(P_{be} / (SA \times P_s \times G_b)\} \quad (1)$$

Where:

T_F = asphalt film thickness (micron),

P_{be} = surface area (m^2/kg),

P_s = percentage of aggregate by weight of mixture,

Gb= asphalt bulk specific gravity.

Radovskiy [11]: suggested an equation to find the surface area of the aggregates, which is calculated from Equation 2 as follows:

$$SA=0.01\sum_{i=1}^{N} PPi \; x \; CPi \quad (2)$$

Where:

N = number of sieves considered in the surface area calculation,

PPi = percentage of aggregate passing sieve I (defined for sieves of 9.5, 4.75, 2.36, 1.18, 0.60, 0.30, 0.15, and 0.075 mm), and

CPi = surface area factor outlined in Asphalt Institute MS-2 [14]

Elseifi et al. [10] selected nominal maximum size of 9.5 mm and an asphalt binder content of 4.9%. 100-mm cores were taken from the field, and laboratory testing indicated that the average air voids content of 6.6%. The using of Equation 2 results that the surface area of the aggregates was determined to be 3.02 m^2 /kg. The average film thickness was determined according to Equation 1 was 16.5 µm.

Kandhal et al. [15] suggested using the average asphalt binder film thickness instead of VMA because it correlates with field performance better than VMA. The reason for this is because VMA describes the volumetric properties of the aggregates, whereas the asphalt thickness characterizes the surface area of the aggregates.

The concept of asphalt film thickness was originally proposed by Francis Hveem to estimate a starting point of asphalt content for mix designs. It is defined as a ratio of the effective asphalt volume to the surface area of aggregate (µm), [16].

Hmoud [17] in his study about the evaluation of VMA and film thickness, he investigated the relations between asphalt content, air voids and Voids in Mineral Aggregate (VMA). The researcher found that average thickness of asphalt film coating the aggregate of 8 microns will produce a durable mixture, he focused on evaluating VMA and film thickness where. Because VMA limit has not been included in Iraqi standards, therefore it was recommended to use VMA and film thickness as parameters in the design of asphaltic mixture.

Al-Khateeb [18] used the concept of asphalt binder film thickness (FT_b) to investigate the Superpave VMA criteria. 126 specimens of asphalt mixtures were prepared and tested by Superpave Gyratory Compactor test. The author found a poor relationship ($R^2 \cong 0.01$) between VMA and FT_b (a durability measure), and a relatively good relationship ($R^2 \cong 0.38$) between voids filled with asphalt (VFA) and FT_b, which indicates that the relationship between FT_b and P_{be} was found significant (higher R^2). Other conclusion indicated that, in some cases, asphalt mixtures with adequate asphalt FT_b related to failing Superpave VMA criteria where that of non-adequate FT_b was passed the criteria. The author recommended that the current criteria must be modified.

2. OBJECTIVES

The following are the objectives of this study:

1- To evaluate the effect of asphalt film thickness on stripping resistance of asphalt concrete mixture.

2- To compare mixes composed of different types and quantities of asphalt cement and aggregate for stripping potential.

3- To evaluate the effectiveness of anti-stripping agents in a given mix.

3. MATERIALS USED AND LABORATORY WORKS

3.1. Asphalt Cement

The asphalt cement (AC) used has (60/70) penetration. It was obtained from the Jordanian Petroleum Refinery Company. The properties according to ASTM standards [19] are shown in Table 1. The AC properties do agree with the specifications of the Ministry of Public Works and Housing MPWH [20]

Table 1. Properties of asphalt cement (60/70) used in this study

Property	ASTM Designation	Result
Penetration at 25ºC,100 gm,5sec (0.1mm)	ASTM D 5	65.6
Flash point (ºC)	ASTM D 92	270
Fire point (ºC)	ASTM D 92	277
Ductility (cm)	ASTM D 113	120
Specific gravity at 25ºC	ASTM D 70	1.0197
Softening point, ring and ball (ºC)	ASTM D 2398	49

3.2. Aggregates

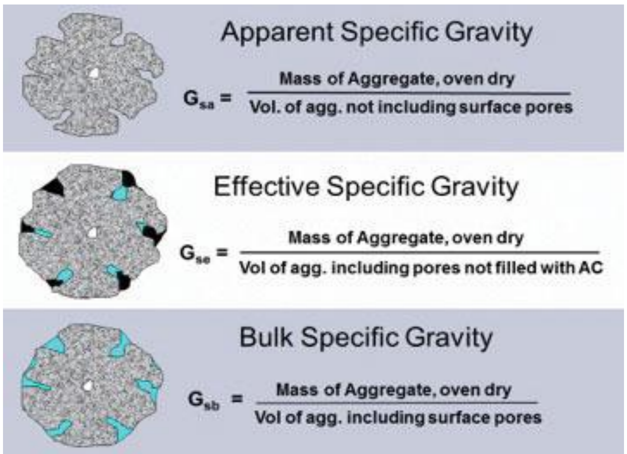
The aggregates were delivered from different parts of Jordan. Three types of aggregate normally used in road construction in Jordan were used in this study: crushed limestone, uncrushed valley gravel, and crushed basalt. The aggregates properties used in this study are shown in Table 2.

