Validating Newly Developed Criteria of Stripping Prediction Using Egyptian Mixes

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***Abstract*—Many transportation agencies in North America and Egypt have reported that stripping can be a significant issue in most pavement distresses such as rutting, fatigue cracking, ravelling, potholes, and flushing. In addition, Canadian airfield asphalt concrete pavements, especially in the Atlantic, Central, and Pacific regions, show evidence of stripping due to moisture susceptibility. It is recognized that density and in-place air-void content (AVC) are important parameters of a properly constructed asphalt pavement. The first objective of this research was to investigate different factors that may affect stripping evaluation. During the development stage samples representing four Canadian airfield mixes were prepared and tested to investigate the effect of soaking duration, air voids content, and soaking temperature. The results of the air-void investigation, which were compatible with the concept of Pessimum theory, showed that samples should be prepared with an air-void content of more than 8.5%, with a soaking duration of 6 to 8 hours and soaking temperature of 70 °C. The second objective of this research is to validate the developed criteria of stripping prediction on Egyptian mixes. The validation was carried out using Egyptian mixes with five different anti-stripping agents and it showed that the developed stripping evaluation guidelines has the ability to predict the effect of anti-stripping agents on the retained tensile strength of the examined mixes.**

***Index Terms*—Asphalt Mixtures, Evaluation, Field, Laboratory, Stripping, Testing Procedures.**

I. Introduction

Numerous laboratory test methods are designed to identify paving mixtures that are susceptible to stripping. If a material is identified as susceptible to stripping, then the necessary actions can be taken to prevent stripping before it starts. Selecting the most reliable or most effective test method is difficult because the types of pavement distress caused by stripping, such as ravelling or rutting, may be caused by other mechanisms. The most basic requirement of a stripping test is that it always fails mixes that strip in service and always passes mixes that perform well. Pavement performance is adversely affected by stripping and unforeseen increases in maintenance budgets are often incurred. The causes of stripping remain unclear and predictability is relatively non-deterministic. Thus the need to unfold an understanding of the mechanisms and to develop simple but reliable tests and judgment criteria remains urgent. This research discusses the process of stripping prediction and validating the developed criteria on Egyptian mixes.

Current tests for evaluating stripping potential may be divided into three categories: (1) tests that visually estimate stripping, (2) tests that measure the time-to-disruption of mix specimens stressed in some manner in the presence of water, and (3) tests that measure the change in the mechanical properties of mix specimens exposed to water in some type of conditioning scheme (Asphalt Institute 1987). The third category includes the largest number of tests currently being used in practice, such as immersion-compression test, Marshall-immersion test, and the Lottman and Tunnicliff-Root versions of the indirect tensile strength (ITS) test (Kennedy et al. 1983, AASHTO 1989). Other tests that are also widely accepted include the American Association of State and Highway Transportation Officials (AASHTO) or Modified Lottman test (AASHTO 1989), Public Work Government Service Canada (PWGSC) test (CSRP 1996), Ontario Ministry of Transportation Static Immersion Test (MTO 1995), and the Strategic Highway Research Program Test (SHRP 1994, Hassan et al 2002, Mostafa et al 2004, Mostafa et al 2005, Mostafa et al 2006, Halim et al 2006).

In the third category of tests, compacted asphalt-aggregate specimens are exposed to conditioning regimes of varying severity. The ratio of the value of a specific mechanical property, such as compressive strength or tensile strength, measured after conditioning to that measured before conditioning provides the gauge for stripping damage. Air-void content (AVC) plays an important role in stripping evaluation and its criterion varies for different standard tests. For example, AASHTO requires 6-8 %, MTO requires 8-12%, and PWGSC requires the mix design AVC which is normally 3-5%. Also, the conditioning procedure has the same severity of variance between these standard tests in terms of soaking duration and temperature. For example, in the PWGSC test the samples are soaked for 24 hours in 60 ºC, while in the AASHTO test the samples are frozen for 16 hours and then soaked at 60 ºC for 48 hours before being cooled to the room temperature.

