Mansoura Engineering Journal, (MEJ), Vol. 36, No. 4, December 2011. C. 52

Effect of Moisture on Durability of HMA Used in Roads Adjacent to Waterways

تأثير الرطوبه على متانة الخلطات الأسفلتيه المستخدمه فى الطرق المتاخمه للقنوات المائيه

Mohammed El-shabrawy[1], Tarek. A. Saafan[2], Mourad H. Ibrahim[1] and Alaa M. Ali[1]

E-mail: adhmawy@yahoo.com
1-Public Works Engineering Department, Faculty of Eng., El-Mansoura University, Egypt.
2-Irrigation & Hydraulics Department. Faculty of Eng., El-Mansoura University, Egypt

Key Words: Durability, Stability, Immersion, HMA, Waterways

الملخص العربى:

تدور الدراسات التى تبحث فى متانه الخلطات الأسفلتيه المرنه عاده حول كيفية ومدى قدرة تلك الخلطات على مقاومه المياه. و يدور موضوع هذا البحث حول تقنيه جديده لتقييم تأثير المياه على متانة الخلطات الأسفلتيه و خاصة المستخدم منها فى الطرق المتاخمه للقنوات المائيه و من ثم إستنباط معيار جديد لتقدير أداء تلك الخلطات و هو ما إقترح تسميته "مقياس المتانه".

تتضمن التقنيه المقترحه تعريض القوالب القياسيه للخلطات الأسفلتيه المرنه نوعى (٣-د) و (٤-ج) و هما الأكثر شيوعا وإستخداما فى تنفيذ طبقات الرصف الأسفلتى السطحى بمصر فى طريقه مارشال التصميميه إلى سلسله متعاقبه من دورات الغمر فى الماء لأزمنه مختلفه (٦ساعات، ١٢ ساعه، ٢٤ ساعه، ثلاثة أيام ، سبعة أيام) وذلك لمحاكاه ظروف تعرض تلك الخلطات للمياه فى الطبيعه ثم إختبار متانة تلك العينات عقب كل دوره وحساب نسبه النقص فى المتانه و كذلك نسبة التفكك للخلطات .تم تكرار نفس الإجراءات على نفس الخلطات الأسفلتيه المنفذه فعليا فى الطبيعه عن طريق إستقطاع قوالب إسطوانيه من طرق ذات ظروف متباينه من حيث وجود وطبيعة القنوات المائيه المتاخمه لها ثم مقارنة نتائج الإختبارات فى الحالتين.

ولتعيين كفاءة ومتانة الخلطات الأسفلتيه المذكوره تم إختيار و تبنى نموذج رياضى بناءا على معايير محددة و بحيث يحقق هذا النموذج تلك المعايير و قد أشتق هذا المعيار من قيم " الفقدان التراكمى للثبات " عبرالأزمنه المشار إليها. حيث تم تكرار دورات التعرض للمياه و قياس الثبات و التفكك لكل من العينات المعمليه والحقليه حتى الوصول للحد الأدنى للثبات المحدد فى الكود المصرى لأعمال الطرق ٢٠١٠ . و عن طريق هذا النموذج الرياضى أمكن من خلال معيار " مقياس المتانه " التنبؤ بالأداء المستقبلى للرصف بناءا على تحديد المدى الزمنى المتوقع لتعرض تلك الخلطات للمياه فى الطبيعه.

Abstract

Studies on the durability assessment have generally been performed to gain Information on the resistance of bituminous mixtures against water. This paper proposes a new technique to investigate the influence of water on Asphalt Mix Durability and hence developing a new criterion for estimating the performance of the HMA used in roads adjacent to waterways through the "Durability Index".

The proposed method involves subjecting standard Marshall HMA samples of both 3-D and 4-C types, which are the most common-used HMA mixes in Egypt, to cycles of time series moisture-Immersion process at 60°C for 6h, 12h, 1day, 3days, and 7days periods to simulate their exposure to water in field. These samples were then tested for stability and percentage of stripping for each individual period. On the other hand, the same procedures and tests were proceed on field cylindrical samples that core-cut from roads adjacent to waterways under different moisture conditions fortest results comparison.

Based on selected criteria, a theoretical model that fulfills these criteria was adopted to assess the durability performance of the assigned HMA. This parameter is derived from the "*accumulative loss of stability*" values along the above-mentioned time series. It was continued up to the minimum required value for stability as per ECP-2010 reached. This criterion is revealed as the *"Durability Index"* which could be utilized in predicting the future performance and durability of different asphalt mixes intended to be used especially in roads adjacent to waterways.

Accepted December 28, 2011.

1. Introduction

Asphalt paving mixtures are designed primarily for stability and durability [1]. Stability criterion requires paving mixtures to have sufficient initial stability to withstand the applied traffic loads. The durability criterion, however, is concerned with the continued satisfactory performance of paving mixtures under the traffic and environmental factors such as rain and soil moisture to which pavements are exposed during their service lives.

The most pavement design methods are focusing on the selection of pavement structure that will be resistant to traffic and environmental conditions; where one factor that pavement materials are frequently swamped for long time periods by water is not considered significantly. However, this factor of safety in terms of skid resistance and durability in different weather conditions should be concerned, as well as pavement durability related with its endurance to control deformation within its service time.