Table 2. Aggregates properties

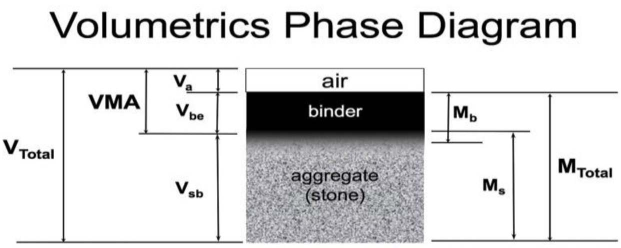
Gradation type	Aggregate property	Aggregate type		
		Limestone	Valley gravel	Basalt
Coarse	Bulk sp. gr. (Gsb)	2.491	2.594	2.766
	Bulk sp. gr.(SSD) (Gse)	2.561	2.637	2.820
	Apparent sp. gr. (Gsa)	2.679	2.711	2.922
	Absorption (%)	2.810	1.659	1.927
	Abrasion (%)	33.60	24.70	19.70
Fine	Bulk sp. Gr.	2.598	2.642	2.804
	Bulk sp. Gr.(SSD)	2.657	2.661	2.911
	Apparent sp. gr.	2.760	2.693	3.091
	Absorption (%)	2.249	1.523	3.810
Filler	Bulk sp. gr.	2.526	2.563	2.688
	Bulk sp. gr.(SSD)	2.588	2.615	2.824
	Apparent sp. Gr.	2.693	2.704	3.110
	Absorption (%)	2.459	2.041	5.040
Total Density (Gsb)		2.519	2.605	2.774

sp. gr. = Specific gravity, SSD = Saturated surface dry

An important check for these value, which should be part of every aggregate and mix design that the relationships Gsa > Gse > Gsb must be valid. Figure (1) shows these relations and how asphalt content is absorbed and coated the aggregate.



(a) Specific gravity types



(b) VMA relations with AC and air voids

Figure 1. Specific gravity and components of asphalt mixture [15]

3.3. Additives

In this research, two anti-stripping additives were used; hydrated lime and a polyamine liquid have a trade name called Morelife.

3.3.1. Hydrated Lime

Lime was added as slurry to the aggregate by dosages of (0.5, 1.0, 1.5, and 2.0 %) from the weight of aggregate. The lime obtained from the local market. The properties of lime used are shown in Table 3-a.

3.3.2. Liquid Additive (Morelife)

A morelife agent is a basic liquid additive added to asphalt binder by a dosage of 0.25, 0.5, 0.75, and 1.0 by weight of asphalt binder. The manufacturer provides its characteristics; the pH test was the only test that carried out in this study. The properties of morelife additive are as follows (MPC Bulletin, 1996): it is a premium performance product based on a new and innovative chemical alternative to traditional anti-stripping technologies.

The chemical properties are: (a) it is a Polyamine and mixed Polycyclo-aliphatic consists of 30- 60% by weight Polyalkylene Glyco-Polyamines mixture and Alkyloxylated Aliphatic Polyamines. (b) It is stable under normal conditions of use, but high temperatures must be avoided. (c) It is compatibility with other materials: Oxidizers, Acids, and Basics. (d) It must be stored in cool, dry, well-ventilated areas away from heat, ignition or open flame sources, and direct sunlight. Their physical properties are shown in Table 3-b.

Table 3. The physical properties of additives used in this study

a. Hydrated lime properties (ALBMIC)*	
Physical property	Limit or range
Specific Gravity, ASTM C 29	2.36
Fineness (cm²/g)	4850
Sieve Number	% Passing
50	94.3
80	49.2
200	14.5
b. Morelife properties (MPC) **	
Property	Limit or range
Odor	Slight
Color	Dark brown / viscous liquid
Kinematic viscosity at 77^0F (25^0C) cSt	2000-4500
Weight, 1bs/ gal at 77^0F (25^0C)	8.85 -+ 0.04
Flash point, seta flash	170^0 C (338^0 F)
Pour point, ASTM D-97	7^0 C (45^0 F)
Physical state	Liquid
pH (tested)	12.3
Solubility in water	Miscible
Boiling point	716^0 F(380^0 C)

*Arab Lime and Building Materials Industries Company (ALBMIC) Bulletin, 1987, [21].
** Morton Performance Chemicals (MPC) Bulletin, 1996, [22].

