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Evaluation of Asphalt Stripping Resistance for Different Types of Aggregates and Additives

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ABSTRACT

Stripping is the separation of the asphalt binder film from the aggregate surface due to the action of water. It results from many factors, but moisture or vapor moisture is considered the major reason. Many methods are used to predict stripping and effectiveness of anti-stripping agents. This study was a part of a comprehensive study, which was conducted to solve asphalt road deteriorations in Jordan and conserve natural resources and budgets of road construction and maintenance. To achieve this objective, three types of aggregate (the most used in Jordan) were used: crushed limestone, uncrushed valley gravel and crushed basalt. Asphalt binder of (60/70) penetration and two anti-stripping additives: hydrated lime and a liquid additive (polyamine) were used as well. ASTM (D 3625), Texas boiling test, modified Texas boiling test by stirring and rolling bottle test were run on loose mixtures. Test results have shown that limestone is superior to valley gravel and basalt aggregates. Moreover, lime additive (1.5-2% by weight of aggregate) is better than polyamine (0.75-1% by weight of AC). It was also revealed that aggregate type was the most significant variable affecting stripping. Anti-stripping agents are recommended to be used by the Ministry of Public Works and Housing where stripping potential is high.

KEYWORDS: Asphalt, Stripping, Additives, Boiling test, Rolling bottle test, Visual assessment.

Highlights

* Stripping results from many factors, where moisture is considered the major reason.

* Hydrated lime is an excellent anti-stripping additive.

* Limestone has a better stripping resistance than valley gravel and basalt aggregate

INTRODUCTION

Stripping is a major problem facing highway administrations and agencies. Great efforts have been made and hundreds of research studies were carried out to determine the nature, mechanism and measurement of stripping. Stripping was recognized since 1932 and many anti-stripping agents were identified and used since 1947 (Tunnicliff et al., 1984).

Braik (1987), Kennedy et al. (1983) and Obaidat (1997) defined stripping as a physical separation

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between the asphalt film and the aggregate surface due to the action of water, causing loss of adhesion between the aggregate and the asphalt film. Kandhal and Rickards (2001) defined stripping as the separation and removal of asphalt binder from aggregate surface, occurring due to moisture and/ or moisture vapor.

Kandhal (2001) concluded that many factors affect stripping in asphalt concrete mixes, such as aggregate type, asphalt binder type, mixture design, construction method, temperature variation, moisture and water presence and traffic loads. Each factor has its primary effect and the combined effect with the other factors.

Many test procedures have been developed to predict stripping of asphalt pavement mixtures. However, none of the existing laboratory test procedures is satisfactory to predict stripping with or without anti-stripping additives. Tunnicliff et al. (1984) studied the chemistry of aggregate surface which was considered a significant factor that affects stripping. For example, using basic additives will neutralize the surface of acidic aggregates, such as granite. Hagen et al. (1996) studied asphalt aggregate interactions characterized by Zeta potential (mV) and retained strength for natural and organo-silane-treated aggregates. Hard limestone gave the best results and weak limestone was acceptable.

Taylor and Khosla (1983) reported that there might be five different mechanisms for stripping of asphalt; these may act individually or together. The definitions of the mechanisms of the stripping as suggested by many researchers are given as follows:

1- Detachment: this is the separation of an asphalt film caused by a thin layer of water with no obvious break in the asphalt film (Asphalt Institute, 1981).
2- Displacement: stripping results from the penetration of water into the aggregate surface through a break in the asphalt film. This break may result from an incomplete coating of aggregate or crushing of aggregate during compaction (Kim et al., 1999; Tunnicliff and Root, 1995).
3- Spontaneous emulsification: water and asphalt combine to form an inverted emulsion, where asphalt represents the continuous phase and water represents the discontinuous phase, which results in a total loss of adhesion (Asphalt Institute, 1981; Tunnicliff and Root, 1995; Scott, 1978).
4- Pore pressure: it is suggested as a mechanism of stripping in high-void mixes. Traffic or high temperatures in summer may induce high excess pore pressures causing stripping (Asphalt Institute, 1981; Tunnicliff and Root, 1955).
5- Hydraulic scouring: this results from the action of vehicle tires on a saturated pavement surface and causes water to make a compression – tension cycle due to loading- unloading of tires, which contributes to stripping (Asphalt Institute, 1981).

