STRIPPING ON SAUDI ARABIAN ROADS – PREDICTION AND PREVENTION

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ABSTRACT

Pavement weathering or stripping is a major distress in the highway network in the Kingdom of Saudi Arabia. Stripping severity varies between the regions of the Kingdom. The highway networks of the Al-Qassim and Hail regions are the most affected by pavement stripping in the Kingdom. Saudi roads, which are experiencing stripping and weathering, have passed locally used water sensitivity tests. In this study, which is funded by King Abdulaziz City for Science and Technology (KACST), seventeen road test sections were selected, out of which eight were stripped and nine were unstripped sections. These sections were selected across the Kingdom to cover the different stripping affected regions. Aggregates from quarries used to build these sections were also collected for laboratory analysis evaluation. Collected materials were subjected to detailed physical and chemical testing to evaluate the ability of these tests to distinguish between stripped and non-stripped sections. Out of these tests, modified Lottman which has the highest significance and currently adopted as a result of SHRP research, worldwide, in addition to Swedish Rolling Bottle which has the ability to screen asphalt-aggregate materials for their stripping potential, were selected. Eleven antistripping liquid additives, lime, and cement in addition to two polymers were evaluated for their ability to reduce/eliminate stripping potential of stripping-prone aggregates. It was found that EE-2 Polymer and Portland cement and their combination were effective with all aggregate sources.

Keywords: *Stripping, ECS, Polymer, Antistripping agents, Lottman.*

الملخص

يمثل انفصال الحصمة مشكلة رئيسية في طرق المملكة العربية السعودية حيث تتباين شدة انفصال الحصمة من منطقة إلى أخرى وتتأثر شبكة الطرق في منطقة القصيم وحائل بانفصال الحصمة بشكل كبير , ولقد اجتازت جميع الطرق المتأثرة بهذه الظاهرة اختبار حساسية الماء المستخدم محلياً لتحديد هذه الظاهرة. وفي هذه الدراسة المدعمة

من قبل مدينة الملك عبدالعزيز للعلوم والتقنية, تم اختبار عدد من مقاطع الطرق منها ثمانية متأثرة بالظاهرة وتسعة في حالة جيدة وتم اختيار هذه المقاطع من مختلف المناطق كما جمعت عينات حصمة من المحاجر التي بنيت منها هذه الطرق , ولقد عملت تجارب تفصيلية فيزيائية وكيميائية لتحديد قدرة هذه التجارب على التمييز بين المقاطع المتطايرة والمقاطع غير المتطايرة , ولقد تبين من هذه التجارب أن اختبار (لوتمان) واختبار الزجاجة السويدية الدوارة لها القدرة على التمييز بين المواد بناءاً على مقاومة التطاير. تم تقييم أحد عشر مادة لمقاومة انفصال الحصمة بالإضافة إلى الجير و الأسمنت البورتلاندي ونوعين من اللدائن المستخدمة لتحسين خصائص الاسفلت , ولقد دلت النتائج أن الأسمنت البورتلاندي واللدين نوع (EE-2) ومخاليطهما أدت إلى أفضل النتائج لمقاومة انفصال الحصمة.

1. BACKGROUND

Aggregate chemistry plays a key role in asphalt-aggregate adhesion. It was found (Curtis et al., 1993) that where cohesive asphalt failures do not occur, aggregate chemistry is much more influential than asphalt composition. Active sites on the aggregate surface promote adsorption of polar asphaltic compounds. When these active sites are covered by non-polar compounds or dust that occur naturally on the aggregate surface, the bonding force that maintains the pavement is weakened. Curtis et al. (1991) have developed a test which is called limestone reactivity test that determines the amount of active sites present on the aggregate surface.