3.4. Asphalt content and film thickness

3.4.1. Sample preparation

a) A (100) gram of each aggregate passing sieve 3/8 inch and retained on sieve No. 4, were washed then dried in an oven for 24 hours. The dry aggregates were completely mixed with (3.5, 4.0, 4.5, 5.0, 5.5) % of asphalt cement at 160˚C, and let to cool at room temperature for 24 hours.

b) For the same aggregates and percent of asphalt cement, add additives with a dosage of lime and morelife as stated before. Lime added to aggregate before heating and mixing. Also, other samples with different morelife dosages added to the heated asphalt cement with completely mixing before mixing with aggregate.

c) Nine specimens for each percent of asphalt cement, lime, morelife, and aggregate types were prepared, which would be used for different boiling tests.

d) Three additional specimens for each of optimum dosages of asphalt cement, lime, morelife, and aggregate types were prepared, for different aggregate types [23].

e) Other samples having the optimum lime dosage that obtained from the five pulse indirect tensile test were added as slurry to aggregate before mixing and heating, to find the effect of the additive on stripping potential. Also, optimum morelife dosages were added to heated asphalt cement and completely mixed with aggregate, to find the effect of the additive on stripping potential [23].

f) Marshall specimens: to obtain the optimum asphalt content, a compaction of 75 blows per each side is used for different asphalt content [23].

3.4.2. Boiling Test

ASTM D 3625 describes this test. The mix is immersed in boiling water under certain conditions and the percentage of asphalt retaining is estimated visually and used as stripping indicator. Besides this test, it was used Texas boiling test. Boiling tests consist of the following steps:

To find the effect of asphalt cement film thickness on stripping potential, the following steps should be proceeding on specimens were prepared at steps (a, b, c) before:

a) Boiling time: the coated aggregate was placed in a glass beaker (1 liter) filled with boiling distilled water and boiled for 10 minutes.

a) Agitation: the coated aggregates with different asphalt content, and with additive dosages or without were then stirred by glass rod every 3 minutes, and the stripped asphalt film was removed during the water boiling by paper.

c) Cooling conditions: the boiled loose mix was then taken out from the beaker and spread at a white paper sheet and let to cool at room temperature to the next day.

d) Estimated stripping: the stripped aggregate was estimated at least by a panel of three engineers or technicians with direct eye or by a lens. The retained asphalt on the aggregate surface by each panel number was estimated, and the average of the three was considered to calculate the retained asphalt coating aggregate.

e) Other samples: similar tests should be done on all aggregates mixed with optimum asphalt content for HMA for all aggregate types as the previous steps.

4. RESULTS AND DISCUSSION

The aggregate, asphalt binder, and air voids are considered the main parts of asphalt concrete mixture. The stability and capability to carry vehicles loads and to maintain a long time against climate conditions depend on all materials and methods of mixing and compaction. Therefore, high air voids produce hair cracks in pavement due to oxidation of asphalt or striping of aggregate due to filling the voids by water. In the research about the asphalt content; if it low, this will increase the stiffness of pavement, where the skidding problems will increase if it high.

It is important to study both air voids and asphalt content together, the sum of them represented as Voids in Mineral Aggregate (VMA). Another goal of this research has analyzed the results, which are necessary to discuss the stripping potential that may be affected by the following variables: a) aggregate type, b) mixture type, c) additive type and dosage, and d) film thickness.

HMA pavement has three components: aggregate by (94 – 96), (81 – 85), asphalt binder by (4 – 7), (11 - 12), and air by (0), (4 – 6) as a typical percentage by mass and by volume respectively. Due to the significant difference between air voids mass and volume, it couldn't add the binder (AC %) to the percent of air voids to get the VMA, that AC is a percentage by mass and air voids represent as a percentage by volume, as the following equations:

$$VMA\ (\%) = AV(\%) + AC\ (\%)\ (film)\ \text{volume percentage} \qquad (3)$$

Where:

$$AC\ (\%) = AC\ (absorbed) + AC\ (film)\ \text{mass percentage}$$

The following equation states the average film thickness T_F, (μm): [16]

$$T_F = 1000\ \{ V_{asp} / (SA)(W) \} \qquad (4)$$

Where:

V_{asp} = volume of effective asphalt binder ($V_{asp} = P_{be} / G_b$, L),

SA = aggregate surface area (m^2/kg), which show at Table 4, and

W = aggregate weight (kg).

Table 4. Surface area for commonly used aggregate gradation for asphalt mixture [19]

Sieve size (mm)	Surface area factor m^2/kg
25.4, 19.1, 16.1, 12.7, 9.5 (Maximum aggregate size)	0.41
4.75	0.41
2.36	0.82
1.18	1.64
0.60	2.87
0.30	6.14
0.15	12.29
0.075	32.77

The Texas boiling test (3 stirring cycles) procedure was used to detect the effect of film thickness on striping. This procedure showed the difference in striping for different asphalt film thickness as shown in Table 5 and Figure 4. This difference was very clear for basalt and valley gravel aggregate. The percent retained of asphalt cement increased from 80% to 94% with increasing asphalt film thickness from 55 to 93 microns when limestone aggregate is used. An increase from 61% to 85 % has occurred due to an increase of asphalt film thickness from 73 to 109 microns when valley gravel aggregate is used. Another increase from 38 % to 90 % has resulted due to an increase of asphalt film thickness from 73 to 109 microns when basalt aggregate was used. This is due to physical characteristics of aggregate, as the roughness of aggregate surfaces, and due to chemical characteristics of aggregate compositions.