Many methods are used to increase the bonding and adhesion between asphalt and aggregate, thus reducing the stripping potential. There are many types of anti-stripping additives still in use. Some of them are powders, such as lime and cement and others are chemicals used as liquids. Most of these chemical liquids contain nitrogen in different forms. Merusi et al. (2010) obtained better results for stripping resistance when using wax as an anti-stripping agent. Various additives were used and hydrated lime slurry, when added to aggregates, remains the most effective one. Stripping can reduce the asphalt concrete fatigue life, which leads to permanent cracks (Tunnicliff et al., 1984; Braik, 1987; Khedaywi, 1992; Kandahl and Rickards, 2001).

Watson et al. (2013) conducted field tests on a conventional superpave section that used three different anti-strip agents; hydrated lime, liquid additive and warm-mix asphalt anti-strip and applied multiple 0, 1, 5 and 10 freeze-thaw cycles. The results showed that hydrated lime was the only additive which verified the minimum of 80% tensile strength ratio (TSR).

Wood (2013) studied the stripping occurrence expectancy before the chip seal spread. He found that air voids, permeability and density tests are valid to predict stripping after the use of chip seal. He suggested that nuclear density test is the easiest and least invasive test to predict the stripping of pavements.

Celaya and Nazarian (2007) used portable seismic property analyzer (PSPA) as well as two methods: ultrasonic surface wave (USW) method and impact echo (IE) method. PSPA results and field cores were retrieved (ground-truth data). To predict the extent and depth of asphalt stripping, they recommended using the USW method, which is more effective than the IE method.

In Jordan, as in many countries, no profound research concerning the stripping phenomenon on Jordanian aggregates has been carried out. MPWH spends a considerable budget for maintenance and rehabilitation of road pavements every year due to stripping problems. This research project will be of great significance to the efforts of MPWH in improving pavement construction and maintenance for the Jordanian road network (Kheder, 1991).

Objectives

The objectives of this study can be summarized as follows:

1- To determine the degree of resistance provided by the mixture against the action of water.
2- To compare mixes composed of different types or quantities of asphalt and aggregate for stripping potential.
3- To evaluate the effectiveness of anti-stripping agents in a given mix and determine the optimum percentages.
4- To find the best aggregate types and the additive dosages which conserve natural resources and budgets.

Materials Used

In Jordan, there are four different types of aggregate: limestone, valley gravel, basalt and granite. All of these four types are used in hot mix asphalt pavement construction. Limestone aggregate is the most one used, but due to the high cost of hauling aggregates from one location to another, which exceeds the cost of the aggregate itself, the tendency to use other available aggregate types has become vital. Aggregate characteristics are different and asphalt pavement mixtures are different too. One of the different major characteristics is moisture susceptibility, which reflects the stripping ratio.

This study incorporates the following variables:

1- One type of asphalt binder (AC 60/70).
2- Three types of aggregate (limestone, valley gravel and basalt).
3- Two types of additives (lime and polyamine).
4- Two types of conditioning (moderate saturation and high saturation).
5- Types of tests are: ASTM, boiling test, modified boiling test and rolling test.

The material properties are considered among the major factors affecting the stripping potential of asphalt concrete mixtures. In this study, material properties are tested before running potential stripping tests.

Asphalt Binder

The asphalt binder (AC) used had (60/70) penetration. It was obtained from the Jordanian Petroleum Refinery Company. This type is the main grade used for heavy traffic highway pavements in Jordan. Table 1 presents the properties of the asphalt binder used.

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

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

Aggregates

The aggregates used in this study were delivered from different parts of Jordan. Three types of aggregate normally used in road construction in Jordan are used in this study:

1- Crushed limestone obtained from Shatana quarries southwest of Irbid city.
2- Uncrushed valley gravel obtained from the Jordan Valley quarries.
3- Crushed basalt obtained from Wadi Al-Mojib quarries southwest of Madaba city.

The physical characteristics of these aggregates were tested according to ASTM standard specifications. Table 2 shows the results of these tests which show a comparison between the properties of these aggregates. The gradation of aggregate was passing sieve 3/8 inch and retained on sieve no. 4.