After laying the pavement, asphalt-aggregate bonding forces can be weakened by the effects of water. Water molecules intrude or diffuse to the aggregate surface and compete with the polar asphaltic compounds for interactions with the active sites. The affinity or compatibility of an asphalt-aggregate pair is very important in minimizing water damage. If the affinity is large, only a small percentage of the asphalt-aggregate interaction sites will be lost to water molecules. Pairs of low affinity will lose a large percentage of the asphalt-aggregate interaction sites to the more polar and hydrogen bonding water molecules, which leads to stripping. Tests were devised (Curtis et al., 1993) to determine this important affinity or compatibility for different pairs of asphalt-aggregate. If water is the cause of an asphalt-aggregate problem, these tests allow one to evaluate the possibility of future pavement stripping based on this affinity.

When aggregate absorbs water, the asphalt is “stripped” away, which ultimately leads to pavement failure. Moisture degrades the integrity of an asphalt concrete matrix in three areas: (1) loss of cohesive strength in the asphalt film, (2) failure of the adhesive bond between the aggregate and asphalt (stripping), and (3) loss of the chemical bond (integrity) between the asphalt film and the aggregate.

Other modes of pavement failure due to the presence of water are possible. Water can remove the soluble compounds from the asphalt causing it to fail. Failure within the aggregate is also possible. Water can also promote phase separation within the asphalt, where the more polar molecules form a separate phase with water, which also leads to stripping.

Reduction in water damage can be achieved by selecting asphalt-aggregate pairs of high affinity, modifying the aggregate surface through silylation, or adding antistripping agents. Building roads with low air voids and good drainage reduces water damage by limiting the exposure to water.

The pH of the medium can also affect the asphalt-aggregate bond. It was found (Curtis et al., 1993) that high pH (basic or alkaline environment) is detrimental to most asphalt-aggregate bonds. Additives such as lime or some liquid antistripping agents can improve the performance of some asphalt-aggregate pairs in highly basic environments.

Among the many factors that contribute to the degradation of asphalt concrete pavements, moisture is a key element in the deterioration of the asphalt mix. Since the 1930s, pavement engineers have been working to determine the moisture sensitivity of asphalt concrete mixtures. Since that time, numerous tests have been developed to help identify moisture-susceptible asphalt concrete mixtures.

In general, there are two categories into which the water sensitivity tests can be divided. The first category is tests which coat "standard" aggregate with an asphalt cement. The loose mixture is immersed in water (either at room temperature or at boiling temperature), and a visual evaluation is then made of the separation of asphalt from the aggregate. The second category is those tests, which use compacted specimens (either laboratory compacted or cores from existing pavement structures) (Terrel and Shute, 1989). These specimens are then water conditioned to simulate the in-service conditions of the pavement structure. The results of these tests are generally evaluated by the ratios of conditioned to unconditioned results using a stiffness or strength test, such as the diametral resilient modulus test.

Several methods have been developed to determine if an asphalt concrete mix is sensitive to water. The main methods can be summarized as follows (Terrel and Shute, 1989; Curtis et al., 1991; Terrel and Al-Swailmi, 1992; AASHTO, 1995):

1. NCHRP 246 – Indirect Tensile Test and/or Modulus Test with Lottman Conditioning.
2. NCHRP 247 – Indirect Tensile Test with Tunnicliff and Root Conditioning.
3. AASHTO T-283 – Combines feature of NCHRP 246 and 247.
4. Boiling Water Tests.
5. Immersion-Compression Tests (AASHTO T-165, ASTM D 1075).
6. Freeze-Thaw Pedestal Test.
7. Static Immersion Test (AASHTO T-182, ASTM D 1664).
8. Conditioning with Stability Test (AASHTO T-245).
9. Net Absorption/Desorption Test (developed by SHRP).
10. Environmental Conditioning System (ECS) (developed by SHRP).