For the third category, the degree of susceptibility to moisture-induced damage is determined by testing laboratory specimens according to the required standards. The specimens are compacted to specific AVC, and each set of samples is divided into two subsets of approximately equal air-void contents. One subset is maintained dry (unconditioned) and is used as a control subset and the other subset is treated in water (conditioned). The tensile strength of each subset is determined using the tensile strength test. In addition, the potential for moisture-induced damage is measured by the ratio of the tensile strength of the conditioned subset to that of the control subset. The test procedure for the third category may include one or more of the following steps: sample preparation with a specific AVC, soaking the samples in a 60 °C water bath for a certain duration, cooling the samples in a water bath at 25 °C for certain duration, vacuuming the samples to a certain degree of saturation,

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freeze-thaw cycles, and testing of mechanical properties.

The available test methods range from simple and inexpensive to complex, expensive, and time-consuming. In addition, there is often a lack of correlation between laboratory results and field performance. Therefore, the test results can be affected by the cost, the experience of the personnel performing the test, and, more importantly, the time required to achieve the test. Moreover, it is necessary to have proper knowledge of the unique characteristics of asphalt mixes, including their moisture susceptibility and the factors affecting them in order to solve the problem. The main tests of the third category have been evaluated by the authors and the outcome of the evaluation showed that none of the current standard tests was able to identify strippable from none-strippable asphalt pavement mixes (Hassan et al 2002, Mostafa et al 2004, Mostafa et al 2005, Mostafa et al 2006, Halim et al 2006).

The main objective of this paper was to develop new criteria to enhance the ability of predicting stripping for asphalt pavement mixes and to validate the developed criteria of stripping prediction on Egyptian mixes. The following sections present a background on stripping characteristics, the testing program and results. The analysis of the results is then presented followed by the conclusions.

II. STRIPPING CHARACTERISTICS

Available literature in the field of asphalt pavements agreed that stripping is associated with the presence of water (Hicks 1991). However, since the resistance of asphalt concrete mixes to moisture damage varies from very poor to very good, other factors must be contributing to stripping. The complexity of moisture damage is also evident from the number of factors affecting it such as mix characteristics, conditions process, operation, and construction. The main factors that are expected to most contribute to stripping prediction are:

1) Environment such as degree of Saturation and soaking temperature
2) Using of anti-stripping agents
3) Construction quality such as Air voids content, compaction
4) Materials such as different mixes

Generally, a factor that improves the adhesive bond between the asphalt and the aggregate will also reduce stripping and improving the resistance to moisture damage, and vice versa. Commonly, any of the test methods that can be used to evaluate moisture damage in an asphalt concrete mix have three distinct components (Kandhal 1991): (1) the specimen air-void content, (2) stripping medium which is water or water vapour that the samples submerged in to produce stripping ‘conditioning’ and (3) accept/reject criterion based on the retained strength. It is important to emphasize that the medium temperature and the soaking duration of the conditioned samples are the core of the conditioning process.

Several types of specimens are used in different moisture susceptibility tests. Some tests have adopted a loose specimen of aggregate coated with asphalt cement, while other tests use fully compacted specimens. These specimens, in turn, can be laboratory-compacted briquettes or cores recovered from the field. In addition, these briquettes can be compacted to the design air-void ratio or to a higher ratio depending on the test method used. Experimental results have shown that tests performed on a specific portion of the aggregate gradation (usually coarse aggregate in loose form) may not provide enough information to predict performance (Skog and Zube 1963). Therefore, compacted specimens that closely simulate the pavement in place on the road are traditionally preferred. Brown et al. (1995) have reported that dense-graded hot mixtures should not strip unless there are excessive air voids, moisture, or insufficient asphalt cement. They reported that the most important factor that affects the dense-grade mix is AVC.

Lottman (1995) has reported that the air voids in asphalt pavement might become water saturated even from vapour condensation due to water in the subgrade or subbase. A temperature rise after this saturation can cause expansion of the water trapped in the mixture voids resulting in significant void pressure when the voids are saturated. Furthermore, if asphalt concrete is permeable, water could flow out of the void spaces under the pressure developed by the temperature rise and, in time, relieve the pressure developed. If not, the tensile stress resulting from the pressure may break the adhesion bounds and the water could flow around the aggregate causing stripping. Conversely, open-graded mixes have been observed to have good stripping resistance (Hicks 1992).