Table 2. Properties of aggregates used in this study

Aggregate size	Aggregate property	Aggregate type		
		Limestone	Valley gravel	Basalt
Coarse, passing sieve 3/8 inch and retained on sieve no. 4	Bulk sp. gr.*	2.491	2.594	2.766
	Bulk sp. gr. (SSD)**	2.561	2.637	2.820
	Apparent sp. gr.	2.679	2.711	2.922
	Absorption (%)	2.810	1.659	1.927
	Abrasion (%)	33.60	24.70	19.70
Total density (Gsb)		2.519	2.605	2.774

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

Anti-Stripping Additives

In this research, two anti-stripping additives were used; hydrated lime and a polyamine liquid with the trading name polyamine. The lime was delivered from the local market and the polyamine additive was imported.

Hydrated Lime

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

Polyamine Liquid Additive (Morelife)

A polyamine agent is a basic liquid additive added to asphalt binder in dosages of 0.25, 0.5, 0.75 and 1.0 percent by weight of the asphalt binder. The manufacturer provides its characteristics; pH test was the only test carried out in this study. The properties of polyamine 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.

Its chemical properties are as follows: (a) it is a polyamine mixed with polycyclo-consisting 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 compatible 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. The physical properties of additives used in this study 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 (cm^2/g)	4850
Sieve number	% Passing
50	94.3
80	49.2
200	14.5
b. Polyamine properties (MPC)**	
Property	**Limit or range**
Odor	Slight
Color	Dark brown / viscous liquid
Kinematic viscosity at 77°F (25°C) cSt	2000-4500
Weight, 1bs/ gal at 77°F (25°C)	8.85 ± 0.04
Flash point, Zeta flash	170° C (338° F)
Pour point, ASTM D-97	7° C (45° F)
Physical state	Liquid
pH (tested)	12.3
Solubility in water	Miscible
Boiling point	716° F (380° C)

* (ALBMIC) Bulletin, 1987.

** Morton Performance Chemicals (MPC) Bulletin, 1996.

Laboratory Work

The moisture effect on asphalt concrete mixtures was evaluated using many variables, including different aggregate types, different additives and different moisture conditions. The manipulation of these variables is discussed here. The tests have been carried out at the Highway Laboratory of the Civil Engineering Department at Jordan University of Science and Technology (JUST).

Three types of aggregate and two types of additives have been designed for testing. Assessment of all stripping tests was a major concern. The incorporation of more than one test is believed necessary to develop the system.

Evaluation of stripping potential of mixtures is thought to be achieved through comparison of standard and dry specimens. Simulation of field conditions is normally hard to achieve. Therefore, saturation is planned to be as found in literature and two degrees of saturation are decided. The tests used in this study aim to predict the stripping potential of the asphalt concrete mixtures based on tests run on loose mixtures (boiling and rolling bottle tests).

Boiling Test

This test is used to give a preliminary indication of moisture susceptibility of the mixes. In this test, the aggregate mix with different % AC with a gradation from 3.5% to 5.5% increased by 0.5% each time is tested to obtain the effect of % AC on the effective film thickness on the aggregate and the obtained mixture is tested under certain conditions. The result obtained is the percent of asphalt coating the aggregate. This result is qualitative and is determined by visual inspection.

This type of test is simple to perform, needs few equipment and is performed in a short time. This test is performed using ASTM D 3625. The mix is immersed in boiling water under certain conditions and the percentage of asphalt retained is estimated visually and used as stripping indicator. The test consists of the following steps:

a) Sample preparation: a (100) gram sample of aggregate passing sieve 3/8 inch and retained on sieve no. 4 was washed and then dried in an oven for 24 hours. The dry aggregate was completely mixed with 5% of the asphalt binder at 160˚C and left to cool at room temperature for 24 hours.
b) Other samples of different lime dosages are added as slurry to the aggregate before heating and mixing was also performed to find the effect of the additive on stripping potential. Also, other samples were prepared with different polyamine dosages and added to the heated asphalt binder with complete mixing before mixing with the aggregate in order to find the effect of the additive on stripping potential. More samples were prepared with different asphalt binder contents to be used to find the effect of film thickness on stripping potential.
c) Boiling time: the coated aggregate was placed in a one-liter glass beaker filled with boiling distilled water and boiled for ten minutes.
d) For a modified test, the coated aggregate was then stirred by a glass rod every 3 minutes and the stripped asphalt film was removed during water boiling by paper.
e) Cooling conditions: the boiled loose mix was then taken out from the beaker, spread on a white paper sheet and left to cool at room temperature to the next day.
f) Estimated stripping: the stripped aggregate was estimated at least by a panel of three engineers or technicians with the nacked eye or by a lens. The retained asphalt on the aggregate surface by each panel member was estimated and the average of the three panel members was taken to calculate the retained asphalt coating aggregate.