One of the major reasons for flexible pavement distress and the deterioration of highway serviceability is the low durability potential of the wearing and binder asphalt courses. The durability potential of bituminous mixtures may be defined as "The resistance of the mixture to the continuous and combined damaging effects of water and temperatures". High durability potential usually implies that mechanical behavior of the mixture will suffer for a long service life [2].

2. Literature Review

Durability Meaning and Prediction:

The durability of an asphalt pavement is its ability to resist factors such as changes in the binder (polymerization and oxidation), disintegration of the aggregate, and stripping of binder films from the aggregate. These factors can be the result of weather, traffic, or a combination of both. The mixture should be resistant to changes against:

a. Ageing of the bitumen, i.e. hardening, principally by oxidation and volatilization that causes reduction in adhesiveness and ductility. The result is raveling and/or fracture of the bitumen leading to disintegration of the pavement surface,

b. The influence of moisture; this may result in certain circumstances in failure or loss of adhesion between the bitumen and the minerals.

There are several definitions of "durability". Two of these definitions are [3]:

Durability: is the safe performance of a structure or a portion of a structure for the designed life expectancy. [9].

Durability: is the capability of maintaining the serviceability of a product, component, assembly, or construction over a specified time. [10].

In assessing durability, a mixture is subjected to environmental conditioning, and a mixture property associated with load-related or environmental distress is measured before and after the conditioning process. Abrasion characteristics of the aggregate in the mixture must also be considered in the assessment of durability. The greater the protection by asphalt concrete, more durable the mix will be. The fewer air voids in the total mix, the slower will be the deterioration of the asphalt concrete itself.

Generally, durability of a mixture can be enhanced by three methods. They are; using maximum binder content, using a dense gradation of stripping-resistant aggregate.

and designing and compacting the mixture for maximum impermeability.

3. Research Methodology

In order to achieve this study, the work sequence flow was planned to be as shown in the attached flowchart Figure (3.1)

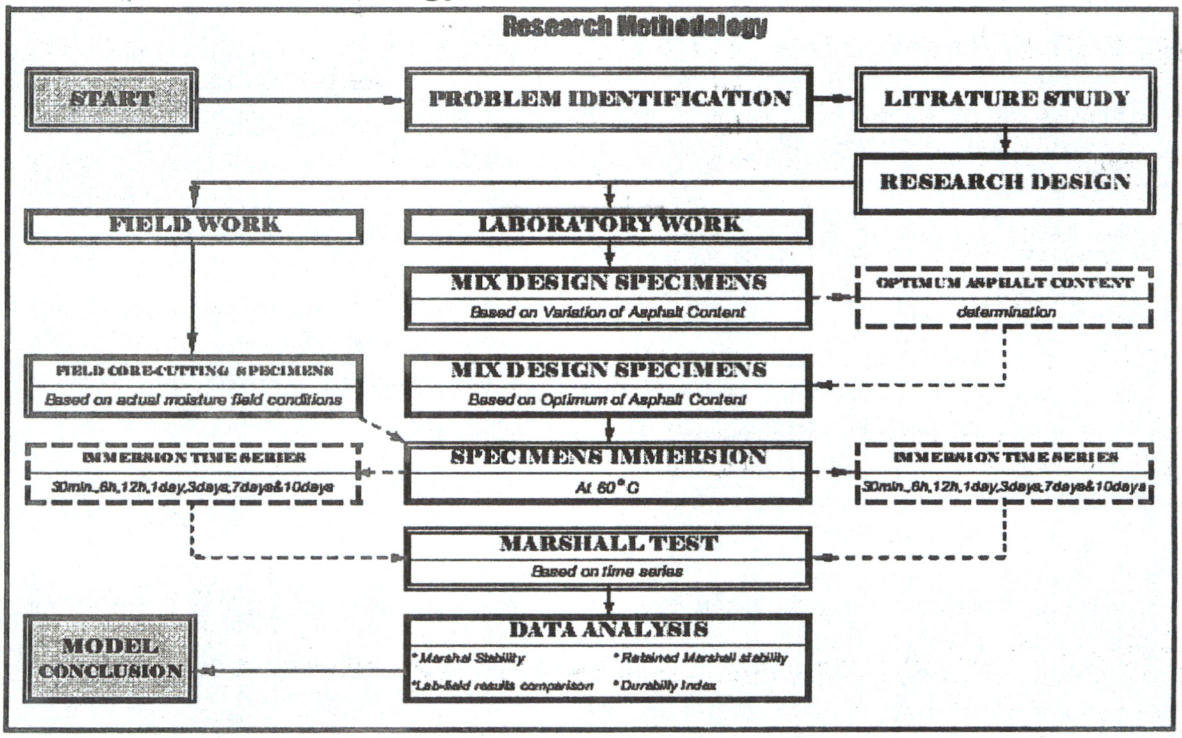

Figure (3.1): Research framework flowchart

4. Experimental work

4.1. Materials reconnaissance

Asphalt Cement: In this study, one type of asphalt cement was used, it was (60-70) penetration grade obtained from Suez Petroleum Refinery. This grade is commonly used for heavy traffic and hot weather conditions in Egypt. Table (4.1) shows tests carried out on asphalt cement, and average results of these tests.