Such superficially contradictory observations have been explained using the concept of Pessimum void content (Terrel and Al-Swailmi 1993). According to this concept, pavements that have low AVC are virtually impermeable as the voids are essentially not interconnected, and therefore the pavements are not affected by moisture. However, when the AVC exceeds a critical value, air voids become larger and more interconnected causing the water to flow more easily through the pavement. It appears that stripping can occur in the mid range between these two limits of the air-void content. This range has been referred to as the Pessimum voids (Terrel and Al-Swailmi 1993). The concept of Pessimum void content explained that the mix retained strength is related to the air-void content. Pessimum voids can represent a concept of quantity (amount of voids in a mix) or quality (size, distribution, and interconnection) as they affect pavement performance.

Pavement construction is one of the major factors that influences the performance related to moisture damage of the laid asphalt pavement (Mostafa and Abd El Halim 2004). The in-place AVC of a newly constructed asphalt pavement, which should be 3-5%, is usually constructed at higher AVC (8-10%). The intrusion of water can be greatly reduced when the asphalt mixture is properly compacted to an air void level of 7% or less. A good measure of the susceptibility of an asphalt concrete pavement to moisture infiltration and possible damage is the hydraulic conductivity of the compacted layer. Since stripping is associated mainly with the presence of water, all stripping tests use water or vapour as the stripping medium. Experimental results showed that moisture damage significantly increases with increasing the

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temperature of soaking water (Mohamed and Abd El Halim 1993), where emphasis has been added to warm or hot soaking of asphalt specimens. In addition, short exposures to cold temperature alone can improve the tensile strength of the mix. Finally, the duration of exposure of the specimens to the stripping medium has been subject to disagreement. Although virtually all tests specify soaking duration of one to three days, it has been argued that such short durations are not enough to induce moisture damage that is indicative of field conditions (Fromm 1974). However, although a longer duration of exposure to the stripping medium may be well suited for research purposes, it would severely compromise the practicality of the test as a tool for quality control.

III. TESTING PROGRAM AND RESULTS

Density and in-place air voids are important parameters of a properly designed and constructed asphalt pavement. Selecting the proper compaction level during the mix-design phase is critical for proper pavement performance. In addition, the conditioned samples are affected by the soaking temperature and duration. Therefore, this investigation consists of five stages as follows:

Stage 1: Relationship between compaction effort and AVC
Stage 2: Effect of AVC on Tensile Strength Ratio (TSR).
Stage 3: Examine the effect of AVC on TSR at different soaking temperatures.

Knowing that results of stages 1 to 3 can be found on the previously published papers (Hassan et al 2002, Mostafa et al 2004, Mostafa et al 2005, Mostafa et al 2006, Halim et al 2006)

Stage 4: Examine the effect of soaking duration on TSR.
Stage 5: Verifying the testing procedure using Egyptian asphalt pavement mixes.

The experimental investigation of stages 1 to 4 was designed and carried out at Carleton University, Canada, involved mix selection, sample preparation, and laboratory testing. After consultation with the pavement engineers in the Public Works Service Government Canada (PWGSC), five airfield mixes were selected and supplied by the agency. Three of the mixes were taken from the MacDonald Cartier Airport (Ottawa, ON) and the other two mixes were taken from the Penticton Airport (Vancouver, BC). The mixes were examined for asphalt content, gradation, and other properties. Details of the physical properties and gradation can be found elsewhere (Mostafa 2005). The fifth stage was designed and carried out at Mataria School of Engineering; Helwan University, Egypt, using Egyptian asphalt mixes that known by their susceptibility to stripping with five different anti-stripping agent additives.

There are differences in asphalt content and gradation, especially between Mix 3 and other mixes for both binders and gradation. In addition, Mix 1, Mix 2, Mix 4, and Mix 5 used Modified Performance Graded Binders (PG) 58-34 while Mix 3 used PG 58-28. In summary, for the surface course mixes, Mix 1 is almost the same as Mix 2 except that Mix 2 has dolomite stone aggregate and both are slightly different from Mix 4 and Mix 5 in terms of gradation and asphalt content. The main difference between Mix 4 and Mix 5 is the use of anti-stripping agent (Mix 4 was delivered by the PWGSC from a source known for its susceptibility to stripping). On the other hand, Mix 3 is a base course. On the other hand the fifth stage was carried out using Egyptian surface layer mixes that is known by its susceptibility to stripping (five types of anti-striping agents were tried). The procedure for the fifth stages of the experimental program and the results are presented below.

