Effect of Prolonged and Cyclic Immersion Time on Durability of Flexible Pavement Asphalt Mixes

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***Abstract*:** Studies on the hot mix asphalt (HMA) durability assessment have generally been performed to find out the resistance of bituminous mixtures to water. Egypt road network covering north and delta regions are showing severe deterioration due to water intrusion that breaks the bond between aggregates and asphalt film causing raveling and stripping distresses.

The main purpose of this paper is to recognize the effect of moisture due to water puddles that coming after rains and floods at winter on durability of HMA of road pavement. The paper proposes 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 through an indicator called "Durability Index".

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 until reaching the minimum required value for stability as per Egyptian code of practice (ECP2010). 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.

Index Terms; Pavement durability, asphalt mix, moisture, immersion time

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 life.

One of the major reasons for flexible pavement distress and 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*" **[2]**.

Durability of an asphalt pavement is measured by 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 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. Influence of moisture; this may result in certain circumstances in failure or loss of adhesion between the bitumen and the minerals.

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; using maximum binder content, using dense gradation of stripping-resistant aggregate, and compacting the mixture for maximum impermeability.

2. Experimental Program

In order to obtain the necessary information to investigate the hot mix asphalt (HMA) criteria, a series of laboratory tests were carried out to determine binder, aggregate and mix properties.

1. 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-1 shows tests carried out on bitumen and their average results.

Table-1:Lab. Test Results of asphalt cement of asphalt mix.

Test	Unit	Specification	*Average*
Specific Gravity	*gm/cm^3*	ASTM – D70	1.03
Penetration	*0.01mm*	ASTM – D05	67
Flash Point	*^oC*	ASTM – D92	303

2. 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-2 shows the tests conducted on the aggregate three times and their average results.

3. 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 Egyptian Code of Practice (ECP2010) specification. Tables 3 and 4 show the blending mix design as well as the obtained Job Mix limits of both types and their compliance to the specifications considered by ECP-2010 as adopted in this research

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Table 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)*	gm/cm^3	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	25.0	26.0	26.0	**26.0**	40 Max.
5	Soundness *($MgSo_4$)*	%	ASTM – C088	9.2	8.9	9.1	**9.0**	12 Max.

Table 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
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: 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
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^oC. 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^oC 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 30min at 60^oC. Average results of tests are given in Table-5 for type 3-D and Table-6 for type 4-C respectively

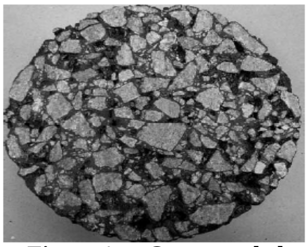

Figure 1-a: Open-graded 3-D type HMA

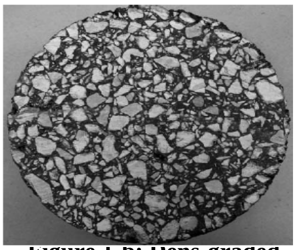

Figure 1-b: Dens-graded 4-C type HMA

Table 5: HMA average test result of mechanical properties for A.C. Binder (type3-D)

Criteria	Bitumen (%)	Stability (Kg)	Flow (mm)	Density (kg/cm^3)	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.	-----	-----

Table 6: HMA average test result of mechanical properties for A.C. wearing (type4-C)

Criteria	Bitumen (%)	Stability (Kg)	Flow (mm)	Density (kg/cm^3)	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.	-----	-----

The cross section of the specimen tested for both types of mix are shown in Figure 1-a for 3-D binder mix, which appears coarse and open graded while Figure1-b shows a tested specimen of 4-C wearing mix that seems to be dense-graded.

3. MODIFIED MARSHALL PROLONGED IMMERSION TEST

In many cases, mixtures passed the standard Marshall Immersion criterion *(75% retained strength after 24 hrs immersion on 60^oC)* but they may failed completely after longer periods of immersion or deteriorated rapidly under actual service condition **[3]**. 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^oC 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 is developed to obtain a single quantitative parameter that can represent the durability characteristics over the immersion period.

4. LABORATORY TESTING AND INVESTIGATION

In this study, five periods of immersion were used, i.e. 6 hrs, 12hrs, 1, 3, and 7 days. Six specimens for each proposed period were prepared and then immersed in water at 60^oC. After immersion, the Marshall Stability was measured, and then compared with the control stability values as can be seen on Tables 7 and 8. 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 2 and 3. 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 -7: 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	6	5.0	*700*	1290	1245	96.5
12h	6	8.0			1405	109.1
1 day	6	10.0			1090	84.5
3 days	6	15.0			960	74.5
7 days	6	25.0			**625**	48.3

Table -8: 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	6	2.0	*900*	1050	1055	100.5
12h	6	5.0			1045	99.5
1 day	6	8.0			985	93.8
3 days	6	15.0			**924**	88.0
7 days	6	20.0			715	68.3