Table 5. Asphalt film thickness (T_F) (micron) for coated aggregate at different AC (%)

Aggregate type	Weight of AC (%) absorption	AC (%)									
		5.5		5.0		4.5		4.0		3.5	
		T_F	AC ret.	T_F	AC ret.	T_F	AC ret.	T_F	AC ret.	T_F	AC ret.
Limestone	1.25	104	97	93	94	79	86	67	84	55	80
Valley gravel	0.55	121	89	109	85	96	83	84	78	72	61
Basalt	1.02	109	90	99	66	85	54	73	38	61	22

Table 6 shows the **e**ffect of AC (%) content on asphalt retained (%) using Texas boiling test for different dosages of lime and morelife. It is clear that both AC (%) and additives dosages are increased the asphalt retained (%). Limestone shows best results with or without additives, where basalt shows the lowest percent of asphalt retained. The addition of additives was not inevitable when the (%) retained asphalt reached 90% and above. Any improvement in stripping potential for such mixtures could be unnecessary and hardly can be detected visually. Thus additives should not be added for stripping cases greater than 90%, because they are none-stripper aggregates and don't need any anti-stripping additive.

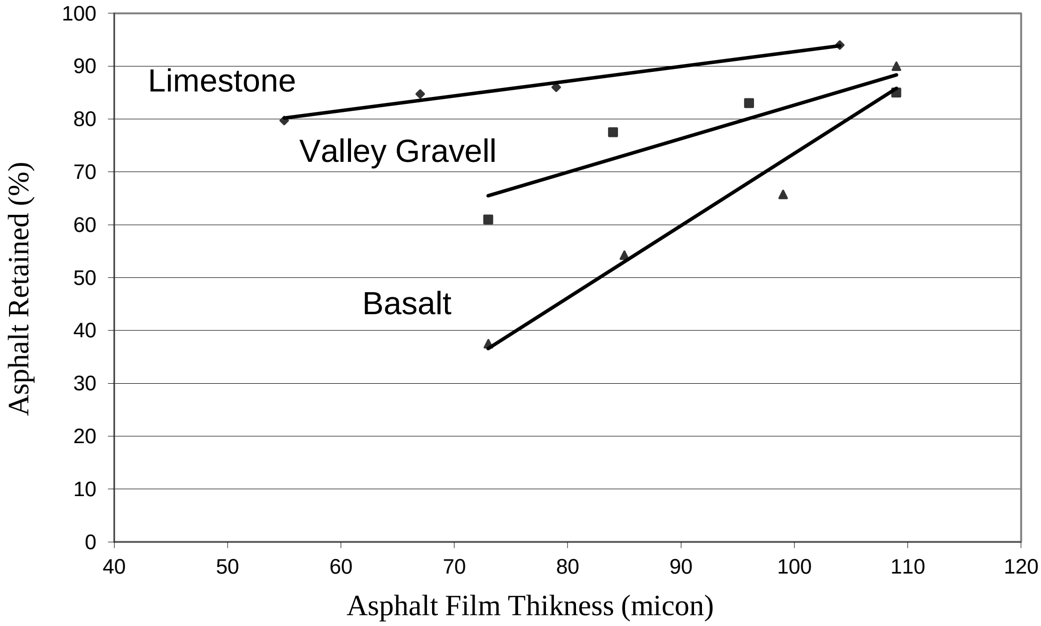


Figure 2. The relationship between asphalt film thickness and asphalt retained (%) for aggregates using Texas boiling test (no additive)