Aggregates: One type, crushed dolomite aggregate with fraction sizes 1" and 2" were used in this study, as they are the most widely types used in asphalt mixes in Egypt. Table 4-2 shows the tests conducted on crushed dolomite aggregate as well as the average test results

Asphalt Mix: Two types, 3-D for binder course and 4-C for wearing course, were considered in this study, as they are the most extensive types used in Egypt. The upper and lower limits of these courses gradation are following the ECP-2010 specification. Tables 4-3 and 4-4 show the blending mix design as well as the obtained Job Mix limits of both types and their compliance to the specifications employed by ECP-2010 as adopted in this research.

Table 4.1: Laboratory Test Results of asphalt cement used in asphalt mix.

	Test	Unit	Specification	Test Results			Average
				Test -1	Test -2	Test -3	
1	Specific Gravity	---	ASTM – D70	1.04	1.03	1.02	1.03
2	Penetration	0.01mm	ASTM – D05	66	67	67	67
3	Flash Point	^{o}C	ASTM – D92	300	302	304	303

Table 4.2: Laboratory Test Results of Crushed Dolomite Aggregate used in Asphalt mix.

	Test	Unit	Specification	Test Results			Average	Specs. Required
				Test-1	Test-2	Test 3		
1	Specific Gravity *(coarse)*	---	ASTM – C127	2.731	2.733	2.733	2.732	N.S.
2	Specific Gravity *(Fine)*		ASTM – C128	2.755	2.753	2.754	2.754	N.S.
3	Specific Gravity *(Filler)*		ASTM – C120	2.780	2.790	2.793	2.788	N.S.
4	Abrasion *(Los Angeles)*	%	ASTM – C131	25	26	26	26	40 Max.
5	Soundness *(MgSo4)*	%	ASTM – C088	9.2	8.9	9.1	9.0	12 Max.

Table 4.3: HMA test result for components blending of A.C. Binder course (type3-D)

Sieve open / Material	1"	3/4"	3/8"	# 4	# 8	# 30	# 50	# 80	# 200	Mixing Ratio
Agg.-2	100	72.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	31%
Agg.-1	100	100	60.7	2.6	0.8	0.7	0.7	0.7	0.4	35%
Sand	100	100	100	99.1	98.9	48.8	4.8	1.0	0.2	31%
Filler	100	100	100	100	100	100	100	98	96	3%
Mix	100	91.5	55.3	34.6	33.9	18.4	4.7	3.6	3.2	
JMF	100	86.5-96.5	50.3-60.3	30.6-38.6	29.9-35.0	14.4-20.0	3.0-8.7	2.0-8.0	3.2-4.0	
Specs.	100	75-100	45-70	30-50	20-35	5-20	3-12	2-8	0-4	

Table 4.4: HMA test result for components blending of A.C. wearing course (type4-C)

Sieve open / Material	1"	3/4"	3/8"	# 4	# 8	# 30	# 50	# 100	# 200	Mixing Ratio
Agg.-2	100	72.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	10%
Agg.-1	100	100	60.7	2.6	0.8	0.7	0.7	0.7	0.4	40%
Sand	100	100	100	99.1	98.9	48.8	4.8	1.0	0.2	43%
Filler	100	100	100	100	100	100	100	98	96	7%
Mix	**100**	**97.3**	**74.3**	**50.7**	**49.8**	**28.3**	**13.6**	**7.7**	**7.2**	
JMF	100	92.3-100	69.3-79.5	48.0-54.7	45.8-50.0	24.3-32.0	13.0-17.6	7.0-11.7	7.2-8.0	
Specs.	100	80-100	60-80	48-65	35-50	19-36	13-23	7-15	3-8	

In preparing each specimen, graded crushed dolomite aggregates were heated to 155-160°C. The asphalt cement was also heated separately to the same temperature and then added to the heated aggregates in the assigned percentages to bring the weight of total mix to 1200g. The aggregates, and asphalt cement were mixed together and then compacted in the Marshall mould at a temperature150±3°C employing 75 blows on each side. Specimens were left to cool at room temperature for one day, and then weighed in air and in water to determine the bulk specific gravity according to ASTM D2726. The specimens were tested for Marshall Stability and Flow after being soaked in water for 30 minutes at 60°C. Average results of tests are given in tables 4.5 for type 3-D binder course and 4-6 for type 4-C wearing course respectively.

Table 4.5: HMA average test result of mechanical properties for A.C.Binder (type3-D)

Criteria	Bitumen (%)	Stability (Kg)	Flow (mm)	Density (kg/cm³)	Air voids (%)	VMA (%)	VFB (%)	Stiffnes (kg/cm)
3-D Mix	4.50	1290	2.95	2.298	4.0	15.0	70.4	4370
Specs.	3.0 – 6.0	Min.700	2 – 4	-----	3.0 – 8.0	Min. 15.0	-----	-----

Table 4.6: HMA average test result of mechanical properties for A.C. wearing (type4-C)

Criteria	Bitumen (%)	Stability (Kg)	Flow (mm)	Density (kg/cm³)	Air voids (%)	VMA (%)	VFB (%)	Stiffnes (kg/cm)
4-C Mix	5.20	1051	3.30	2.344	3.55	15.5	87.0	4570
Specs.	4.0 – 7.5	Min 900	2 – 4	-----	3.0 – 5.0	Min. 15.0	-----	-----

