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LABORATORY EVALUATION OF MOISTURE DAMAGE AND DURABILITY OF HOT MIX ASPHALT (HMA)

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Abstract: The increasing of road material demand particularly on mineral filler and additives has been followed-up by finding the new alternative materials. Local materials such as Portland cement, and lime may potentially use to substitute current need. Therefore, it is essential to study the performance and durability of these materials in HMA mixture. To find the durability index, the specimens are immersed around 0 (unconditioned) to 14 days at 60ºC and tested by using Marshall and ITS tests. Based on Marshall test, the index values for mixes variations; DCF, DPC, DL, DPF, and DC are found to be; 42.965%, 36.59%, 36.582%, 35.68%, and 33.42% respectively.

Keywords: *Durability, Cement, Lime, performance*.

تقييم مختبري لأضرار الرطوبة و الديمومة للخلطة الاسفلتية (HMA)

الخلاصة: أن زيادة الطلب على مواد انشاء الطرق و بصورة خاصة لانواع المادة المالئة المستخدمة في الخلطة الاسفلتية و كذلك المضافات دفع لأيجاد مواد بديلة. ان المواد المتوفرة محليا كالأسمنت البورتلاندي و الجبس يمكن ان تكون بديلا للحاجة الحالية. لذلك، فمن الضروري دراسة أداء وديمومة هذه المواد في الخلطة الاسفلتية. للحصول على مؤشر قوة التحمل، العينات تم غمرها لمدة 0 (غير معرض للغمر) الى مدة 14 يوما في درجة حرارة 60ºC و فحصها باستخدام طريقة مارشال. قيم المؤشر للخلطات المختلفة التي تم استخدامها هي DCF, DPC, DL, DPF, DC هي 42.965%, 36.59%, 36.582%, 35.68%, and 33.42% تباعا.

1. Introduction

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 the pavement materials frequently inundated for long time periods are by water. However, this factor of safety in terms of skid resistance and durability in different weather conditions should be concerned, and also pavement durability related with its endurance to restrain deformation within its service time.

This research is to improve durability characteristics and asphalt stability of hot mix asphalt using different types of mineral filler (Rock dust for control specimen, Portland cement, and Lime) and Polyethylene polymer as an additive. In this research the boundary conditions were used as mentioned below:

1. This research was used Marshall Test.
2. This research is a study on the durability behavior of hot mix asphalt (HMA).
3. Durability behaviors were studied as Marshall Properties (Marshall Stability value and Retained Marshall Stability value).
4. The optimum asphalt content 4.7%
5. The used crushed aggregate obtained from Al- Nibaie quarry.
6. The outcomes are observation result of pavement characteristic in Transportation Laboratory, Highway & Transport Eng. Department, Al-Mustansiryah University.

2. Experimental Work

2.1 Material

Materials were that used in this research are locally available in Iraq and used in road works. The coarse aggregate is brought from Al-Nibaee quarry at Al-Taji. The fine aggregate refers to a combination of natural sand (river sand) brought from Kerbala and the crushed sand brought from Al-Nibaee quarry. The chemical composition and physical properties of the aggregate are shown in Tables (1) and (2) respectively. The State Corporation for Roads & Bridges in Iraq (SCRB) established standard specifications for base course. The gradation used in this study is shown in Table (3) and Figure (1).

Table (1): Chemical Composition of Nibaee Aggregates.

Chemical Compound	Content %
Silica, Sio2	82.52
Lime, CaO	5.37
Magnwasia, MgO	0.78
Sulphuric Anhydride, SO	2.7
Alumina,AlO	0.48
Ferric Oxide, FeO	0.69
Loss on Ignition	6.55
Total 99.09	99.09
Mineral composition	
Quartz	80.3
Calcite	10.92

Table (2): Physical Properties of Al-Nibaee Coarse and Fine Aggregates.

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C127 and C128)	2.610	2.631
Apparent Specific Gravity (ASTM C127 and C128)	2.641	2.6802
Percent Water Absorption (ASTM C127 and C128)	0.423	0.542
Percent Wear (Los-Angeles Abrasion) (ASTM C131)	20.10	……

Table (3): Gradation of the Aggregate for Base Course (SCRB, 2003).