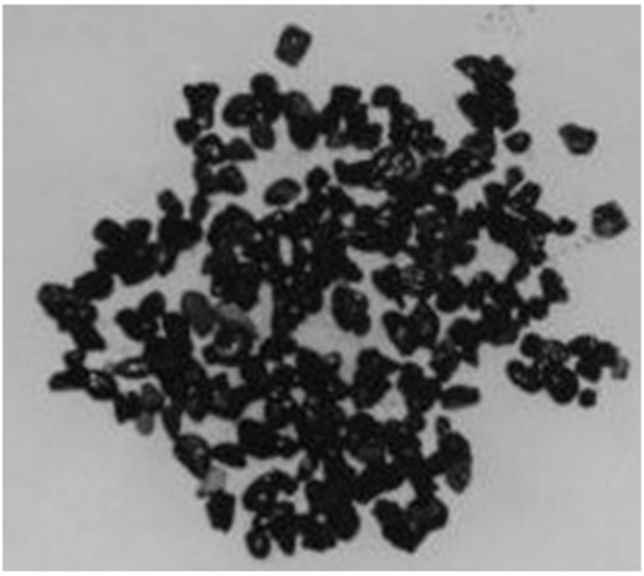
Figure (1) shows the stripped aggregates due to the boiling test. The boiling test procedure is shown in the flow chart illustrated in Figure (2).

Rolling Bottle Test

This test is used to find the retained asphalt percentage on the aggregate by rolling loose-coated aggregate inside a bottle filled with water. This test is proposed as an European standard (Torbjorn, 2002). In the mix, the sample is immersed in water at room temperature conditions and the percentage of asphalt retained is estimated visually and used as stripping indicator. The test consists of the following steps:

a) Sample preparation: 150 grams of aggregate passing sieve 3/8 inch and retained on sieve no. 4 were washed and then dried in an oven for 24 hours. Complete mixing and coating with 3.5% of asphalt binder by weight of the aggregate were carried out at a temperature of 160˚C and the mix was left to cool at room temperature for 24 hours. The optimum polyamine dosages were added to the heated asphalt binder and completely mixed with the aggregate to find the effect of the additive on stripping potential. Another asphalt binder content of 5% was used to find the effect of asphalt binder film on stripping potential.
b) Rolling time: the coated aggregates were put in a one-liter glass bottle filled with distilled water for 6 hours at room temperature.
c) Agitation: the machine was rolled with a speed of 60 rpm at ambient temperature and the glass rod was fixed to the cap of the bottle to help in stirring the coated aggregate. After 6 hours of rolling, water was removed and the rotated-coated aggregate spread on a white paper sheet and then left to cool at room temperature for 24 hours.
d) Estimated stripping: the same method and the same panel of estimators like in the boiling test were used to estimate the stripped aggregate. The procedure of the rolling test is shown in Figure (3).