2. PROBLEM DEFINITION

Pavement weathering or stripping is one of the major distresses in the highway network in the Kingdom of Saudi Arabia. Stripping severity varies from region to region in the Kingdom. The highway network in Al-Qassim and Hail regions are the most affected by pavement stripping. In certain roads where maintenance programs are not efficient, stripping develops potholes that severely affect road performance. The water sensitivity test used in local road departments is the typical water conditioning and evaluation by Marshall stability test. The conditioning phase includes partial saturation of three specimens with asphalt and then soaking in a water bath at 60°C for 24 hours. The three specimens are then tested for Marshall stability and compared with the result of unconditioned specimens. If the ratio (condition divided by unconditioned) is less than 75%, the mixture is considered sensitive to water. Those roads experiencing stripping and weathering have passed the water sensitivity test. This has proved to the road agencies in the Kingdom that the water sensitivity test using the Marshall stability is not efficient in determining the sensitivity of asphalt mixtures to water.

3. STUDY OBJECTIVES

The overall objective is to study the stripping problems of the highway network in the Kingdom. The study includes specifically the following steps:

- Review current "State of the Practices" by road agencies,
- Analyze the binder aggregate adhesion and susceptibility of that adhesion to water damage,
- Adapt or modify comprehensive test(s) that predict the resistivity of asphalt-aggregate materials (individually or as a mix), and
- Suggest practical treatment methods to improve stripping resistance of local mixes.

4. PROJECT DESIGN

In order to achieve the stated project objectives, the study covered asphalt, aggregates, and mixes used in different regions of the Kingdom. The work was carried out in seven tasks and extended for 30 months. A schematic flow chart for the design of the first phase of the study is shown in Table 1. Details of the planned work are as follows:

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Table 1. Experimental design for the first phase.

			NUMBER OF REPLICATES																			
			STRIPPED SECTIONS										NON-STRIPPED SECTIONS									
			FIELD SAMPLES					LABORATORY SAMPLES					FIELD SAMPLES					LABORATORY SAMPLES				
ROAD SECTION NUMBER			1	2	3	.	8	1	2	3	.	8	1	2	3	.	9	1	2	3	.	9
LABORATORY TEST	Aggregate-Asphalt Blend	Swedish Rolling Bottle	X	X	X	.	X	2	2	2	.	2	X	X	X	.	X	2	2	2	.	2
		Absorption-Desorption	X	X	X	.	X	2	2	2	.	2	X	X	X	.	X	2	2	2	.	2
	Asphalt Concrete Mix	Volumetric Properties	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3
		Marshall Compaction, Vacuum Saturation Conditioning and Resilient Modulus Testing	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3
		Marshall Compaction, Vacuum Saturation Conditioning and Split Tensile Testing	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3
		Marshall Compaction, Marshall Conditioning and Split Tensile Testing	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3
		Gyratory Compaction, Vacuum Saturation Conditioning and Split Tensile Testing (7% Air Voids)	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3
		Marshall Stability Loss	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3	3	3	3	.	3
		Environmental Conditioning System (ECS)	2	2	2	.	2	2	2	2	.	2	2	2	2	.	2	2	2	2	.	2

X = Test is not applicable.

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4.1. Task 1. Literature review

Available literature from main research institutions locally and abroad related to the subject of the project were collected, summarized, and utilized to support the knowledge of the researchers in this field.

4.2. Task 2. Stripping Test Selection And Evaluation

Different tests (physical and chemical) that might be used to detect susceptibility of pavement mixes and/or materials to stripping were evaluated in the first phase. Construction materials (fresh aggregates, slabs, and cores) from known performance road sections were collected, in consultation with the Ministry of Communications' personnel, from different regions of the Kingdom based on an experimental design that considered all factors that contribute to stripping. These materials were subjected to different tests to evaluate their ability in predicting stripping potential. A total of seventeen test sections were selected. The total number of selected sections is eight stripped and nine unstripped sections covering all regions of the Kingdom as shown in Table 2. In selecting the study sections, the following criteria were ensured:

– Adequate drainage should be present to drain the pavement surface.

– Construction should be according to specifications, i.e. percent air voids (AV%) should be within design limits, compaction temperature within allowable limits, no overheating of asphalt, aggregate gradation within limits, etc.

– Aggregate quarry used for supplying aggregate in the asphaltic concrete layers should be known and active so that fresh aggregate can be obtained similar to that used in the section.