Sieve size	Sieve opening (mm)	Percentage passing by Weight of total Aggregate	
		Specification Limits (S.C.R.B)	Mid-point Gradation
3/4"	19	100	100
1/2"	12.5	90-100	95
3/8"	9.5	76-90	83
No.4	4.75	44-74	59
No.8	2.36	28-58	43
No.50	0.3	5-21	13
No.200	0.075	4-10	7

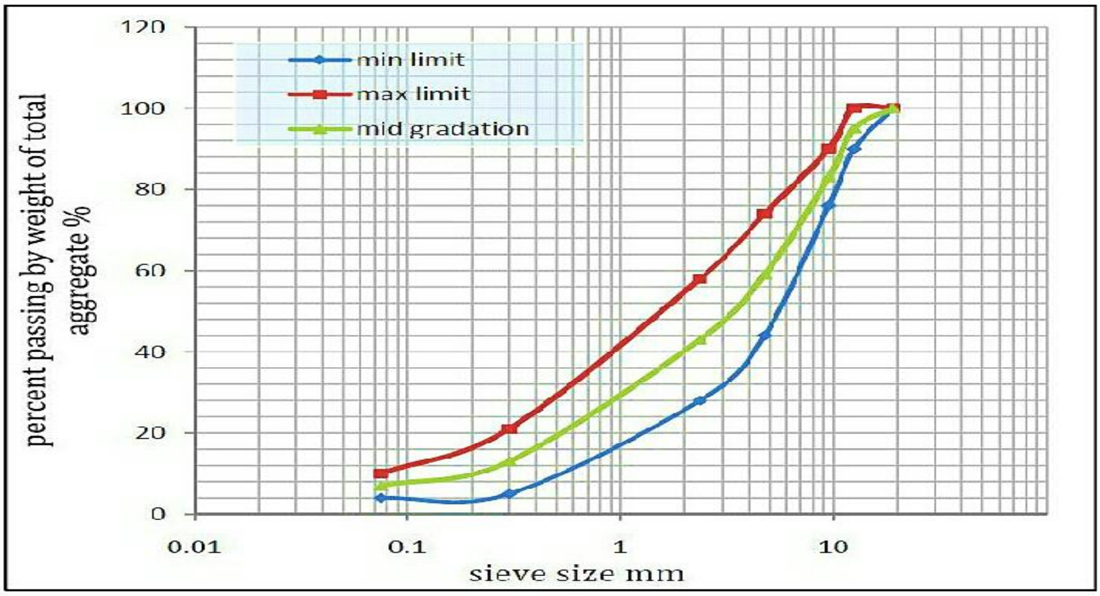


Figure (1): Specification Limits and Mid-Point Gradation of (SCRB, 2003) for Wearing Course Layer.

2.2 Mineral Filler

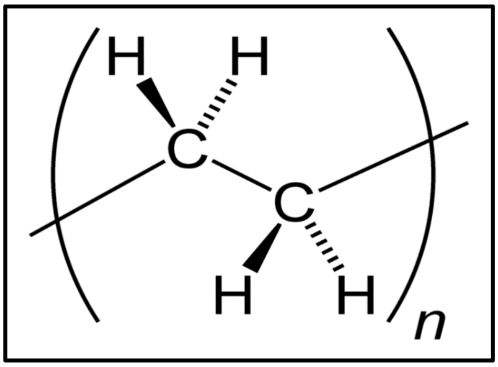
Three types of mineral filler are used in this research:
-Dust filler is a non-plastic material passing sieve No.200 (0.075mm), usually used to improve mixture properties.
-Limestone was thoroughly dry and free from lumps or aggregations of fine particles.
-Ordinary Portland cement it is thoroughly dry and free from lumps or aggregations of fine particles.

2.3 Additives

There are many types of additives available in the local market and used road works. One type of Polyethylene polymer has been used in this research as an additive to (40-50) asphalt cement are described below:

2.3.1 Polyethylene polymer

Polyethylene is a thermoplastic polymer and the most commonly used plastic in the world. It is obtained by the polymerization of ethane. It is primarily used in plastic bags and geo-membranes etc. It is a semi-crystalline material consists of long chains of repeated small molecules produced by combination of the ingredient monomer ethylene. It has a wide range of properties including good chemical, fatigue and wear resistance. In a molecule of polyethylene, there are repeated units of two carbon atoms and two hydrogen atoms are attached to each carbon atom.



(a)

(b)

Figure (2): a) The repeating unit of polyethylene. b) Polyethylene.

3. Literature Review

3.1 Hot Mix Asphalt

The purpose of designing Asphalt Concrete Wearing Course is to provide a stable mixture by means of a well graded aggregate with good mechanical interlock held together with the binder.