A. Stage 1: Establishing Relationship between Compaction Effort and Air Voids

The objective of Stage 1 was to develop a relationship between the number of blows and AVC in the specimen for each mix. Fifteen samples were prepared for each mix (Mixes 1, 3, 4, and 5) and divided into five sets where each set represents a different number of blows (compaction effort). The samples were then compacted in standard Marshall moulds to the required air-void content depending on the number of blows (Mostafa and Kandil, 2008 and Mostafa and Ouf, 2010)

B. Stage 2: Examining Effect of Air Voids on Tensile Strength Ratio (TSR)

The objective of Stage 2 was to investigate the effect of different AVC on the retained strength at a constant soaking temperature (60 ºC). The conditioning process was identical for all sets where the samples were soaked at 60 ºC for 12 hours and then cooled at 25 ºC before being tested using the ITS test and the TSR was calculated (Mostafa and Kandil, 2008 and Mostafa and Ouf, 2010)

C. Stage 3: Examining Effect of Different Soaking Temperature on TSR

This stage of the experimental program used samples from Mixes 4 and 5 with three different soaking temperatures: 60 ºC, 70 ºC, and 80 ºC. Since Stage 2 already covered the soaking temperature of 60º C, this stage covered the soaking temperatures of 70 ºC and 80 ºC. The results of this stage were calculated and analysed elsewhere (Mostafa and Kandil, 2008 and Mostafa and Ouf, 2010)

D. Stage 4: Examining Effect of Soaking Duration on TSR

To investigate the effect of the soaking duration in the warm-water bath on the ITS and in turn on the TSR which is a measure of stripping, four mixes with five different sets of samples were prepared: three laboratory samples (Mix 1, Mix 4, and Mix 5) and two field cores extracted from Mix 1 and Mix 2. A total of 120 samples were prepared. The following steps were followed to evaluate the limitations of the PWGSC test and to examine the effect of the warm-water bath duration:

- All sets were soaked into the warm-water bath for different durations (0.25, 0.5, 1, 2, 4, 6, 8, and 24 hours). The samples were soaked in a warm-water bath at 60 °C.
- The mechanical properties of the samples were examined using the ITS test.

The ITS is presented in Table 1 knowing that the control set of samples are those have the soaking duration of 0.25 hour.

Table 1 shows the percent change in ITS with the soaking duration. Most mixes showed insignificant changed between 8 to 24 hours which mean that soaking duration from 6 to 8 hours is more than enough to examine. As is commonly

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known, the PWGSC test procedure requires the unconditioned samples to be immersed in a warm-water bath for 30-40 minutes, which (based on the results of this study) reduces the tensile strength of the examined samples to a minimum of 30% at half an hour, compared to the control set and 70% at 8 hours. Based on the results, it seems to be reasoning to eliminating the soaking of the unconditioned samples in the warm-water bath and shortening the warm-water bath duration for the conditioned samples to 8 hours. In addition, Fig. 1 showed the relationship between soaking duration and ITS and it proved that 8 hours of soaking has the same effect as the 24.

TABLE I. THE PERCENT CHANGE IN ITS.

Redu. %[a]	Lab Mix 5	Lab Mix 4	Field Mix 2	Field Mix 1	Lab Mix 1	Duration Hours
0	0	0	0	0	0	0.25 (control)
-31	-29	-32	-39	-42	-14	0.5
-45	-44	-42	-52	-52	-34	1
-55	-59	-44	-70	-59	-43	2
-58	-59	-51	-64	-71	-43	4
-63	-68	-57	-69	-74	-46	6
-70	-68	-64	-86	-78	-52	8
-72	-73	-65	-88	-78	-57	24

[a]Average reduction %.

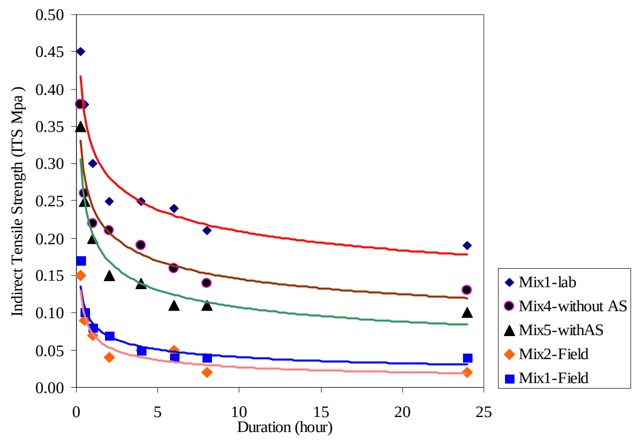

Figure 1. Relationship between soaking duration and ITS.