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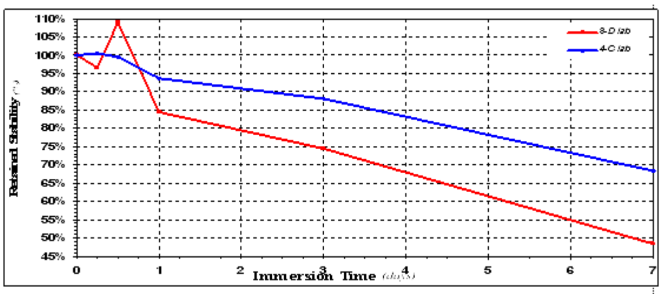

Figure-2: Correlation between the percent Retained Stability and Immersion time for HMA

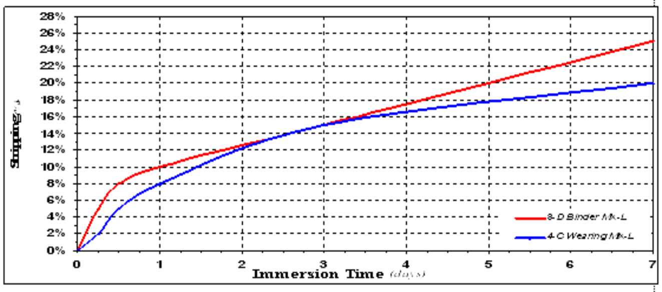

Figure-3: Correlation between the percent Stripping and Immersion time for HMA

5. Theoretical Approach

Marshal Stability: Marshall Stability is calculated from equation [1]:

$$S_o = R \times O \times T \qquad (1)$$

Where;

S_o = Standard absolute Marshall Stability (lbs).
R = Stability timepiece reading on Marshall Test (lbs)
O = Proving ring calibration factor.
T = Specimen test correction 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 specimen after an immersion process as a percentage of the initial (absolute) Marshall Stability of the specimen. The RMS values were then determined as follows:

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

Where;

RMS = Retained Marshall Stability (%)
S_i = Maxi. Stability in conditioned set based on time series
S_o = Max. 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 successive sections of the durability curves*". Based on Figure (4), this Index (r) is expressed as follows **[5]**:

$$r = \sum_{i=0}^{n-1} \frac{S_i - S_{i+1}}{t_{i+1} - t_i} \qquad (3)$$

Where;

r = Durability Index
S_i = Percent retained strength at time t_i
S_{i+1} = Percent retained strength at time t_{i+1}
t_i, t_{i+1} = immersion periods (from beginning of test).

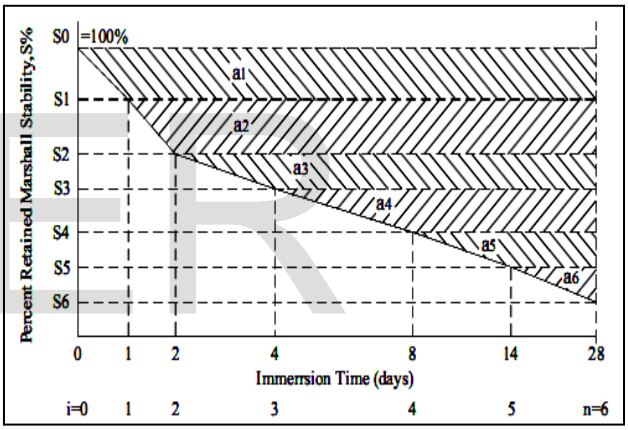

Figure-4: Schematic Description of Durability Curve, with Parameters defining Durability Index

when strength measurements were taken after 1, 2, 4, 8, 14, and 28 days of immersion, equation (3) was as follows **[4]**:

$$r = \frac{S_0 - S_1}{1} + \frac{S_1 - S_2}{1} + \frac{S_2 - S_3}{2} + \frac{S_3 - S_4}{4} + \frac{S_4 - S_5}{6} + \frac{S_5 - S_6}{14} \qquad (4)$$

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 weighed loss in strengths (R) as follows **[5]**:

$$R = \frac{r}{100} S_o \qquad (5)$$

Where;

R =absolute values of the weighed loss in strengths
S_o = the absolute value of the initial strength

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6. Analysis and Discussion

Figures 2, 3 and tables 6, 7 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 greater than the percentage lost during the next three days of immersion (6.2%, 5.8%) for laboratory prepared mixes.

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 type 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 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 mixture, and then decreases 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 duration of the immersion period. This was indicated by the trend of the curve at immersion periods longer than 3 days immersion when it remains relatively constant.

Applying equation (4) on test results obtained as shown in Figures (2) through (3), the **D**urability **I**ndex for the different cases will be as shown in Table-9,

Table 9: Durability Index for different types and cases of HMA

HMA Type	Durability Index r (%)	Loss in strength R (kg)
3-D Binder	17.5	225
4-C Wearing	11.5	120

The above obtained results presents the values of the ***Durability Index*** as defined in Equation 4 and 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.

7. Modified Marshall Cyclic Immersion Test

The effect of cyclic water on pavement is evaluated through applying cycles of watering on the specimens in successive increasing number of 30 minutes cycles for each, and then left for 24h interval before testing. This proposed process is performed to simulate the actual natural condition of exposure the pavement to cycles of moisture and dryness due to either repetitive cyclic rainfall in winter or fluctuating groundwater at summer. At the end of each moisture-immersion cycle, a Marshall Index of Retained Strength was calculated from Equation-2. The percentage of stripping is also assessed outer and inner as mentioned earlier.