The collected materials were subjected to a number of chemical and physical evaluation tests to evaluate the ability of those tests to predict stripping. These tests include:

- Environmental Conditioning System (ECS).
- Modified Lottman test.
- Net Adsorption in the presence of moisture.
- Swedish Rolling Bottle.
- Methylene Blue Value (MBV).
- Marshall durability test was also included to be evaluated as the only locally adopted practice.

Experimental design for the first phase of the project is shown in Figure 1. The response variables measured on individual materials, mixtures, compacted specimens, pavement cores were used for selection of applicable physical and/or chemical tests that are able to predict stripping and used for evaluation of the different mixes in the second phase of the study.

4.3. Task 3. Material Collection Mix Designs And Evaluation

In the second phase, different additives that are known from literature of being useful in preventing stripping were collected and used with the collected aggregate from stripped sections to prepare asphalt mixes using different additives percentages and combinations. Optimized mixes were evaluated using the selected applicable stripping tests from the first phase.

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Table 2. Selected test sections

Serial #	Crusher	Road name	Pavement condition	Age	Symbol
Al-Qassim					
1	Al-Swailem	Ring road (North + East)	Excellent	5–6 years	QN-1
2	Burma	Ring road mid-east flange	V. good	5–6 years	QN-2
3	Debiah	414 west road Stat. 45+600	V. good	10 years	QN-3
4	Artic	Al-Jamal Avenue junction road	Medium stripping	3 years	QS-4
5	Al-Fahd	Ring road-West flange Stat. 14+550	High stripping	5–6 years	QS-5
Hail					
6	Al-Swailem	Bagaà road	Low stripping	3 years	HS-1
7	Al-Hudaires	At Humairah road (Madinah junction) (RD-7771)	Medium to high stripping	5 years	HS-2
8	Al-Namlah	Ring road Stat. 17+000	V. good	14 years	HN-3
Eastern Province					
9	Road Construction Establishment	Salasel-Abqaiq, KP7	Low stripping	7–8 years	ES-1
10	Al-Hazaà	Nuaireah-Qaysoma road, after Nuaireah intersection bridge	Excellent	6–7 years	EN-2
Riyadh Region					
11	Shibh Al-Jazira	Riyadh-Dammam Expressway Stat. 980+000	V. good	8 years	RN-1
12	Al-Awaidah	Riyadh-Taif Expressway Stat. 511+00	Medium stripping	5 years	RS-2
Taif					
13	Al-Harameen	Taif-Baha road, KP 1220	V. good	5-6 years	TN-1
Abha					
14	Ben-Jarrallah	Prince Salman Sport City road	V. good	7-8 years	AN-1
Al-Jouf					
15	Al-Swailem	Sakaka Domat Al-Jandal road	V. good	5-6 years	JN-1
16	Al-Harbi	Tabargel Al-Quriyat road	High stripping	15 years	JS-2
Northern Region					
17	Al-Sagaf	Arar-Taif Highway, km sign 1523	Low stripping	7 years	NS-1