3.2 Durability Behavior

Durability of an asphalt mixture is defined as the resistance to weathering and the abrasive action of traffic. In terms of its application to asphalt paving materials, durability can be defined as the ability of the materials in the asphalt pavement structure to withstand the effects of environmental conditions, such as water, temperature variations and ageing without any substantial deterioration for a comprehensive period for a given amount of traffic loading (Scholtz and Brown, 1996 in Suparma, 2001). To evaluate durability, a mixture is subjected to environmental conditioning, and a mixture property associated with environmental or load-related is distress measured before and after the conditioning process. The better the protection by asphalt concrete, more durable the mix will be. The less air voids in the total mix, the slower will be the deterioration of the asphalt concrete itself. This test covers the measurement of Marshall stability of cylindrical specimens of bituminous paving mixtures it has been immersed in water for multiple days (0, 1, 4, 7, and 14 days) at 25°C by means of the Marshall apparatus according to ASTM (D 1559) (ASTM, 2003).

4. Theoretical Approach

4.1 Marshall Test

The Marshall Test is applicable to hot mix asphalt paving mixtures using asphalt cement and containing dense or fine graded aggregates with a maximum size of (12.5) mm. It may be used for both laboratory design and field control of asphalt hot mix paving. The stability and flow of an asphalt concrete mix for optimum asphalt content determination are defined in terms of the empirical Marshall test. (Croney and Croney; 1998) described briefly that Marshall test is carried out on compacted samples of the mixture prepared in a steel mold 101.6 mm in diameter.

4.2 Durability Test

In durability evaluation, a mixture is subjected to environmental conditioning, and a mixture property correlating with load-related environmental distress or load-related is measured before and after the conditioning process. The Marshall test is usable to hot mix asphalt paving mixtures using optimum asphalt content and containing dense or fine graded aggregates with a maximum size of of (12.5) mm. It used for laboratory investigate for durability of HMA. Marshall Stability, Retained Marshall Stability (RMS) and Durability Index (DI) of an optimum asphalt content are defined in terms of the empirical Marshall test to evaluate the durability of HMA.

4.2.1 Marshall Stability

Marshall Stability is computed from the following equation:

$S_o = O \times R \times T$

Where:

O = stability timepiece reading on Marshall test (kN).
S_O = stability numeral (kN).
R = Proving ring calibration.
T = the matter test correction factor.
Figures (3) show the results of the Marshall Stability test for (0, 1, 4, 7, and 14 days) immerse time.

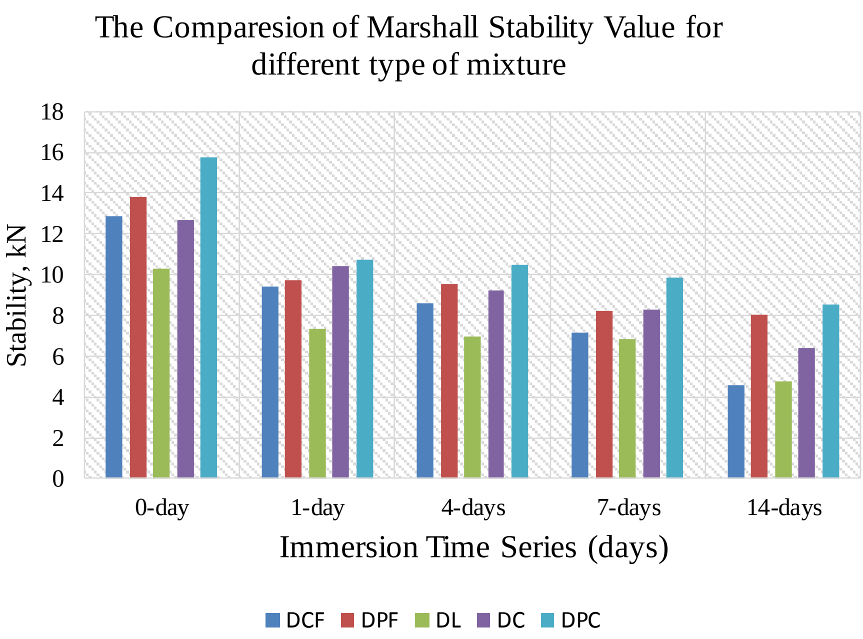


Figure (3): The Comparison of the Marshall Stability value for different type of mixture.

4.2.2 Retained Marshall Stability (RMS)

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

$$RMS = \frac{Si}{S_o} \times 100\%$$

Where:
RMS = Retained Marshall Stability (%).
S_i = maximum stability in conditioned set based on times series.
S_O = maximum stability in unconditioned set (0 days).