(a) Group of test specimens



(b) Stripped aggregate

Figure (1): Stripping of specimens by boiling test

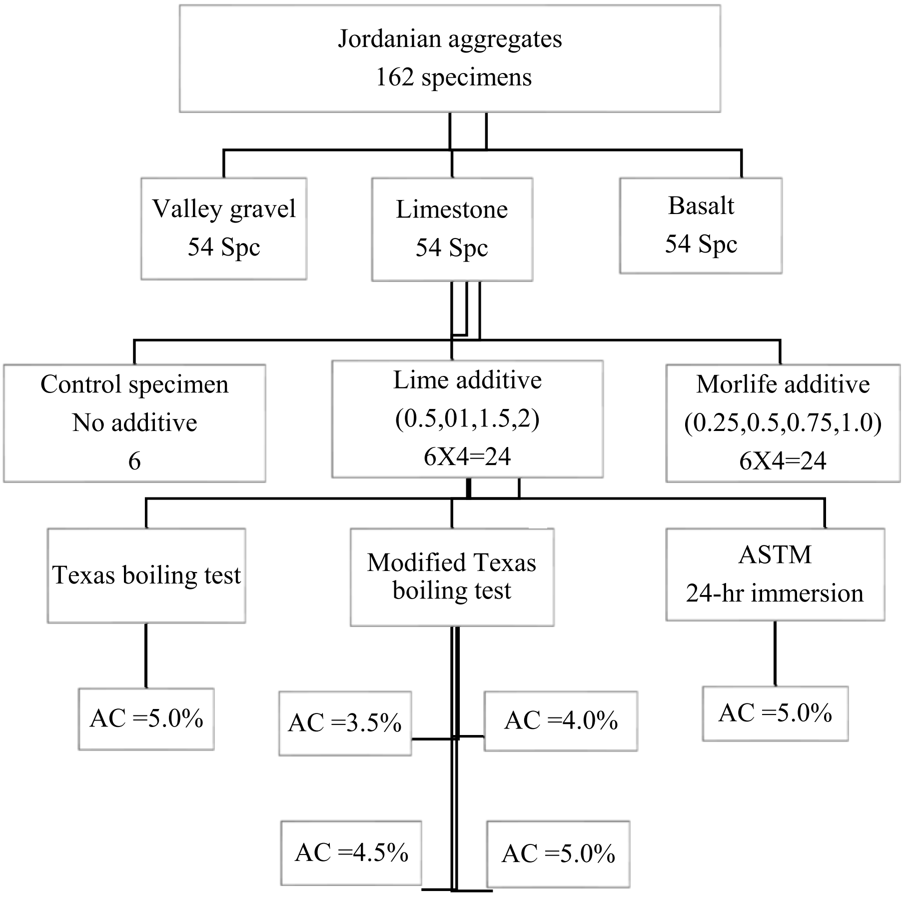


Figure (2): Flow chart for boiling test

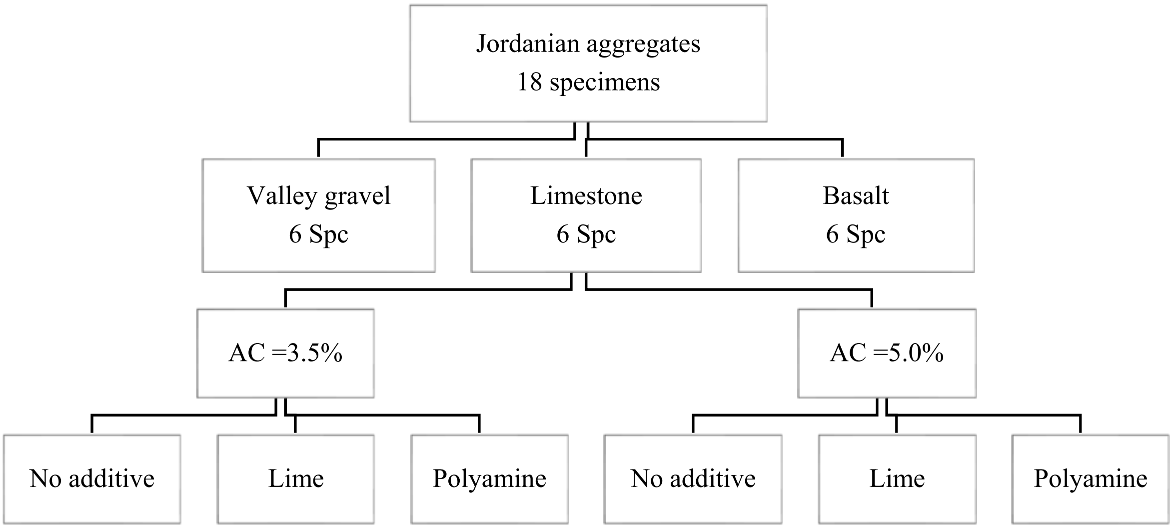


Figure (3): Flow chart for rolling bottle test

Test Results and Discussion

Evaluation of Materials

The purpose of using different types of aggregates and additives was to employ more than one variable that may affect the stripping potential of the Jordanian materials. Literature review furnished a database for the characteristics of some types of aggregates and additives. The results of this research showed good agreement with those in the literature review. A limit of stripping was stated as a percentage of asphalt retained on aggregate as 80%. All aggregate types have shown a tendency for stripping at a high degree of saturation. Limestone was found to have a high stripping resistance. Valley gravel and basalt aggregates were of less stripping resistance. In Jordan, the majority of pavements are made with limestone. Since it is highly resistant to stripping, limestone pavements are expected to be less prone to water attack. Valley gravel and basalt aggregates, although being not commonly used, may resist stripping only if they are treated with additives. The use of additives has shown to be of great effect on valley gravel and basalt aggregates. The use of hydrated lime is economical and simple and it is available in the local market. The liquid additive is hardly available (imported from outside) and sometimes not safe (pH= 12.8), as shown in Figure (4). The required percentages of both additives needed to restore the original stripping potential of each aggregate type are shown in Table 4. These percentages are expected to counteract the action of moisture in places where moisture is not expected to reach a high level.