Based on test results obtained, Figure-5 shows the correlation between number of water cycles that HMA is exposed to, and the reduction in stability due to this exposure expressed as retained strength for both mixes in which it can be seen that;

- The curves for both 3-D and 4-C follow the same pattern, i.e. the percentage of retained stability ***(R.S.)*** increased up to 3 cycles then decreased as the number of cycles increased.
- The ***R.S*** of 3-D mix decreased more rapidly than that of 4-C mix when the number of cycles is greater than 6 cycles.
- The strength gain of the 3-D mix up to 3 cycles is-on the average- higher than that of 4-C mix *(4% for 3-D against 1% for 4-C)*, this may be ***referred to*** the differences in internal air voids that could be filled with water and consolidate a piece of applied load and then increase the strength.
- However, both mixes can maintain stability even though more than 30 cycles are applied. Neither mixture has a retained stability less than 75% after 35 cycles; moreover, the retained stability is still greater than 85% for 4-C mix.

Commentary observation on the results obtained from the two adopted durability tests, it compares well with the result pattern of the cyclic water and the modified Marshall Immersion tests for both mixtures. There is remarkable aspect about the magnitude of the strength loss between the two tests. In the modified Marshall Immersion test, the retained strength differential, i.e. the difference between maximum and minimum values, are 60.8% for 3-D mix and 32.2% for 4-C mix, respectively. The corresponding values for the cyclic water test are 45.0% for 3-D mix and 14.4% for 4-C mix. It could be seen that the cyclic water test results is a less significant of loss in strength than the modified Marshall Immersion test. The number of cycles selected also contributes to this result, i.e. the results of the cyclic water test are appearing significant only in long-term period of test.

For the cyclic water test, at the 5 cycles of immersion, the specimens have attained optimum strength and the influence of water is still too small to reduce the strength of the specimens. When the number of cycles is greater than 5, the influence of water becomes progressively more significant. One reason for this phenomenon is that the water repetitive effect is greater in magnitude, so the adhesion bond between aggregate and bitumen is broken more quickly. That is why the drop in strength of the specimens, especially 3-D, in the cyclic water test is higher than in the Marshall Immersion test. This test does not decrease the strength of 4-C significantly, except when it lasts for a long period, i.e. after 25 cycles of Immersion as shown in Figure-6.

Using both durability indices as seen in Figures 2 and 6, it is indicated that the mixtures tested using the cyclic water test exhibit a greater strength than when the modified Marshall Immersion test is used.

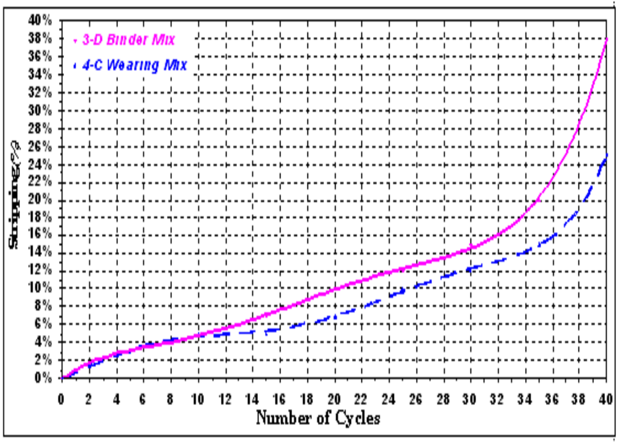

Figure-5: HMA percent Stripping VS Number of water cycles

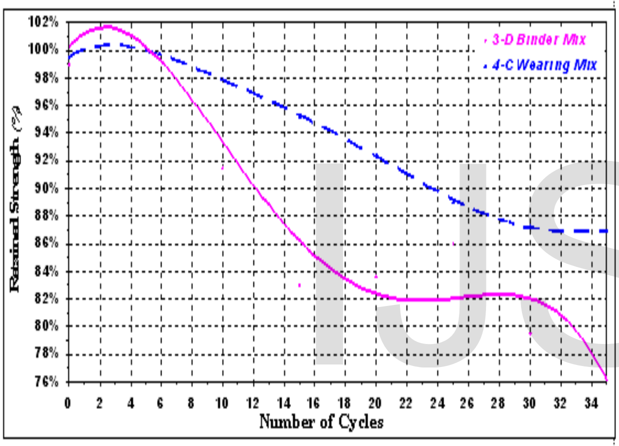

Figure-6: HMA percent Retained Strength VS Number of water cycles

8. Conclusions

1. Based on the presented research, it was clear that the gradation type and the immersion time are greatly affecting the durability of the asphalt mixes.
2. The immersion time has a marked effect on the durability of asphalt concrete mixtures, when this is assessed by the Marshall Stability tests. The values of Marshall Stability decrease with increase in immersion time. The stability falls rapidly in the first day and then decreases gradually after that.
3. 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.
4. 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.
5. 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.
6. 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.

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