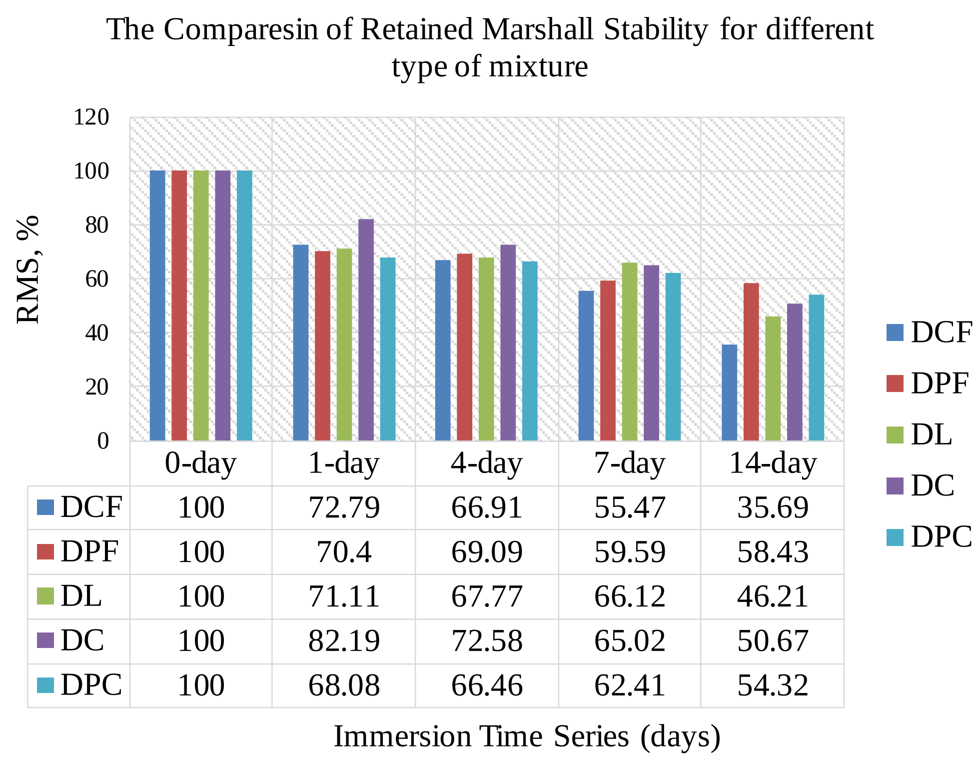


Figure (4): The Comparison of the Marshall Retained Stability value for different type of mixture.

The Retained Marshall Stability (RMS) value for all aggregate variation is descends along immersion time series. This shows specimen strength is becoming lower which contrary to the immersion time series. Hence, the RMS value is especially beneficial when applied to asphalt whose Marshall Stability (when not containing said surfactant) is reduced by at least 20%, more preferably by at least 30%.

4.2.3 Durability Index (DI)

The equation is used to calculate durability index is adopted from durability index formula when Marshall Test. Durability index is calculated from the following equation:

$$DI = \left(\frac{1}{2\ tn}\right)\sum_{t=0}^{n-1}(Si - Si + 1) \times [2\ tn - (ti + 1 - t)]$$

Where:
S_i = percent retained strength at time t$\boldsymbol{i}$.
S_{i+1}= percent retained strength at time t$\boldsymbol{i}$+1.
t_i, t_{i+1}= immersion time (calculate from beginning of test)
Durability Index was defined as the average strength loss area enclosed between the durability curve as shown in figure (5).

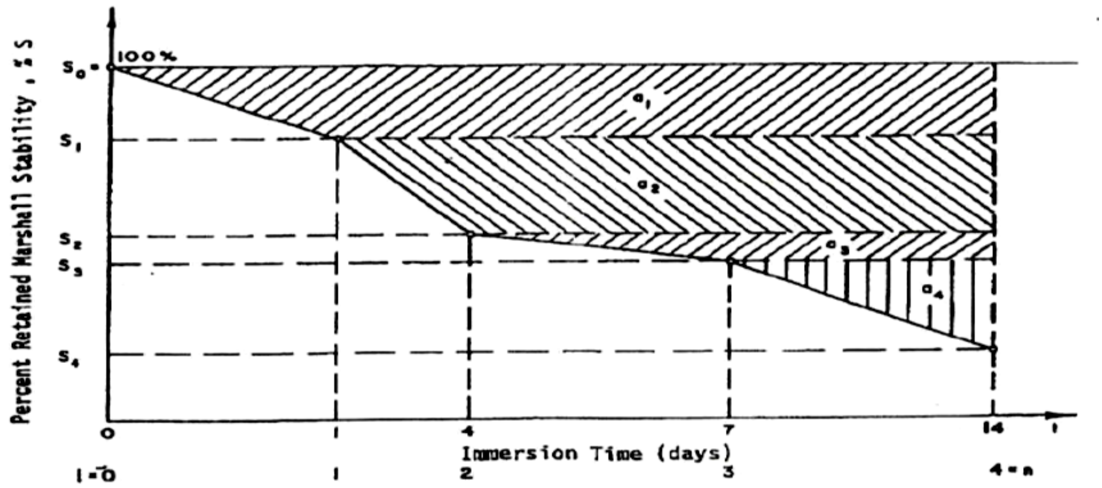


Figure (5): Schematic Description of Durability Curve (Hapsari,W.M., 2007)