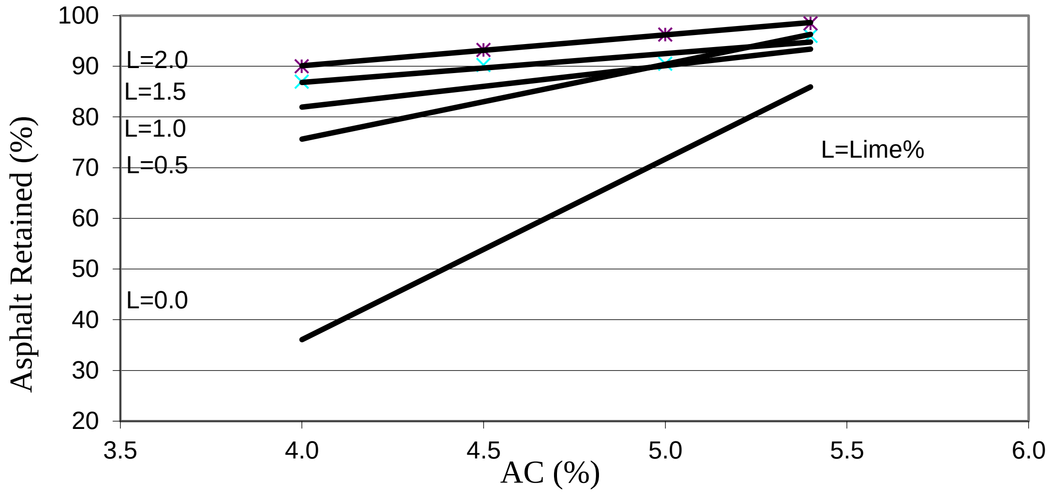


Figure 3. The relationship between AC (%) and stripping retained (%) for basalt treated with lime (%)

However, it was found that both types of additives have increased the percent retained of asphalt cement on aggregate surface. Figure 4 shows the effect of the additives on stripping resistance by using the ASTM, Texas boiling, and Modified Texas boiling tests at the optimum asphalt content for each aggregate for limestone. Other types of aggregate results present the same trend. When the additive dosage was increased, the asphalt retained for the mixtures were increased for the three methods used, especially for the modified Texas test, which is the most severe test due to its additional mechanical effect of 9 times stirring. Where no additive was used or at the low additive dosage, stripping of the mixture could easily be detected by any test, due to the existence of uncoated particles. At a high dosage of additives, the mixture gains high resistance to stripping and the used test could hardly detect any signs of stripping, therefore all the tests give similar indications of stripping due to the non-existence of uncoated particles.

Table 6. Effect of asphalt cement content on asphalt retained (%) using Texas boiling test

Aggregate Type	Asphalt Cement (%)	Asphalt Film (micron)	Asphalt Cement Retained (%)									
			Lime % (by weight of aggregate)					Morelife % (by weight of AC)				
			0	0.5	1	1.5	2	0	0.5	1	1.5	2
Limestone	5.2	95	94	96	98	100	100	94	99	100	100	100
	5.0	93	94	95	96	97	98	94	97	99	100	100
	4.5	79	86	90	90	95	98	86	96	96	98	100
	4.0	67	84	89	89	93	95	85	94	95	97	99
	3.5	55	80	85	87	91	92	80	91	94	97	99
Valley Gravel	5.0	109	85	92	93	95	96	85	86	93	96	100
	4.5	96	83	87	90	92	95	83	83	88	95	99
	4.0	84	78	84	89	91	94	78	79	86	92	96
	3.5	72	61	81	85	88	92	61	75	82	88	91
Basalt	5.4	104	90	97	96	96	99	90	96	97	98	100
	5.0	99	66	89	87	91	96	66	80	90	97	100
	4.5	85	54	83	86	90	93	54	80	85	90	95
	4.0	73	38	76	83	87	90	38	75	80	88	93

The modified test procedure (boiling with 9 times stirring) was so severe that all the aggregates have shown some stripping potential. The retained asphalt cement percent on aggregate surface at optimum asphalt content for limestone, valley gravel, and basalt aggregates were 69 %, 63 %. and 64 % respectively as shown at Table 7-b. The increased in the number of mixing from 3 to 9 times reduce the retained asphalt cement by about 30% for all aggregate, which reflects the mechanical effect on stripping potential. Comparison between Texas standard and modified test results are shown in Table 7-b below.