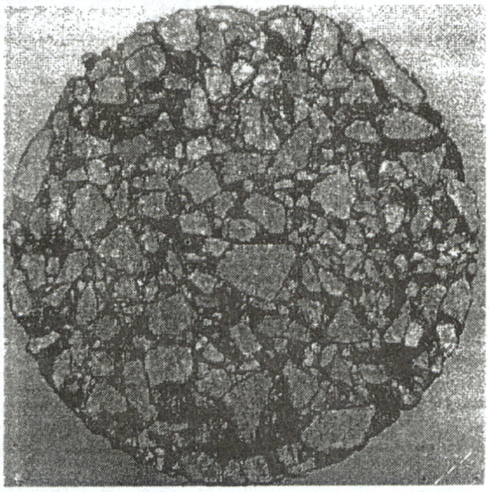

Figure (4.1a): Open-graded 3-D type HMA

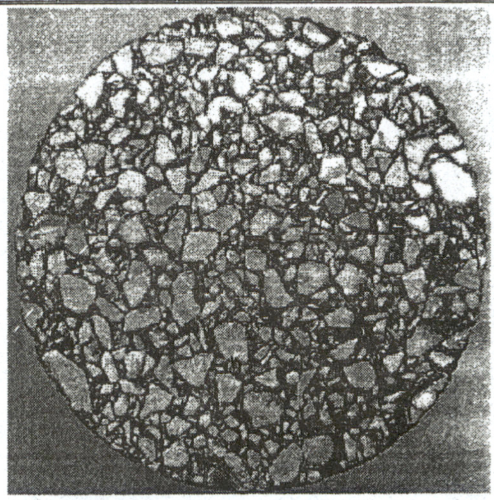

Figure (4.1b): Dens-graded 4-C type HMA

The cross section of the specimen tested for both types of mix are shown in Figures (4.1a) for 3-D binder mix, which appears coarse and open graded while Figure (4.1b) shows a tested specimen of 4-C wearing mix that seems to be dense-graded.

The Modified Marshall Immersion Test: In many cases, mixtures passed the standard Marshall Immersion criterion *(75% retained strength after 24 hrs immersion on 60°C)* but they may failed completely after longer periods of immersion or deteriorated rapidly under actual service condition [5]. The "Modified Marshall Immersion" **(MMI)** test is an examination of the durability of standard specimens with different asphalt contents that immersed in the water at 60°C for longer periods and searched for a quantitative parameter or index to characterize the entire durability potential over the immersion period.

The test data were evaluated using two parameters, i.e. the Marshall Index of Retained Stability and the Durability Index. The Marshall Index of Retained Stability is used to evaluate resistance to water damage and the efficiency of binder-aggregate adhesion. In addition, indices of retained stability obtained using modified Marshall immersion procedure was also used to evaluate the trend of mechanical properties of the specimens over the period of immersion. The Durability Index was developed to obtain a single quantitative parameter that can represent the durability characteristics over the period of immersion.

Stripping: The general definition of stripping is the breaking of the adhesive bond between aggregate surface and asphalt cement in an asphalt mixture [7].

It depends on many variables, including the type and use of the mix, asphalt type, aggregate nature and traffic characteristics. However, the presence of moisture is the common factor for all stripping reasons.

The mechanism of stripping damage due to void water pressure and external cyclic stresses (by traffic) is internally occurred in the specimens; the exterior of the specimens does not show considered stripping damage. Stripping usually appears when the specimen is splitting up for visual examination as shown clearly in Figure (4.2)

Figure (4.2a): Sample subjected to dry conditioning

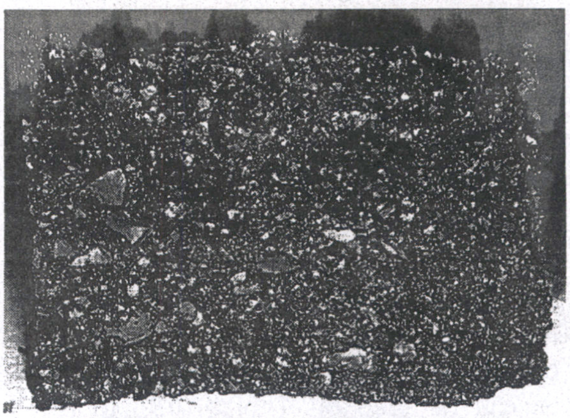

Figure (4.2b): Sample subjected to wet conditioning

5. Field work

In this study, two roads adjacent to waterways were selected to be studied. The first is *"El-Mansoura-Belqas"* road, which is 7.5 m wide with ***one-sided*** waterway, while the other was *"El-Mansoura-Dekernes"* road that 9.0 m wide with ***double-sided*** waterway. A length of 1.0 km of each road was assigned and two slabs of 35x35 cm were cut for testing against gradation and percentage of binder for each road. In addition, six cores staggered in plan were taken to verify stability, flow, and degree of compaction for each road. Tables 5.1 to 5.4 summarize the compliance and average test results of extraction and mechanical properties for both roads.