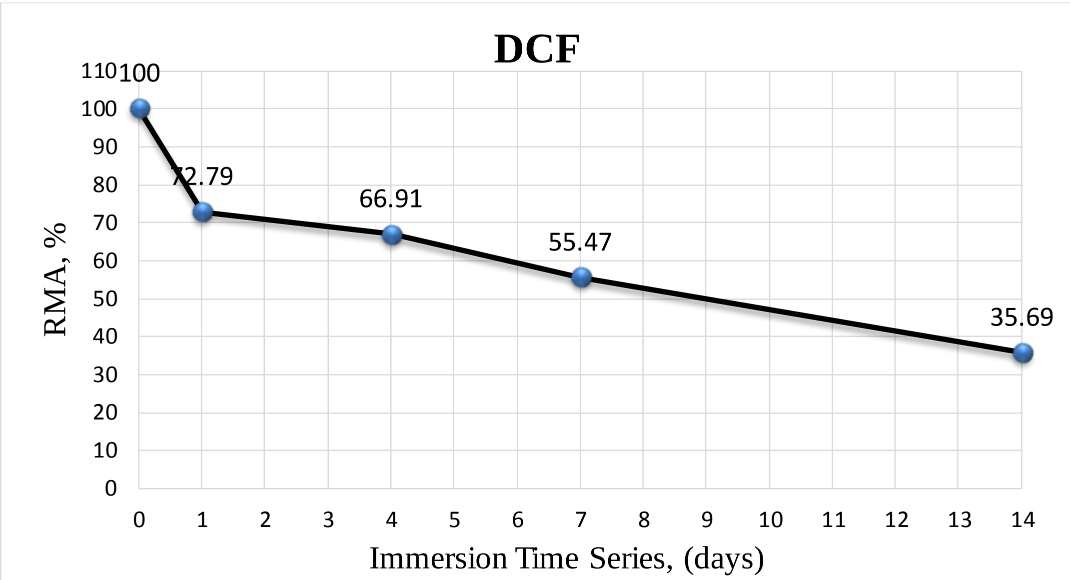


Figure (6): Durability Index curve for control mix with mineral filler (DCF) based on Marshall Properties (Retained Marshall Stability).

Table (4): Durability Index calculation for control mix with mineral filler (DCF) based on Marshall Properties (Retained Marshall Stability).

Area Code	Area (cm^2)	Total Immersion days	Durability Index (%)
a1	(14+13)*(0.5*(100-72.79))=367.335	14	26.24
a2	(13+10)*(0.5*(72.79-66.91))=67.62	14	4.83
a3	(10+17)*(0.5*(66.91-55.47))=97.24	14	6.95
a4	(0.5*(55.47-35.69)*7)=69.23	14	4.945
		Total Durability Index (%) =	42.965

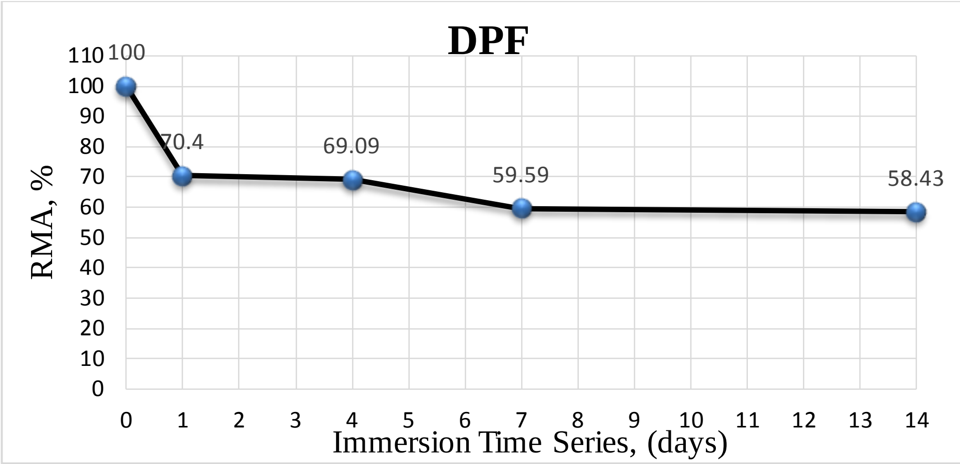


Figure (7): Durability Index curve for mix with mineral filler and additive Polyethylene polymer (DPF) based on Marshall Properties (Retained Marshall Stability).