Table 7. The effect of optimum asphalt contents for all aggregate

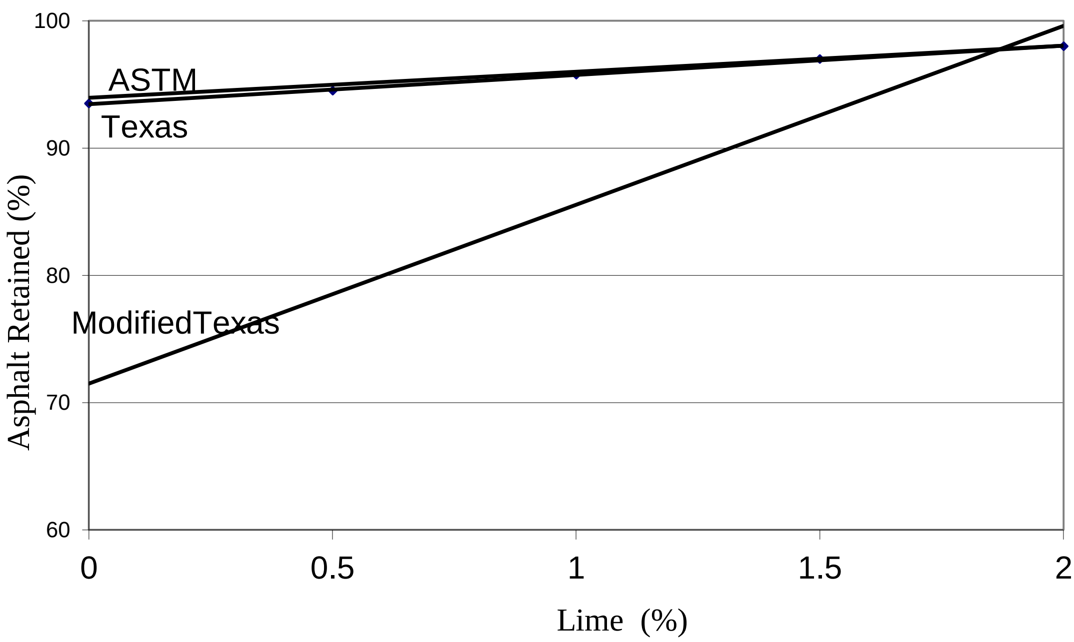
a) Characteristics of design mixtures

Aggregate type	AC% by wt. of mix	Bulk sp.gr. (Gmb)	Air Void (%)	VMA (%)	Stability (kN)	Flow (mm)	VFA* (%)
Limestone	5.2	2.310	4.4	13.1	1460	3.8	67.0
Valley gravel	4.2	2.367	3.1	13.0	1500	2.0	77.0
Basalt	5.4	2.468	4.6	14.1	1130	2.7	68.0

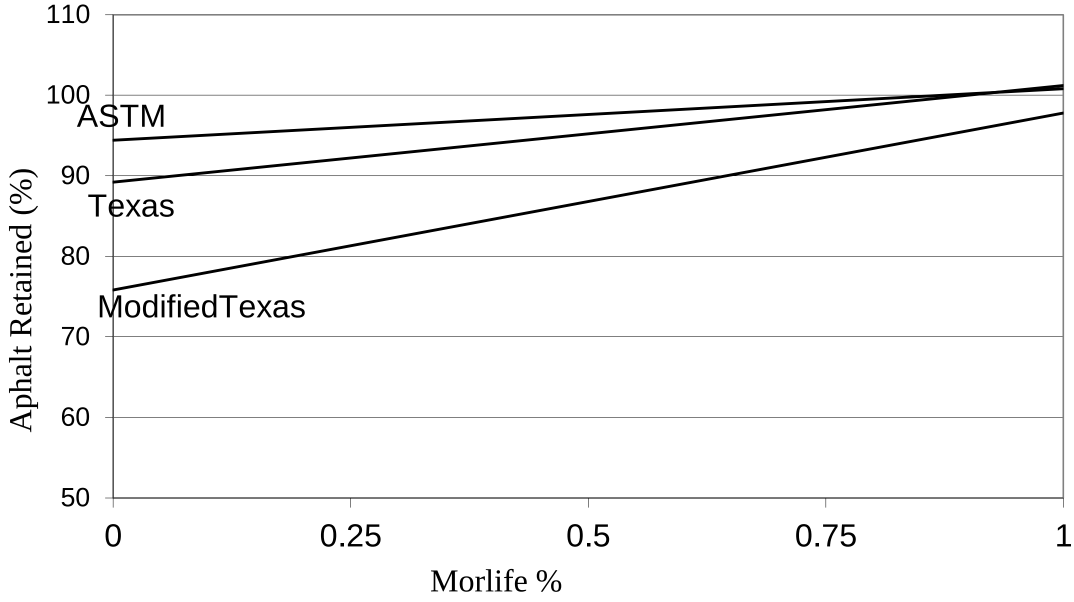
b) Asphalt retained (%) using boiling test

Aggregate type	Asphalt film (micron)	Texas standard	Modified Texas
Limestone	93	94 %	69 %
Valley gravel	93	85 %	63 %
Basalt	104	90%	64 %

*VFA= void filled with asphalt



(a) Lime (%) for Limestone



(b): Morelife (%)

Figure 4. Relationship between asphalt retained (%) and additives for limestone

Table 8. Gradation of wearing and binder courses aggregate for heavy traffic asphalt mixes*

% Passing				
	Wearing course		Binder course	
Sieve size	Specification limit	Used	Specification limit	Used
1 in	100	100	100	100
3/4 in	90-100	95	70-100	85
1/2 in	71-90	80.5	53-90	71.5
3/8 in	56-80	68	40-80	60
No. 4	35-56	45.5	30-56	43
No.8	23-38	30.5	23-38	30.5
No. 20	13-27	20	13-27	20
No. 50	5-17	11	5-17	11
No. 80	4-14	9	4-14	9
No. 200	2-8	5	2-8	5
Pan	0	0	0	0

* MPWH Specification [20]

Table 9. Aggregate gradation surface area for heavy traffic

Sieve	Passing (%)	SA factor m^2/kg	SA m^2/kg
1"	100	0.41	0.41
(3/4)"	95	*	
(1/2)"	80.5	*	
(3/8)"	68	*	
No. 4	45.5	0.41	0.187
No. 8	30.5	0.82	0.251
No.20	20	1.367	0.273
No. 50	11	6.14	0.675
No.80	9	9.83	0.553
No.200	5	32.77	1.639
Total SA (m^2/kg)			3.988

To determine the surface area for asphalt mixture, we must find the weight and volume for each Marshall specimen and calculate the average of three at the same AC (%). Then find the SA using Equation. (4) and Table 9 as shown in Table 10.