E. Stage 5: Validating the developed stripping prediction criteria

Conventional additives such as lime were added to the mix with three different percentages of 0.5%, 1%, and 1.5% by dry weight of aggregate. Aggregate –lime mix was left to cure for 15-30 minutes for curing. Hot asphalt was added and the mix was then heated to 160 ºC. Marshall Samples were prepared by applying 75 blows per face representing heavy traffic. The second anti-stripping agent, cement, was tried using three different percentages of 0.25%, 0.5%, and 1%.

Three chemical additives (stearic acid, styrene acrylic, and tilos) were added to the hot mix asphalt. Three percentages (0.5%, 0.75%, and 1%) were tried from each type of the chemical additives. The prepared samples were left to cure for three hours and then heated to 160 ºC before compacted using Marshall compactor. Summary of the results of the fifth stage is presented in Table 2.

TABLE II. THE EFFECT OF ANTI-STRIPPING ADDITIVES ON TSR.

Type of additive	Additive %	Cond.[a] kg	Uncond.[b] kg	Ratio (%)
Control	zero	59	155	38
Cement	0.25	146	154	95
	0.5	138	154.5	89
	1.0	124	165	75
Lime	0.5	136.5	146.5	93
	1.0	136	153	89
	1.5	145	147.5	98
Stearic Acid	0.5	96.5	158.5	61
	0.75	98	153.5	94
	1.0	99	152	95
Styrene Acrylic	0.5	95	167	57
	0.75	91.5	146.5	63
	1.0	94	150	63
Tilos	0.5	121	152	80
	0.75	135	175	77
	1.0	99	165	60

[a]Conditioned.
[b]Unconditioned.

IV. ANALYSIS OF RESULTS

The outcomes of stages one to three showed that the compaction affects the air voids content as well as the soaking temperature affects the stripping prediction. It was recommended that air voids content should be around 8.5% with a tolerance that needs to be determined. In addition; soaking temperature should be 70 ºC to identify the stripping because it was found that above a certain level of air-void content, the probability of identifying stripping is more likely to occur (Hassan et al 2002, Mostafa et al 2004, Mostafa et al 2005, Mostafa et al 2006, Halim et al 2006 and Mostafa and Ouf 2010).

Finally, the change in the ITS slope at different soaking durations was calculated to examine the effect of soaking and decide on the best soaking period at which the duration will not significantly affect the slope (Table 3). The TSR was calculated by dividing the ITS conditioned samples at different soaking duration by the control soaking duration at 0.25 hour. As noted from Table 3, the change in the slope starts with very high value and decreases dramatically as the soaking duration increases. Three hours of soaking causes a loss of 95% of slope change (Δ TSR), six hours of soaking causes a loss of 98%. Moreover, the difference in the rate of change in the slope of the Δ TSR between 8 and 24 hours of soaking is less than 2% which indicates that the effect of soaking will not be effective after six hours. Based on above results, the six- to eight hours of soaking duration in the warm-water bath seems to produce the same effect as the 24 hours.

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TABLE III. RATE OF CHANGE IN INDIRECT TENSILE STRENGTH WITH SOAKING DURATION.

Δ TSR Slope[a] (%)	Average	Lab Mix 5	Lab Mix 4	Field Mix 2	Field Mix 1	Lab Mix 1	Soaking Duration (hrs)
	Rate of Change in the slope of the ITS (KPa /min)						
100	-452.7	-345.8	-1208	-219.6	-177.7	-312.1	0.25
42	-189.9	-142.1	-517.9	-81.8	-70.8	-137	0.5
17.6 [b]	-79.9	-58.4	-222	-30.5	-28.2	-60.2	1
7.4	-33.6	-24	-95.2	-11.4	-11.2	-26.4	2
4.5	-20.3	-14.3	-58	-6.4	-6.6	-16.3	3
3.1	-14.2	-9.9	-40.8	-4.2	-4.5	-11.6	4
2.4	-10.8	-7.4	-31.1	-3.1	-3.3	-8.9	5
1.9	-8.6	-5.9	-24.9	-2.4	-2.6	-7.2	6
1.6	-7.1	-4.8	-20.6	-1.9	-2.1	-6	7
1.3	-6	-4.1	-17.5	-1.6	-1.8	-5.1	8
1.2	-5.2	-3.5	-15.1	-1.3	-1.5	-4.4	9
1	-4.6	-3	-13.3	-1.2	-1.3	-3.9	10
0.6	-2.5	-1.7	-7.5	-0.6	-0.7	-2.2	16
0.3	-1.5	-1	-4.6	-0.3	-0.4	-1.4	24