Table (5): Durability Index calculation for mix with mineral filler and additive Polyethylene polymer (DPF) based on Marshall Properties (Retained Marshall Stability).

Area Code	Area (cm²)	Total Immersion days	Durability Index (%)
a1	(14+13)*(0.5*(100-70.4))=399.6	14	28.54
a2	(13+10)*(0.5*(70.4-69.09))=15.065	14	1.08
a3	(10+17)*(0.5*(69.09-59.59))=80.75	14	5.77
a4	(0.5*(59.59-58.43)*7)=4.06	14	0.29
		Total Durability Index (%) =	35.68

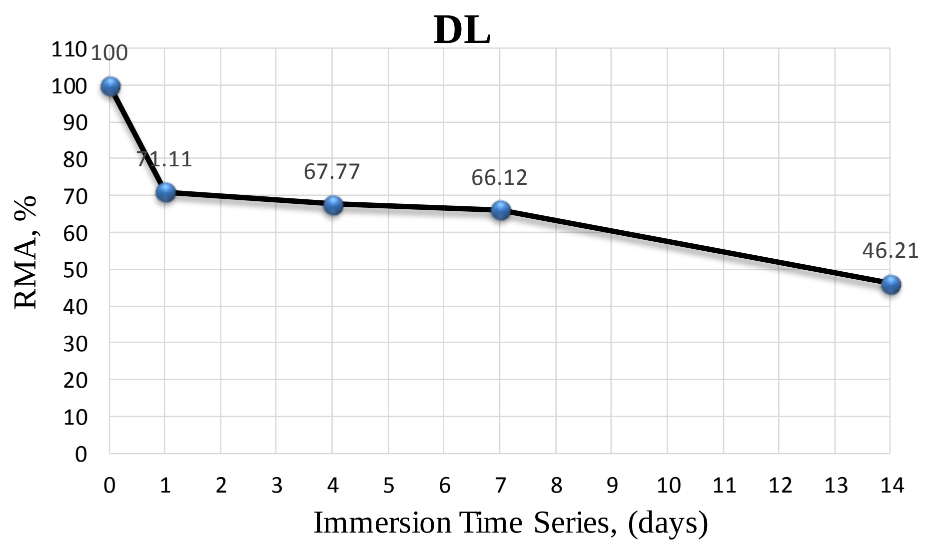


Figure (8): Durability Index curve for mix with lime filler (DL). based on Marshall Properties (Retained Marshall Stability).

Table (6): Durability Index calculation for mix with lime filler (DL). based on Marshall Properties (Retained Marshall Stability).

Area Code	Area (cm^2)	Total Immersion days	Durability Index (%)
a1	(14+13)*(0.5*(100-71.11))=390.015	14	27.86
a2	(13+10)*(0.5*(71.11-67.77))=38.41	14	2.74
a3	(10+17)*(0.5*(67.77-66.12))=14.025	14	1.002
a4	(0.5*(66.12-46.21)*7)=69.69	14	4.98
		Total Durability Index (%) =	36.582