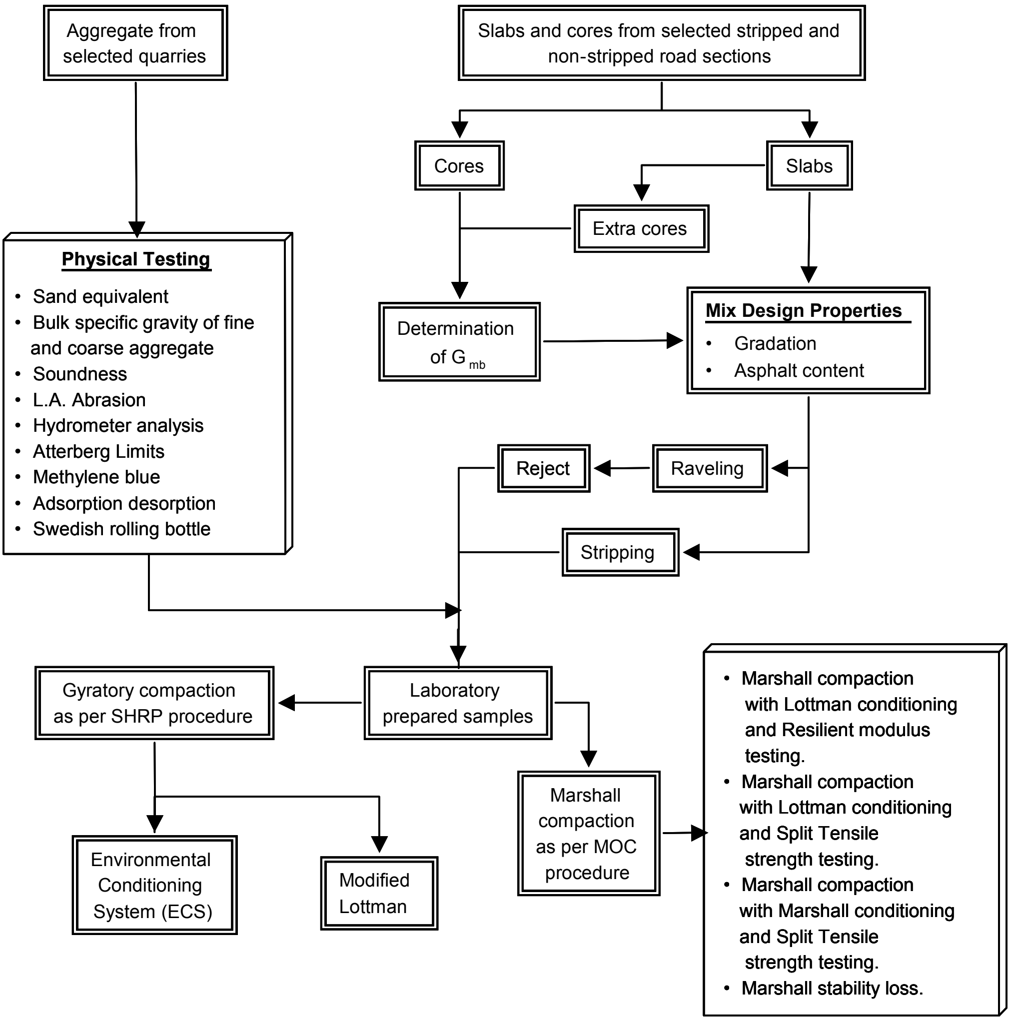

Figure 1: Flow chart for Phase I experimental program.

5. ANALYSIS

5.1. First Phase

In the experimental design of the project, two sets of test sections were selected and tested. The first set consisted of eight stripped sections while the second set consisted of nine non-stripped sections distributed in different regions around the Kingdom.

As an initial step in the statistical analysis, the normality assumption of the distribution of the obtained test results was checked by drawing normal probability plots of the obtained data. The statistical data analysis was then carried out in three stages. Stage I, the preliminary analysis, was to confirm that there is a difference in behavior between stripped and non-stripped sections and that the grouping of the sections was correct. Therefore, the statistical evaluation tests for this stage were performed on the test results of the extracted field cores. Stage II was to find which of the laboratory tests is capable of predicting the stripping potential of the asphalt concrete mixes. Therefore, the statistical evaluation tests for this stage were performed on the test results of the fresh aggregate and the laboratory prepared mixes. Stage III was to find the test limits of significant tests which can be set to screen mixes which are prone to stripping based on the test results of the fresh aggregate and the laboratory prepared mixes. In this stage, specification limits were calculated for each of the obtained significant tests. These limits can be used to test if the mix is prone to stripping, i.e. if the result of the evaluation test is higher than the set limit, then the mix will be prone to stripping. Assuming normal distribution of the obtained test results, the average and standard deviation values for the tested samples, listed in Table 3, were used to find the test limits. The idea was to find the limit that would produce an equal probability of classifying the mix as not being prone to stripping if the test value was lower than the limit, to the probability of classifying the mix as being prone to stripping if the test value was higher than the limit. Table 3 shows the calculated discriminant limits for each of the significant tests and the probability of the limits of being correct in predicting the stripping potential of a mix. It can be seen from Table 3 that both the modified Lottman test (AASHTO T-283) and Marshall stability loss test (MOC-MRDTM 410) have the highest discriminant probability. The discriminating limits for these tests are 48% and 25%. Lottman, however, has P-value of 4.6E-09 as compared to P-value of 9.4E-08 for Marshall stability loss. Marshall stability loss is being implemented locally but sometimes with negative consequences such as stripped sections selected for this study. Moreover, the MOC is in the process of adopting Superpave mix design, which will eliminate the use of Marshall mix design. Lottman is a simple test that has wealth of data supporting its effectiveness and currently adapted across the United States. This led the research team to favor Lottman test. It was selected as a discriminating test for the second phase of the study for compacted asphalt mixes.