It should be noted that the percentages shown in Table 4 are suitable for the gradations and materials used in this study. If other gradations or materials are used, other percentages have to be set.

Evaluation of Conditioning Methods

Although it is very hard to simulate field conditions in the laboratory, it was decided to expose the mixtures to a high degree of saturation (condition 2) that would force the mix to strip. A stripper aggregate can be early detected under a low degree of saturation. High degree of saturation was applied to verify that non-stripper aggregate still resists water action. Non-stripper aggregate can resist severe water saturation conditioning regimes. Thus, for high moisture susceptible mixtures, condition 1 and condition 2 provide less difference in the ratios retained. Therefore, the medium degree of saturation (condition1) would be enough to detect stripping. For low moisture susceptible mixtures, the more severe saturation condition (condition 2) may be needed to ensure that the stripping process is fully developed.

Evaluation of Tests

Researchers commonly use standardized tests. For the boiling test, the modified Texas boiling test was suggested; the modification came because of deficiency of the standard test in stirring the mix during boiling. It’s concluded that nine stirrings are suitable to simulate severe action of moisture in the field. The modified test was more able to detect stripping of valley gravel and basalt aggregates, as shown in Table 4-a. The rolling bottle test was time-consuming and gave similar results to those of the Texas boiling test. Therefore, the test could be used as an alternative to the boiling test and not as a supplementary test, as shown in Table 4-b.