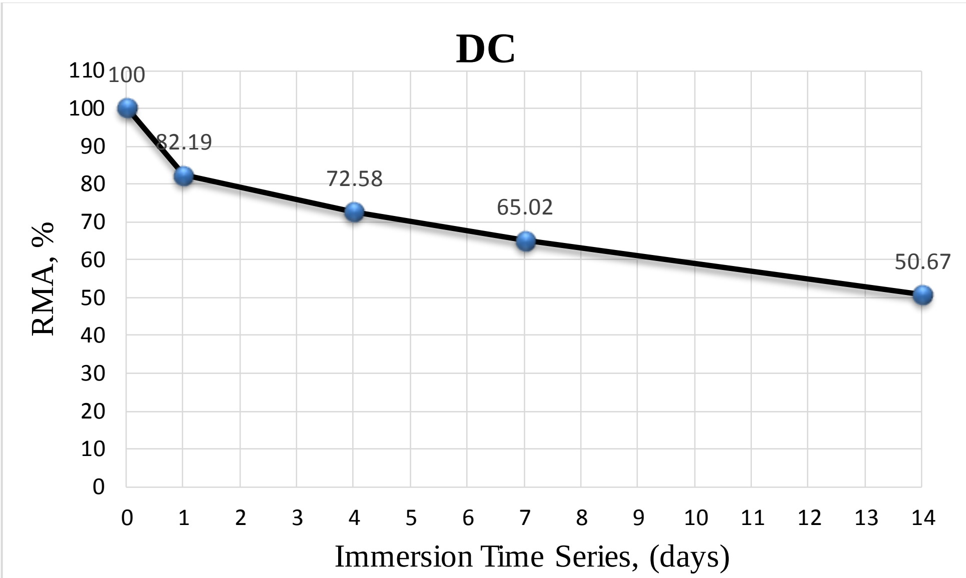


Figure (9): Durability Index curve for mix with Portland cement filler (DC). based on Marshall Properties (Retained Marshall Stability).

Table (7): Durability Index calculation for mix with Portland cement filler (DC) based on Marshall Properties (Retained Marshall Stability).

Area Code	Area (cm^2)	Total Immersion days	Durability Index (%)
a1	(14+13)*(0.5*(100-82.19))=240.435	14	17.17
a2	(13+10)*(0.5*(82.19-72.58))=110.515	14	7.89
a3	(10+17)*(0.5*(72.58-65.02))=64.26	14	4.59
a4	(0.5*(65.02-50.67)*7)=69.69	14	3.59
		Total Durability Index (%) =	33.24

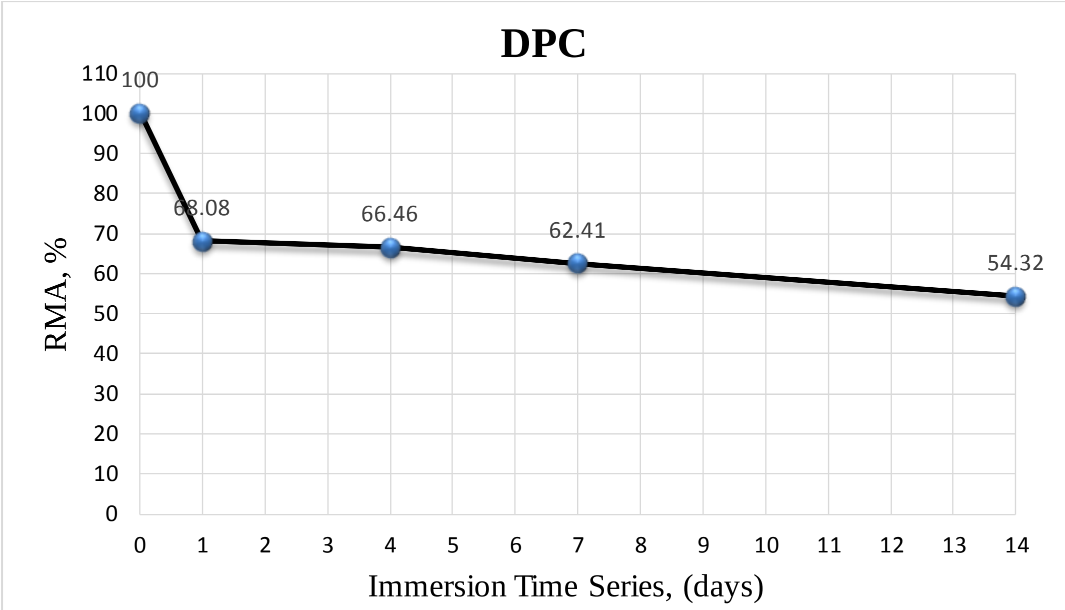
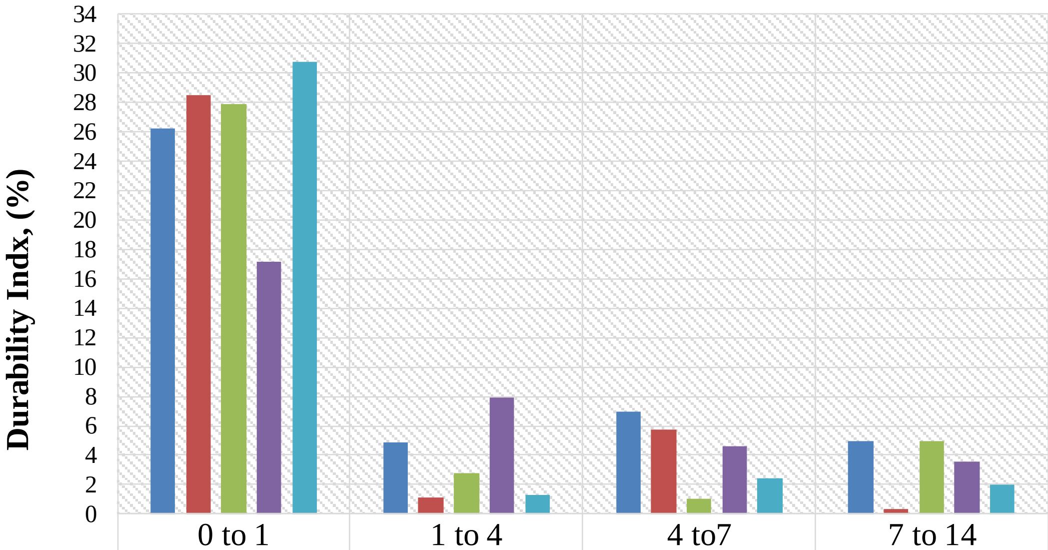