Swedish Rolling Bottle, which is a significant test (P = .02715) to distinguish between aggregate-asphalt stripping tendency, was also used to evaluate aggregate-asphalt materials.

5.2. Second Phase

Stripped sections from the first phase were selected to be included in the second phase of this study. Selected sections cover different regions of the Kingdom. Enough aggregates were collected from all sections to last for the whole project. 500 liters of 60/70 pen. (PG 64-22) asphalt cement were collected from Riyadh Refinery, which is the major asphalt cement supplier/refinery in the Kingdom. Asphalt cement was sealed and stored in 5-liter containers.

In addition to lime and cement dust, several liquid antistripping agents were purchased and specifications of the products as provided by the companies were also obtained. Table 4 shows the list of liquid antistripping agents that have been collected together with their physical properties and chemical names.

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Table 3. Summary of the analysis of variance results for the significant tests (phase I).

Test	P-value	Non-Stripped Sections		Stripped Sections		Discriminant test limit	Probability of being not stripped if observation is less than set limit*
		Average	Standard dev.	Average	Standard dev.		
% Loss of resilient modulus	4.3E-05	38.13	10.01	60.84	23.57	45	75%
% Loss of split tensile strength+ (vacuum saturation)	8.6E-07	41.49	7.65	63.63	18.34	48	80%
% Loss of split tensile strength (no vacuum saturation)	0.00017	32.25	10.03	53.31	24.29	38	73%
Marshall stability loss, %	9.4E-08	20.05	4.77	52.13	25.87	25	80%
% Loss of split tensile strength++ (gyratory compaction)	4.6E-09	38.20	9.26	66.40	17.48	48	86%
Environmental Conditioning System (ECS), after first loading cycle (%)	0.00082	16.67	6.99	32.48	15.80	22	78%
Environmental Conditioning System (ECS), after second loading cycle (%)	0.00455	30.63	10.77	45.94	16.49	37	72%
Environmental Conditioning System (ECS), after third loading cycle (%)	0.01452	42.99	7.40	54.78	17.04	47	71%
Swedish Rolling Bottle value after 12 hrs.	0.02715	36.33	17.52	56.92	12.21	48	75%
Aggregate soundness test	0.0023	7.64	1.65	13.36	4.35	9	83%

*Similarly, the probability of being stripped if observation is greater than set limit.

+Conventional Lottman test.

++Modified Lottman test (AASHTO T-283).

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Table 4. Collected liquid antistripping agents.