Table 4. Percentages of asphalt binder retained

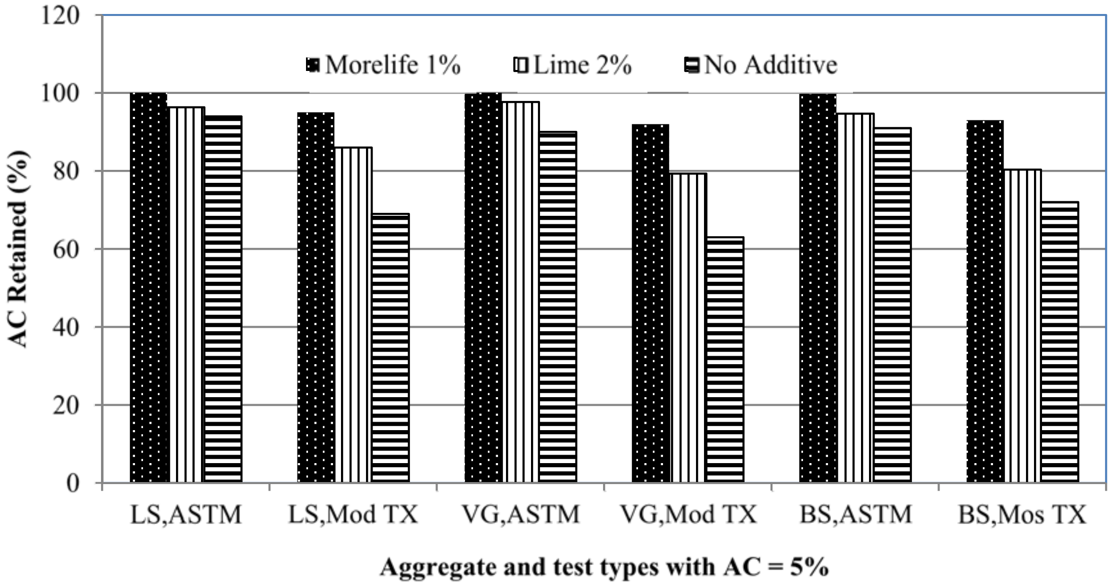
a. Modified boiling test

Aggregate type	Condition/ stirring	AC (%)	Asphalt binder retained (%)		
			No additive	Lime 2 %	Polyamine 1%
Limestone	ASTM	5/Fresh	94	96	100
	Boiling, St.9*	5.0/24h	69	86	95
Valley gravel	ASTM	5/Fresh	90	98	100
	Boiling, St.9	5/24h	63	79	92
Basalt	ASTM	5/Fresh	91	95	100
	Boiling, St.9	5/24h	72	80	93

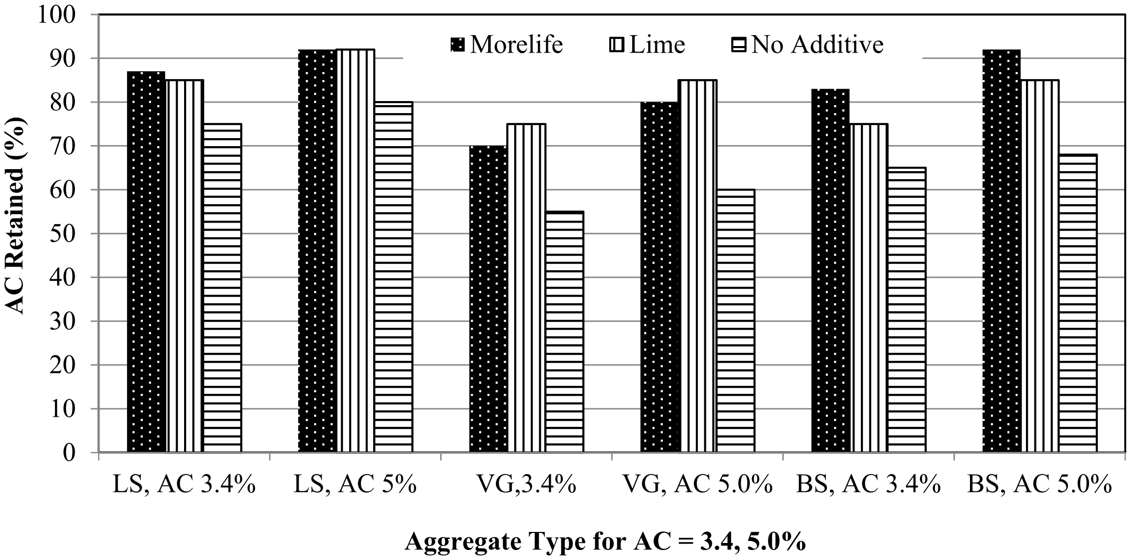
* St.9: Nine-time stirring.

b. Rolling test

Aggregate type	Condition/ stirring	AC (%)	Asphalt binder retained (%)		
			No additive	Lime 2 %	Polyamine 1%
Limestone	6 hr.	3.4	75	85	87
	6 hr	5.0	80	92	92
Valley gravel	6 hr	3.4	55	75	70
	6 hr	5.0	60	85	80
Basalt	6 hr	3.4	65	75	83
	6 hr	5.0	68	85	92



(a): Modified boiling test



(b): Rolling test

Figure (4): Relationship between asphalt retained (%) and (%) AC, (%) lime and polyamine

CONCLUSIONS

The following conclusions can be drawn from this study:

1) Limestone has proven to be a stripping-resistant aggregate and smooth, rounded valley gravel aggregate produces asphalt mixtures of high moisture susceptibility, which agrees with previous research.
2) Basalt aggregate has better resistance to stripping than valley gravel, but lower than limestone.
3) The use of additives was very significant in reducing the stripping potential of all mixtures.
4) In general, it was found that the dosage of lime needed is between 1.5% and 2.0% by weight of the aggregate, where for polyamine, the dosage needed was between 0.75% and 1% by weight of the asphalt binder.
5) Lime additive showed better effect on stripping potential than polyamine (liquid) additive.
6) Visual assessment of boiling test and rolling test is not enough to accurately predict stripping.
7) It is highly recommended for the MPWH to use the additive dosages obtained in this study without any further investigation of stripping potentials of the three types of aggregates used in the study.

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