Table 4.9: HMA field test result for extraction of A.C. Binder course (type3-D)

Sieve open / Material	*1"*	*3/4"*	*3/8"*	*# 4*	*# 8*	*# 30*	*# 50*	*# 80*	*# 200*
Mix	100	86.0	60.1	36.6	29.6	19.9	8.2	4.5	3.3
Specs.	**100**	**86.5-96.5**	**50.3-60.3**	**30.6-38.6**	**29.9-35.0**	**14.4-20.0**	**3.0-8.7**	**2.0-8.0**	**3.2-4.0**

Table 4.10: HMA field average test result of mechanical properties for A.C.Binder (type3-D)

Criteria	*Bitumen (%)*	*Stability (Kg)*	*Flow (mm)*	*Density (kg/cm³)*	*Compaction (%)*	*Stiffness (kg/cm)*
3-D Mix	**4.62**	**890**	**3.20**	**2.228**	**97.0**	**2780**
Specs.	*4.25-4.75*	*Min.700*	*2 – 4*	-----	*Min. 97%*	-----

Table 4.12: HMA test result for extraction of A.C. Wearing course (type4-C)

Sieve open / Material	1"	3/4"	3/8"	# 4	# 8	# 30	# 50	# 100	# 200
Mix	100	91.6	75.5	53.1	45.9	30.6	16.2	10.6	7.8
Specs.	100	92.3-100	69.3-79.5	48.0-54.7	45.8-50.0	24.3-32.0	13.0-17.6	7.0-11.7	7.2-8.0

Table 4.13: HMA field average test result of mechanical properties for A.C.Binder (type4-C)

Criteria	Bitumen (%)	Stability (Kg)	Flow (mm)	Density (kg/cm^3)	Compaction (%)	Stiffness (kg/cm)
4-C Mix	**5.12**	**870**	**3.85**	**2.346**	**100.1**	**2260**
Specs.	4.95-5.45	Min.900	2 – 4	-----	Min. 97%	-----

6. Testing and Investigation

In this study, five periods of immersion were used, i.e. 6 hrs, 12hrs, 1, 3, and 7 days. Three specimens for each proposed period were prepared and then immersed in water at 60°C. After immersion, the Marshall Stability was measured, and then compared with the control stability values as can be seen on Tables (6.1) to (6.4). After each specimen is tested, it was split longitudinally to assess the percentage of stripping. Using these indices of retained strength and percentage of stripping, graphs of immersion period versus percent-retained Marshall Stability and percentage of stripping were then plotted as shown in Figures (6.1) and (6.2). Using the Marshall Index of Retained Stability, all of the results of the modified Marshall Immersion tests are comply with the specification, i.e. minimum 75% of standard stability after one day.

Table 6.1 Laboratory: Modified Marshal Immersion test results for (3-D) class HMA

Immersion time	Number of specimens	Stripping (%)	Min. Required Stability (Kg)	Laboratory Stability (Kg)	Immersed Stability (Kg)	Retained Stability (%)
6 h	3	5.0	700	1290	1245	96.5
12h	3	8.0			1405	109.1
1 day	3	10.0			1090	84.5
3 days	3	15.0			960	74.5
7 days	3	25.0			*625*	48.3

Table 6.2: Laboratory Modified Marshal Immersion test results for (4-C) class HMA

Immersion time	Number of specimens	Stripping (%)	Min. Required Stability (Kg)	Laboratory Stability (Kg)	Immersed Stability (Kg)	Retained Stability (%)
6 h	3	2.0	900	1050	1055	100.5
12h	3	5.0			1045	99.5
1 day	3	8.0			985	93.8
3 days	3	15.0			*924*	88.0
7 days	3	20.0			715	68.3

Table 6.3: Field Modified Marshal Immersion test results for (3-D) class HMA

Immersion time	Number of specimens	Stripping (%)	Min. Required Stability (Kg)	Field Stability (Kg)	Immersed Stability (Kg)	Retained Stability (%)
6 h	3	2.0	700	895	900	101.0
12h	3	5.0			910	102.5
1 day	3	8.0			*695*	77.6
3 days	3	15.0			560	62.5
7 days	3	20.0			490	54.9

Table 6,4: Field Modified Marshal Immersion test results for (4-C) class HMA

Immersion time	Number of specimens	Stripping (%)	Min. Required Stability (Kg)	Field Stability (Kg)	Immersed Stability (Kg)	Retained Stability (%)
6 h	3	3.0	*900*	870	880	101.0
12h	3	6.0			795	91.5
1 day	3	10.0			730	83.6
3 days	3	17.0			500	57.5
7 days	3	27.0			225	51.5