S.N.	Product name	Physical state	Recommended dosage (wt%)*	Stability	Chemical name	Flash point
1	Lilamin VP 75E	Liquid	0.2–0.4	heat stable	mixture of alkyl and alkylene amines	120°C
2	WETFIX AD-4F	m.p. 63ºC			fatty amine salt	>150ºC
3	WETFIX® BE	viscous liquid; b.p. >200ºC	0.2–0.5	heat stable (upto 170ºC)	fatty acid + polyamine	>100ºC
4	ITERLENE IN/400-S	liquid	0.2–0.4	heat stable (170ºC)	alkylamido-imidazo-polyamine	>180ºC
5	CECABASE® 260	liquid	0.2–0.4	heat stable	alkylamido-imidazo-polyamine	>100ºC
6	POLYRAM® L200	liquid		heat stable	N-alkyl'tallow' dipropylene triamine	>100ºC
7	EC9194A (EXXON Energy Chemicals)	liquid	0.2–0.4	heat stable (<250ºC)	alkyl imidazoline in aromatic hydrocarbons	
8	ITERLENE IN/400	liquid	0.3–0.6	heat stable (upto 170°C)	alkylamido-imidazo-polyamine	>180°C
9	ITERLENE IN/400-R	liquid	0.2–0.4	heat stable (upto 170°C)	fatty alkylamido-imidazo-polyamine	>180°C
10	ITERLENE IN/400-R-1	liquid	0.2–0.4	heat stable (upto 170°C)	fatty alkylamido-imidazo-polyamine	>180°C
11	MORELIFE 3300	viscous liquid	0.2–0.5	heat stable (upto 150°C)	polycyclo-aliphatic polyamines	170°C
12	POLYBILT	granules	2.0–5.0	heat stable >200°C		>200°C
13	EE-2 Polymer	granules	2.0–5.0	heat stable >200°C	modified olefin	>200°C
14	Cement	powder	2.0–4.0	–	Portland cement	–
15	Lime	powder	2.0–4.0	–	hydrated lime (calcium hydroxide)	–

*weight (%) of the antistripping agent added to the bitumen

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Marshall mix design (as implemented by MOC) has been used to arrive at the optimum asphalt content for the four selected stripped locations. Eleven liquid antistripping agents have been collected from the original manufacturers and administered at the maximum recommended percentage. Moreover, cement, lime and two polymers (Polybilt 101 and Eastman EE-2) were used at a dosage of 4% as recommended by MOC and polymer manufacturers. Work was carried out in two stages. At stage I, the maximum recommended dosages of the antistripping additives were used to quantify the effect of the additive on stripping phenomena and screen the effective additives at their maximum recommended percentage. At stage II, additive combinations of promising mixes were evaluated. Combinations included dry additives (Portland cement and/or lime) and liquid additives or polymers. Liquid additives were not mixed with polymers to avoid adverse chemical reaction between liquid additives and polymers. Modified Lottman test and Swedish Rolling Bottle test after 12 hours were used to evaluate the effectiveness of the different treatments.

Table 5 shows the typical stage I test results of Eastern Province and Riyadh region. The table shows the loss in the indirect tensile strength values, according to modified Lottman test procedure, for all treatment combinations. The results of the second phase can be summarized as follows:

- The behavior of the additive depends on the aggregate source.
- For Hail aggregate, treatments EC9194A, Iterlene IN/400, Iterlene IN/400-R, Polyram L200, CECABASE 260, WETFIX BE, Lilamin VP 75E, Morelife 3300, EE-2 Polymer, cement, and lime were effective in eliminating the stripping potential of the aggregate.
- For Al-Jouf aggregate, only EE-2 Polymer and cement were effective in eliminating the stripping potential of the aggregate.
- For Eastern Province aggregate, only WETFIX AD-4F, EE-2 Polymer, and cement were the effective additives.
- For Riyadh aggregate, only Morelife 3300 and EE-2 Polymer were the effective additives.
- EE-2 Polymer was effective in eliminating the stripping potential of all aggregates from all sources.

It should be noted that it cannot be generalized that a specific liquid additive is effective for specific regions. So, for each type of aggregate, there are specific antistripping additives that are effective in eliminating the stripping potential of the aggregate. However, cement and EE-2 Polymer combinations were effective in eliminating or effectively reducing the stripping potential of all the tested aggregates.

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Table 5. Effect of the different antistripping agents using modified Lottman test.