[a] Average rate of change in the slope of the TSR

[b] Δ TSR slope = 79.9/452.7 = 17.6%.

The analysis of the fifth stage showed that adding anti-stripping agents to the control mix achieved 38% tensile Strength Ratio (TSR) and that percent increased using the conventional or unconventional additives. Using lime and cement achieved retained strength more than 90% while adding stearic acid, stearic acrylic, and tiliot achieved around 60 to 80 %. Generally, it can be stated that conventional additives are more suitable as anti-stripping agents as the required TSR according to all available standards and the approved criteria is not less than 70%. Fig. 2 showed the effect of using anti-stripping agents on the retained tensile strength ratio.

More importantly, the carried out testing program has approved that the developed guidelines have the ability to predict stripping and therefore it is recommended to try it on different Egyptian mixes that are known by its susceptibility to stripping. In addition, using conventional anti-stripping agents enhanced the resistance to stripping more than unconventional additives.

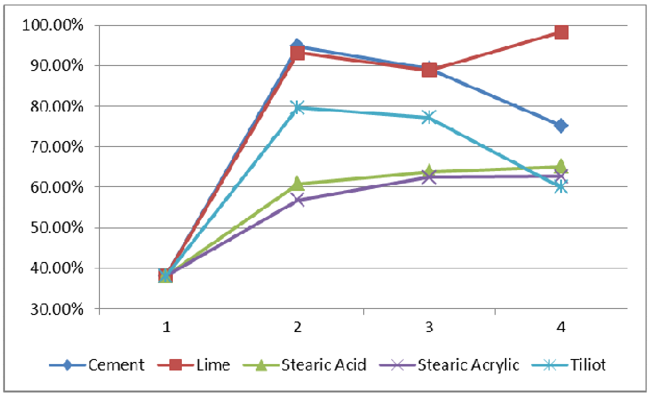

Figure 2. Effect of additives on TSR of the Egyptian mix.

V. CONCLUSION

In practice, the mixture must be constructed to meet tight specifications on density while maintaining the desired air-void content. The density and air-void content can have a significant impact on pavement performance as they cause deterioration in the AC layer. This research was carried out to identify the critical soaking duration in order to evaluate the moisture induced damage for the tested materials. Samples representing four Canadian airfield mixes were prepared and tested at five different AVC for each mix, three levels of soaking temperature, and eight different soaking durations.

Previous publications showed that preparing samples with air voids at 9 ± 0.5 % with soaking temperature 70 °C would be better for stripping prediction, (Hassan et al 2002, Mostafa et al 2004, Mostafa et al 2005, Mostafa et al 2006, Halim et al 2006 and Mostafa and Ouf 2010). Moreover, the results of the effect of warm-water bath duration on TSR showed that the rate of change in the retained strength decreased as the soaking duration increased. After three hours, the change in slope of the TSR for all mixes dropped to 5%, while after six hours it dropped to 2%. These results indicate that six to eight hours of soaking duration in warm-water bath is enough to condition the samples. As a result, if the compaction was not properly performed, water is expected to speed the stripping action. Overall, the recommended criteria of air-void content (9 ± 0.5 %) , soaking duration (6 to 8 hours), and a soak temperature (70 ºC) for the conditioning process of stripping tests are expected to result in better prediction of the moisture induced damage for the Canadian and Egyptian asphalt pavement mixes. It is expected that the results of this research will help improve the evaluation of stripping of asphalt pavements and their field performance. In addition using conventional ant stripping agents such as 1.5% of lime and 0.25 % of cement will

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enhance mixes resistance to stripping.

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