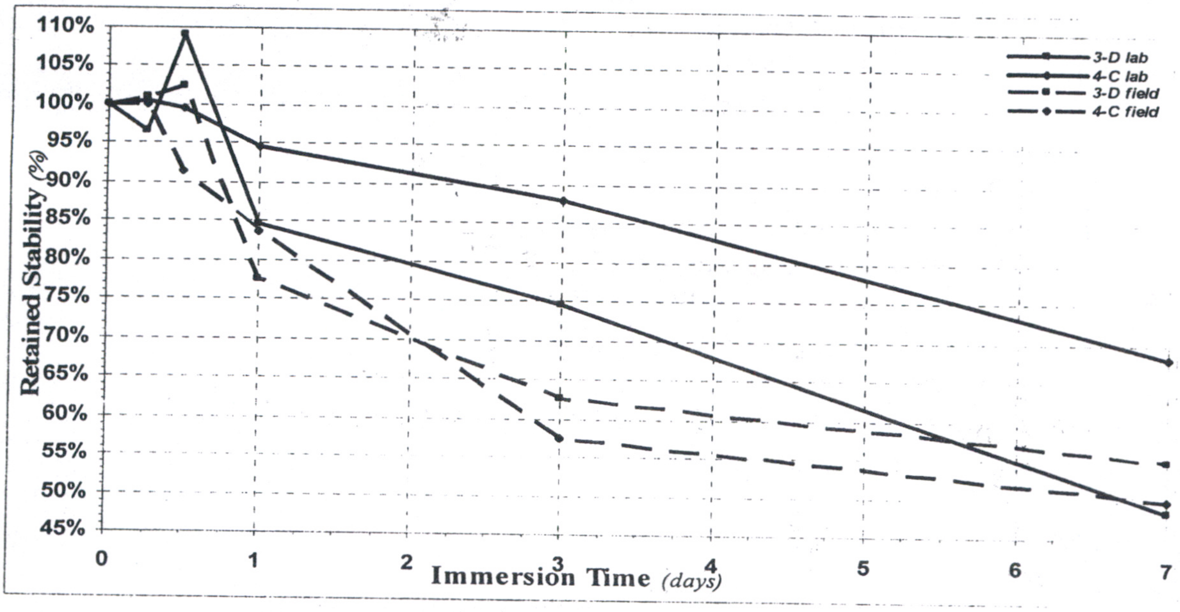

Figure (6.1): HMA Retained Marshall stability VS Immersion time

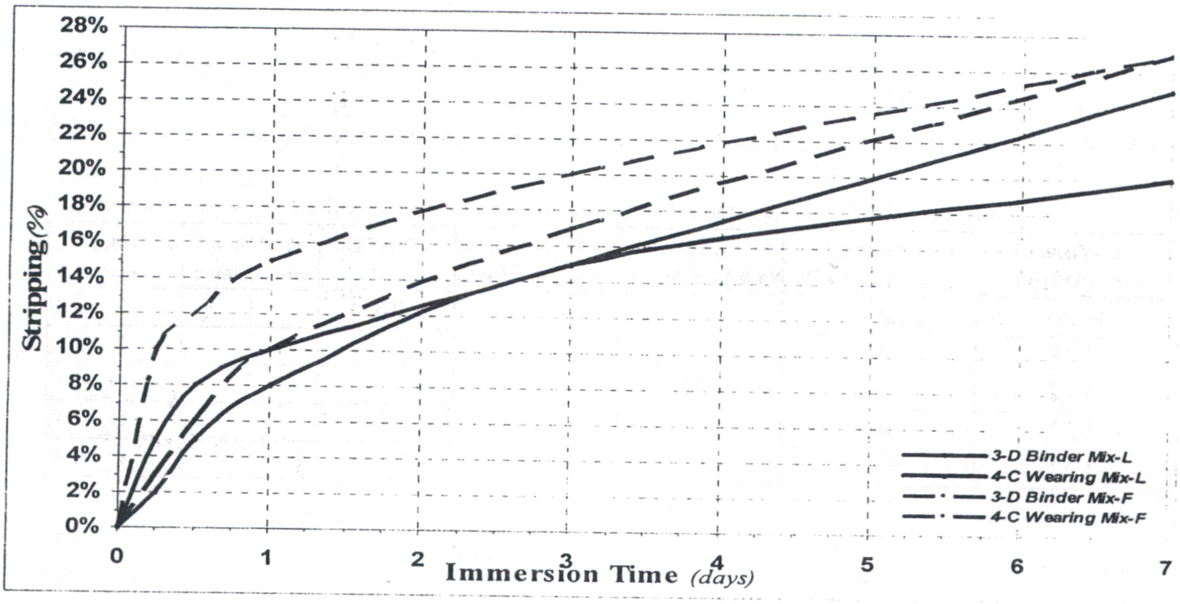

Figure (6.2): HMA Percentage stripping VS Immersion time

7. Theoretical Approach

Marshal Stability: Marshall Stability is calculated from the equation [7]:

$$S_o = R \times o \times T \qquad (7.1)$$

Where;

S_o= Standard absolute Marshall Stability (lbs).

R = Stability timepiece reading on Marshall Test (lbs).

o = Proving ring calibration factor.

The primary use of Marshall Stability is in evaluating the change in stability with increasing asphalt content to aid in assessing the optimum asphalt content.

Retained Marshall Stability (RMS): The Retained Marshall Stability is expressed as a percentage and is defined in terms of the Marshall Stability of the composition after an immersion process as a percentage of the initial (absolute) Marshall Stability of the composition. The RMS values were determined as follows:

$$RMS = \frac{Si}{So} \times 100\% \qquad (7.2)$$

Where;

RMS =Retained Marshall Stability (%)

Si =Maximum stability in conditioned set based on times series

S_o =Maximum stability in unconditioned set (0 days)

In several research works, the durability potential of bituminous mixtures was characterized by testing the mixture during and after longer periods of immersion (extended up to 100 days), using destructive and non-destructive tests. In this research, the relative comparison of the durability curves (retained strength VS. immersion period) was used to characterize the durability behavior of the different mixtures under various moisture conditions.