Antistripping Agent Code	Aggregate Source: Eastern Province (ES_1)					Aggregate Source: Riyadh (RS_2)				
	Initial ITS	Final ITS	Ave. Initial ITS	Ave. Final ITS	Average % Loss	Initial ITS	Final ITS	Ave. Initial ITS	Ave. Final ITS	Average % Loss
Lilamin VP 75E	8.58 10.21 9.91	0 0 0	9.6	0.0	100.0%	9.9 10.4 10.1	0 0 0	10.1	0.0	100.0%
WETFIX AD-4F	9.75 9.43 9.87	5.9 5.7 6.3	9.7	6.0	38.4%	9.8 9.78 10.4	0 0 0	10.0	0.0	100.0%
WETFIX® BE	10.2 9.32 9.39	0 0 0	9.6	0.0	100.0%	10.9 10.34 9.7	0 0 0	10.3	0.0	100.0%
ITERLENE IN/400-S	8.67 8.5 9.22	0 0 0	8.8	0.0	100.0%	10.4 10.21 10.9	0 0 0	10.5	0.0	100.0%
CECABASE® 260	9.9 10.4 10.6	0 0 0	10.3	0.0	100.0%	9.4 9.3 10.3	4.8 4.8 5.6	9.7	5.1	47.6%
POLYRAM® L200	9.28 9.6 10.3	0 0 0	9.7	0.0	100.0%	9.7 9.54 9.5	0 0 0	9.6	0.0	100.0%
EC9194A	8.99 8.87 9.71	0 0 0	9.2	0.0	100.0%	9.1 9.2 9.5	0 0 0	9.3	0.0	100.0%
ITERLENE IN/400	9.01 8.77 8.79	0 0 0	8.9	0.0	100.0%	10.5 10.6 10.2	0 0 0	10.4	0.0	100.0%
ITERLENE IN/400-R	9.27 9.34 9.95	0 0 0	9.5	0.0	100.0%	8.3 7.9 8.6	0 0 0	8.3	0.0	100.0%
ITERLENE IN/400-R-1	9.05 9.56 9.15	0 0 0	9.3	0.0	100.0%	10.7 10.1 10.6	3.4 3.1 3.2	10.5	3.2	69.1%
MORELIFE 3300	9.34 8.7 8.21	0 0 0	8.8	0.0	100.0%	10.1 9.8 10.7	6.8 6.8 7.3	10.2	7.0	31.7%
POLYBILT	10.01 9.87 10.15	0 0 0	10.0	0.0	100.0%	12.4 11.7 13.3	0 0 0	12.5	0.0	100.0%
EE-2 Polymer	11.3 11.51 11.2	7.3 7.23 7.3	11.3	7.3	35.8%	10.8 11 12.1	6.2 6.7 6.8	11.3	6.6	41.9%
Cement	10.77 11.15 11.1	6.5 6.9 6.9	11.0	6.8	38.5%	10.3 9.8 10.8	5.6 5 5.8	10.3	5.5	46.9%
Lime	10.5 10.43 9.8	2.6 2.43 2.5	10.2	2.5	75.5%	9.9 10.1 9.1	2.9 2.1 2.3	9.7	2.4	74.9%
Control	10.5 10.1 10.6	0 0 0	10.4	0.0	100.0%	9.8 8.9 9.3	0 0 0	9.3	0.0	100.0%

6. CONCLUSIONS

This study has achieved the set objectives and the following conclusions were drawn:

1. Modified Lottman test, Marshall stability loss, Environmental Conditioning System (ECS), and resilient modulus loss were effective in distinguishing between stripped and non-stripped mixes. ECS had the lowest significance (P = .00082) among these tests while modified Lottman had the highest significance (P = 4.6E–09).
2. Swedish Rolling Bottle after 12 hours was found to be effective to screen asphalt-aggregate materials for stripping potential.
3. Eastman EE-2 Polymer and Portland cement and their combination proved to be effective with all studied aggregate sources.
4. Morelife 3300 antistripping additive combined with cement was the most effective with Riyadh and Hail aggregates.
5. WETFIX AD-4F combined with cement was the most effective with the Eastern Province aggregate.
6. CECABASE® 260 combined with cement was effective with Al-Jouf aggregate.

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