The results of T_F are presented in Table 10. They are varied from 7.2, 7.6, 7.7 to 11.8, 10.7, and 11 for basalt, valley gravel and limestone respectively. The values of T_F around the optimum AC (%) are agreed with those in similar studied as in introduction. The relationship between T_F and VMA (%) are the same trend for all aggregates that are VMA (%) decreasing with increasing AC (%) until closing to optimum (less or large), then increasing, while T_F values are increasing with AC (%) increased. It was noticed that T_F for different AC (%) and aggregates of asphalt mixtures are small. Therefore, to increase T_F, it is important to reduce the percentage of very fine materials like sieves of #200 and #100, which contained about 55% of total surface area of the aggregates in the asphalt mixture. This recommendation would maintain the acceptable characteristics at optimum AC (%) and values of VMA (%) within the ranges, which would produce asphalt mixture with better stripping resistance.

Table 10. T_F for different AC (%) of asphalt mixtures for wearing course properties

Aggregate type	AC (%)	Wt. at Air, kg	P_{be} vol. Lt	T_F micron	Bulk sp. gr. (Gmb)	Air Void (%)	VMA (%)	Stability (kN)	Flow (mm)	VFA (%)
Limestone	4.5	1.242	0.038	7.7	2.283	6.7	13.46	1225	3.2	50
	5.0	1.252	0.046	9.2	2.307	4.9	12.99	1493	3.5	62
	5.2	1257	0.047	9.4	2.310	4.4	13.1	1460	3.8	67
	5.5	1265	0.050	9.9	2.311	3.9	13.29	1370	4.5	71
	6.0	1280	0.056	11	2.309	2.8	13.84	1283	5.3	80
Valley gravel	3.5	1218	0.037	7.6	2.321	5.8	14.03	1300	1.3	59
	4.0	1233	0.041	8.3	2.353	3.8	13.29	1415	1.8	71
	4.2	1237	0.043	8.7	2.367	3.1	13.0	1500	2.0	77
	4.5	1244	0.047	9.5	2.373	2.2	12.99	1517	2.3	83
	5.0	1247	0.053	10.7	2.370	1.4	13.99	1230	3.3	90
Basalt	4.0	1225	0.035	7.2	2.405	7.6	14.15	1040	1.0	46
	4.5	1243	0.041	8.3	2.420	6.4	14.05	1062	1.5	54
	5.0	1231	0.047	9.6	2.436	5.2	13.94	1098	2.3	63
	5.4	1239	0.052	10.5	2.468	4.6	14.1	1130	2.7	68
	5.5	1241	0.053	10.7	2.447	4.4	14.03	1129	3.0	69
	6.0	1249	0.059	11.8	2.440	3.9	14.67	1028	3.5	73

5. CONCLUSIONS

The following conclusions can be drawn from this study:

1. Limestone has proven to be stripping resistant aggregate, and smooth, rounded valley gravel aggregate produce asphalt mixtures of highest moisture susceptibility.
2. The use of additives was very significant in reducing the stripping potential of all mixtures. Lime additive showed better effects on stripping potential than morelife additive.
3. In general, it found that the dosage of lime needed to retain asphalt bonding with aggregate is between 1.5 to 2.0% by weight of aggregate, where for morelife it was between 0.75 to 1% by weight of asphalt binder.
4. The visual assessment of boiling test is not enough to predict stripping; therefore it is preferred to use a modified boiling test.
5. The asphalt film thickness is an important factor against stripping and it must be more than 55, 80, and 100 microns for limestone, valley gravel, and basalt respectively to give 70% or more of asphalt retained.
6. The average film thickness of asphalt mixtures is about 9-11 micron for all aggregates, it is recommended to increase T_F by decreasing the percentage of very fine particles which decreasing the total surface areas of the mixtures.
7. VMA (%) had approximate values for limestone and valley gravel (13.0%), with AC (%) = 5.2 and 4.2 respectively, that is because valley gravel aggregate is smooth, rounded and less absorption than limestone, where about (14%) for basalt with AC (%) =5.4.

Conflict of Interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Acknowledgment

The authors of this paper are thankful to Jordan University of Science and Technology for their support fund.

REFERENCES

[1] Tunnicliff, D. G; Nebraska, O; and Root, R. E., Use of Anti- Stripping Additives in Asphaltic Concrete Mixtures, National Cooperative Highway Research Program, Report NCHRRP 274, USA, 1984.

[2] Maupin, G.W; Jr., 1999, Evaluation of Stripping in Virginia's Pavements, TRR 1681, TRB, National Research Council, USA, pp. 37-42.