Durability Index (DI): From the above point of view, it was felt necessary to find a single quantitative parameter that would characterize the entire durability curve. The following criteria were assessed for the desired "***Durability index***".

- It should be rational and physically defined.
- It should express both present retained strength and its absolute value.
- It should define the durability potential for a flexible immersion periods.
- It should properly weight the relative contributions of the different increments of the immersion period of the entire durability curve.

Several indices were tried and applied to the durability curves of different mixtures. One index was found to satisfy most of the criteria listed above; hence, it was adopted for the analysis of the durability test data in this research. This index is defined by J. Craus, and I. Ishai as "*the sum of the slopes of the consecutive sections of the durability curves*". Based on Figure (7.1), this Index (r) is expressed as follows [5]:

$$r = \sum_{i=0}^{n-1} \frac{S_i - S_{i+1}}{t_{i+1} - t_i} \qquad 7$$

Where;

r = Durability Index

S_i = Percent retained strength at time t_i

S_{i+}= Percent retained strength at time t_{i+1}

t_i, t_{i+1}= immersion periods (from beginning of test) specifically.

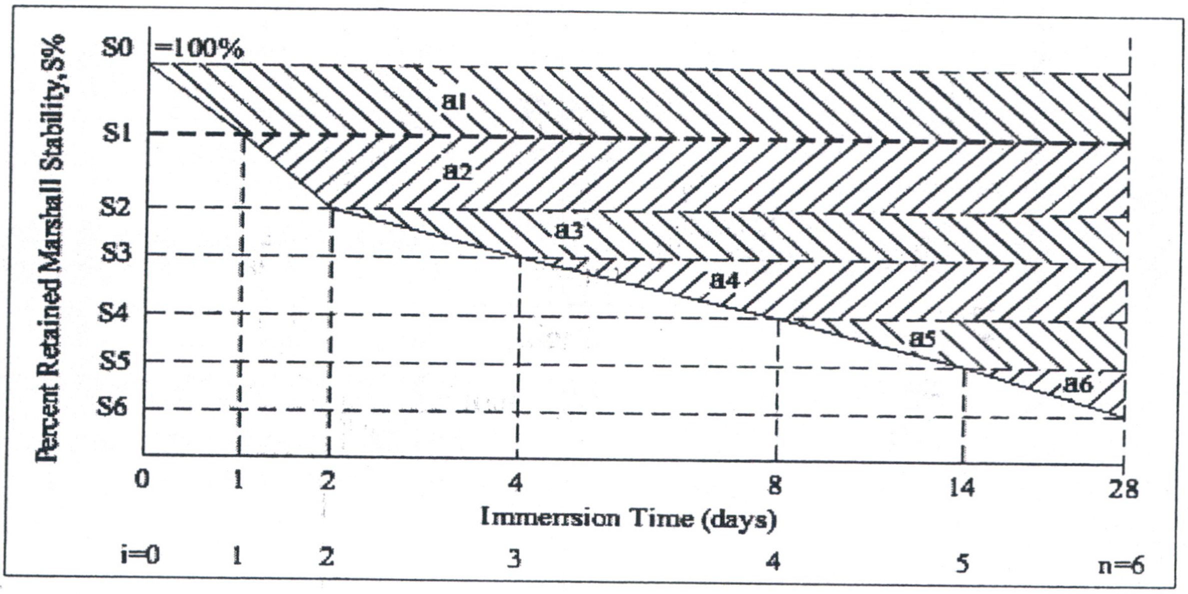

Figure (7.1) Schematic Description of Durability Curve, with Parameters defining Durability Index

when strength measurements were taken after 1, 2, 4, 8, 14, and 28 days of immersion, equation (7.3) was as follows [4]:

$$r = \frac{s_0 - s_i}{1} + \frac{s_1 - s_2}{1} + \frac{s_2 - s_3}{2} + \frac{s_3 - s_4}{4} + \frac{s_4 - s_5}{6} + \frac{s_5 - s_6}{14} \quad (7.4)$$

Practically, the durability index expresses the **percentage loss in strength** as weigh for one day. Positive values of (r) indicate strength loss, while negative values indicate strength gain. It is also possible to define the durability index in terms of the absolute values of the weighed loss in strengths (R) as follows [5]:

$$R = \frac{r}{100} s_0$$

Where;

R = the absolute values of the weighed loss in strengths

s_o = the absolute value of the initial strength.

8. Analysis and Discussion

Figures 6.1, 6.2 and tables 6.1 to 6.4 present the durability and stripping curves as a function of immersion time and Marshall Stability criteria. These curves serve as a basis for the analysis of the moisture factor, which influence the durability characteristics of the HMA mixtures. It is meant here to point out that the loss of stability after first day of water immersion (15.5%, 10.1%) was grater than the percentage lost during the next three days of immersion (6.2%, 5.8%) for laboratory prepared mixes. A different attitude was reported for the field core-cut mixes in the way that the loss of stability in the first day was the same as laboratory prepared for 3-D type (22.3%, 15.3%) while adverse attitude was noticed for 4-C type (16.1%, 26.4%) which may be refer to field compaction resulted from local traffic effect beside the surface sealing of core-cutting process during field sampling that may delay the effect of water penetration .