Figure (10): Durability Index curve for mix with Portland cement filler and additive Polyethylene polymer (DPC) based on Marshall Properties (Retained Marshall Stability).

Table (8): Durability Index calculation for mix with Portland cement filler and additive Polyethylene polymer (DPC). based on Marshall Properties (Retained Marshall Stability).

Area Code	Area (cm²)	Total Immersion days	Durability Index (%)
a1	(14+13)*(0.5*(100-68.08))=430.92	14	30.78
a2	(13+10)*(0.5*(68.08-66.46))=18.63	14	1.33
a3	(10+17)*(0.5*(66.46-62.41))=34.43	14	2.46
a4	(0.5*(62.41-54.32)*7)=28.32	14	2.02
		Total Durability Index (%) =	36.59

Figures (10) shows that the mix with Portland cement filler (DC) has the total durability index (around 33.42%), hence it’s lower than durability index for other mixes followed by mix with mineral filler and additive Polyethylene polymer (DPF) has the total durability index (around 35.68%), followed by mix with lime filler (DL) has the total durability index (around 36.582%), followed by mix with Portland cement filler and additive Polyethylene polymer (DPC) has the total durability index (around 36.59%), and mix mineral filler (DCF) has the total durability index (around 42.965%). The reason is, for the (DC) is lower, where it means less of porosity and water absorption in the mixture. As a result, the water absorption of this mixture with low durability index is lower than the other mixture.



	0 to 1	1 to 4	4 to7	7 to 14
DCF	26.24	4.83	6.95	4.945
DPF	28.54	1.08	5.77	0.29
DL	27.86	2.74	1.002	4.98
DC	17.17	7.89	4.59	3.59
DPC	30.78	1.33	2.46	2.02

Immersion Time Series, (days)

Figure (11): The Comparison of Durability Index based on RMS Value for all Type of Mix.

Based on the Durability Index, Marshall Stability and RMS results, mix with Portland cement filler (DC) has good quality where the strength of it is higher than other mixes. This means less of porosity and water absorption in the mixture.

5. Conclusions

In this research, when immersion time series are; 0, 1, 4, 7 and 14 days in water bath at 60^{o}C, and Marshall test as control or point of reference, the following could be concluded:

1. Marshall Stability values for all mineral filler variations based on the 60ºC immersion time series in water bath are decreased. This is caused by the effect of water due to the damage of the structural integrity of the asphalt-aggregate interface. The mechanisms are generally starting with the water that can causes the loss of cohesion (strength) and stiffness of the asphalt; and secondly, the water attacks the adhesive bond between the asphalt and the aggregate in the mixture (stripping).
2. The Retained Marshall Stability (RMS) values for all mineral filler is descended along immersion time series. This shows that the specimen strength is becoming lower in a contrary to the immersion time series. The RMS value descends became around 30% to 55% after 7 days' immersion from unconditioned strength, and the RMS value descends again to be around 15 % to 20% for 14 days. Hence, the RMS

value is especially beneficial when applied to asphalt whose Marshall Stability (when not containing said surfactant) is reduced by at least 20%, more preferably by at least 30%.

3. The Durability Index value for all mix variation becomes (33.42%) mixed with Portland cement filler (DC), hence it's lower than durability index for other mixes followed by mix with mineral filler and additive Polyethylene polymer (DPF) has the total durability index (around 35.68%), followed by mix with lime filler (DL) has the total durability index (around 36.582%), followed by mix with Portland cement filler and additive Polyethylene polymer (DPC) has the total durability index (around 36.59%), and mix mineral filler (DCF) has the total durability index (around 42.965%).
4. Based on the Durability Index, Marshall Stability and RMS results, mix with Portland cement filler (DC) has good quality where the strength is found to be higher than other mixes. This means less of porosity and water absorption in the mixture.

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