[3] Tunnicliff, D.G; and Root, R. E., 1995, Use of Anti-stripping Additives in Asphalt Concrete Mixture, Field Evaluation, NCHRP, Final Report, Report: 373, NCHRP, USA, 58 p.

[4] Braik, O.A., 1987, Stripping of Asphalt Mixtures and the Effectiveness of Anti-Stripping Additives, MSc Thesis, Jordan University of Science and Technology, Irbid, Jordan.

[5] Khedaywi, T. S., 1992, Utilization of the Indirect Tensile Test to Evaluate the Effectiveness of Additives on Moisture Sensitivity of Asphalt Concrete Mixtures, Indian Highways Journal, pp. 31-38.

[6] Gharaybeh, Fouad A., and Frazier Parker, Jr., 1987, Evaluation of Indirect Tensile Tests for Assessing Stripping of Alabama Asphalt Concrete Mixtures, TRR 1115, TRB, National Research Council, USA, pp. 113-124.

[7] Somogyvari, AF; Zanotto, L; and Jeffries, RB., 1992, The Anti-Stripping Properties of Basic Nitrogen in Hydro-cracked Residues, Fuel Science and Technology, Vol. (10) 4, USA, pp. 531-547. www.199.79.179.82/sundev/

[8] Kandhal, P.S., and S. Chakraborty, 1996, Effect of Asphalt Binder Film Thickness on Short and Long Term Aging of Asphalt Paving Mixtures, NCAT Report 96-01. National Center for Asphalt Technology, Auburn, Ala, USA.

[9] Kennedy, T. W; Roberts, F.L.; and Lee, K. W., 1983, Evaluation of Moisture Susceptibility of Asphalt Mixtures Using the Texas Boiling Test, TRR 911, TRB, National Research Council, USA, pp. 45 – 54.

[10] Mostafa A. Elseifi, Imad L. Al-Qadi, Shih-Hsien Yang, and Samuel H. Carpenter, 2008, Validity of Asphalt Binder Film Thickness Concept in Hot-Mix Asphalt, TRR 2057, TRB. https://doi.org/10.3141/2057-05, https://www.academia.edu/4216604/Validity_of_Asphalt_Binder_Film_Thickness_Concept_in_Hot-Mix_Asphalt.

[11] Radovskiy, B., 2003, Analytical Formulas for Film Thickness in Compacted Asphalt Mixture, TRR 1829, TRB, National Academies, USA, pp. 26–32.

[12] Roberts, F.L., P.S. Kandhal, E.R. Brown, D. Lee, and T.W. Kennedy, 1996, Hot Mix Asphalt Materials, Mixture Design, and Construction, 2nd ed. Napa Education Foundation, Lanham, Md., USA.

[13] Michael Alan Heitzman, 2005, Development of new film thickness models for hot mix asphalt, Ph.D. Iowa State University, USA.

[14] Asphalt Institute, 2014, Mix Design Methods for Asphalt Concrete, Manual Series No. 2 (MS-2), 7th Edition, USA.

[15] Kandhal, P.S., K.Y. Foo, and R.B. Mallick, 1998, A Critical Review of VMA Requirements in Superpave. NCAT Report 98-01, National Center for Asphalt Technology, Auburn, Ala, USA.

[16] National Center for Asphalt Technology, Asphalt Film Thickness Debunked. Auburn University, USA, 2017. http://www.eng.auburn.edu/research/centers/ncat/newsroom/2017-spring/film-thickness.html.

[17] Haydar R. Hmoud, 201, 1Evaluation of VMA and Film Thickness Requirements in Hot-Mix, Modern Applied Science, 5 (4), www.ccsenet.org/mas, https//:doi.org/10.5539/mas.v5n4p166.

[18] Ghazi G. Al-Khateeb, 2016, Conceptualizing the asphalt film thickness to investigate the Superpave VMA criteria. International Journal of Pavement Engineering. https://www.academia.edu/30741111/Conceptualizing_the_asphalt_film_thickness_to_investigate_the_Superpave_VMA_criteria, http://dx.doi.org/10.1080/10298436.2016.1224414.

[19] Annual Book of ASTM Standards, Section 4, Volume 04.03, Philadelphia, Pa., USA, 1990.

[20] Ministry of Public Works and Housing, 2010, Specifications for Highway and Bridge Construction. Part 4, Bituminous Construction, Amman, Jordan.

[21] Arab Lime and Building Materials Industries Company (ALBMIC), 1987, Bulletin, Amman, Jordan.

[22] Morton Performance Chemicals, (MPC), 1996, Bulletin 150, Andover Street, Danvers, MA, USA.

[23] Alkofahi, N., 2003, Development of Systematic Laboratory Testing Procedure to Predict Stripping of Asphalt Concrete Mixtures, Ph.D. Thesis, Jordan University of Science and Technology, Irbid, Jordan.