The influence of immersion time on retained stability is different for the two mixtures. After 6 hours immersion, no loss of stability is apparent for 4-C type specimens while the stability of 3-D type specimens is reduced to 96.5% of standard stability. Mixes of 3-D Asphaltic Concrete exhibit an improvement in retained stability by about 9% after a half-day immersion period. This might be caused by saturated pores of moisture that may create an improvement of strength temporarily while the 4-C wearing type persists around the same value of stability. The 3-D type AC curve decreases after 1 day (24 hours) and drastically drops after more than 3 days. The drop of the AC curve is caused by the fact that the water absorbed by the specimen increases and penetrates into the bitumen-aggregate interface and the pores. The presence of moisture at the interface and in the pores eventually leads to the stripping of bitumen from the surface of the aggregate and causes a reduction in specimen stability. If the time of immersion is extended, (up to 90 days), the specimen may disintegrate; except if the water temperature used is not 60°C, (e.g. at ambient temperature), there may only be a little further reduction in stability [8].

The trend for the 4-C curve is to increase less sharply as compared with the 3-D AC mixture, and then to decrease after 3 days at relatively long periods of immersion, i.e. 7 days, the 4-C mixture exhibits a superior durability potential and lower sensitivity to length of the immersion period. This is indicated by the trend of the curve at immersion periods longer than 3 days immersion when it remains relatively constant.

Applying equation (7.4) on test results obtained as shown in Figures (6.1) through (6.4), the **D**urability **I**ndex for the different cases will be as shown in Table 7.1,

Table 7.1: Durability Index for different types and cases of HMA

HMA		**Durability Index**	**Loss in strength**
Type	***Source***	***r (%)***	***R (kg)***
3-D Binder	Lab.-Prepared	**17.5**	225
	Field-cut	**41.4**	370
4-C Wearing	Lab.-Prepared	**11.5**	120
	Field-cut	**57.6**	500

The above obtained results presents the values of the ***Durability Index*** as defined in Equation 7-4 and 7-5 and determined from the durability curves representing the Marshall Stability criterion. It can be seen that a whole durability curve can be represented by a single durability index value.

9. Conclusions and Recommendations

This laboratory investigation presented a study of the influence of gradation types (3-D & 4-C), and immersion times (0-7days) on the durability of asphalt concrete mixtures, using dolomite aggregates in which both were following ECP2010 specifications. It was clear that both gradation type and immersion time are greatly affecting the durability of the mixes.

- The immersion time has a marked effect on the durability of asphalt concrete mixtures, when this is assessed by the Marshall Stability tests. In general, the values of Marshall Stability decrease with increase in immersion time. The stability falls rapidly in the first day and gradually after that.

- It also found that the binder mix is more affected by moisture-Immersion action and hence gave a bigger value of (R) due to the open graded nature of the mix, which led to higher interaction of water in case of lab. prepared specimens.

- The durability of asphalt concrete mixtures has a much more basic meaning beyond the standard one-day immersion criterion, by testing the immersion samples at least for 7 days. It was evident that the 7 days water immersion period was more applicable than the one-day period on calculating the durability indices (R) and (r); which reflect the better classification of loss of stability and decrease in durability of asphalt concrete mixtures.

- The gradation types have an effect on the durability potential of the mixtures, particularly for a long period of immersion. Durability potential was proved better in case of 4-C gradation type, for a longer period of immersion time.

- It is recommended to incorporate the ***Durability Index*** as mentioned and calculated above into the ECP to predict the future durability of the mixes intended to be used.

10. References

1. Kanitpong, K., H. U. Bahia, C. H. Benson, and X. Wang. Measuring and Predicting Hydraulic Conductivity (Permeability) of compacted Asphalt Mixtures in the Laboratory. Presented at 82nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.

2. Lantcperg U.C, Road Highway and Parking, Moscow, 2008.

3. R. Christopher Williams and Tamer M. Breakah, Evaluation of hot mix asphalt moisture sensitivity using asphalt test equipment, the Iowa Highway Research Board (IHRB Project TR-555) 2010.

4. Standard Specification for Transportation Materials and Methods of sampling and testing, Fifteenth Edition, Part II Tests, Adopted by the American Association of state Highway and Transpiration officials. 1999.

5. Craus J., Ishai I and Sides A., Durability of bituminous paving mixtures as related to filler type and Properties; Proceeding of the Association of Asphalt Paving technologies Vol. 90, 2001.

6. Cooley, L. A., and E. R. Brown, S. Maghsoodloo. Development of Critical Field Permeability and Pavement Density Values for Coarse-Graded Mixtures Pavements. NCAT Report No. 01-03. Auburn University. National Center for Asphalt Technology, 2010.

7. Taylor, M.A. and Khosla, P.N Stripping of Asphalt Pavement: State of the Art, Transportation Research Record 911, pp. 150-158. 2008.

8. Syukri The Influence of Salt Water on The Durability of Hot Rolled Asphalt Mixtures, M. Sc. Thesis, Institut Teknologi Bandung. (2009)

9. ASTM E241 - 09 Standard Guide for Limiting Water-Induced Damage to Buildings (2009)

10. ASTM E632-82 Standard Practice for Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials (2005).