Effects of Moisture, Compaction Temperature and Gradation Types on Durability of Asphalt Concrete Mixtures[1]

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Abstract

This study is devoted to the durability of bituminous mixtures, including the effects of different gradations, compaction temperatures and immersion time on the durability potential of mixtures.
The specific objectives of this study are:
1-To investigate the effect of compaction temperature on the mechanical properties of asphalt concrete mixtures.
2-To investigate the effect of bitumen content on the durability potential of bituminous mixtures.
3-To investigate the effect of different aggregate gradations on the durability of bituminous mixtures.
4-To include durability considerations in the mix design of asphalt concrete mixtures.
This study deals with statistics based on models which are found very attractive and useful for practical engineering applications.

[1] For the paper in Arabic see pages (9-10).

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1- Introduction:

1-1- General:

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 sun, rain, frost and soil moisture to which pavements are exposed during their service lives.

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 endure for a long service life (2).

1-2 The Meaning of Durability and Durability Prediction:

Long – term performance is approximate synonym of durability (3), but there are several definitions of the word “durability”.

Tow definitions of durability and a definition of a related concept, serviceability, which appear in standards prepared by ASTM committee E-6 on performance of building construction are (3):

Durability: The safe performance of a structure or a portion of a structure for the designed life expectancy. (from ASTM recommended practice for increasing durability of building construction against water-induced damage (E241-77)).

Durability: The capability of maintaining the serviceability of a product, component, assembly, or construction over a specified time. (from ASTM recommended practice E632).

Serviceability: The capability of a building product, component, assembly or construction to perform the functions for which it is designed and constructed. (from ASTM recommended practice E632).

2- Materials Used and Tests Conducted

2-I Asphalt Cement:

In this study one type of asphalt cement was used, it was (60-70) penetration grade obtained from Banyas Petroleum Refinery. This grade is widely used in Syria and commonly used for heavy traffic and hot weather conditions.

Table 2-1 shows tests carried out on asphalt cement, and average results of these tests.

Table2-1 Tests Carried Out, and Average Tests Results of Physical Properties of Asphalt Cement "60-70 Penetration"

No	TYPE OF TEST	SPECIFICATION	RESULTS			AVERAGE RESULTS
			Spe 1	Spe 2	Spe 3	
1-	Ductility (cm) 77 F. 5 cm/min	ASTM D113	102	104	102	103
2-	Softening (c) Ring and Ball	ASTM D36	48	48	49	48
3-	Penetration (0.1 mm) 100 gm 5 sec	ASTM D5	66.5	67.5	67	67
4-	Flashpoint and Fire point (c). (C.O.C)*	ASTM D92	300	301	300	300
5-	Specific gravity. 77 F	ASTM D70	1.03	1.03	1.03	1.03

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2-2 Aggregates

One type of rock, crushed dolomite aggregate was used in this study with nine fraction sizes. The upper and the lower limits of wearing course gradations used by ASTM D3515 specification. Three gradations were used they are:

1-Gradation type 1, which is close to the upper limit of ASTM specifications (4).

2- Gradation type 2, which is in the middle of the envelope.

3- Gradation type 3, which is close to the lower limit.

They will be referred to later as gradations type 1, 2 and 3. Three different compaction temperatures (115, 135 and 155) ± 3 ^{o}C were also used.

Table 2-2 shows the tests conducted on crushed dolomite aggregate and Average results while. Table 2-3 shows the upper and lower limits of wearing course gradations according to the specifications employed by ASTM D3515. It also shows the gradations used in this research, these gradations are drawn in fig 2-1.

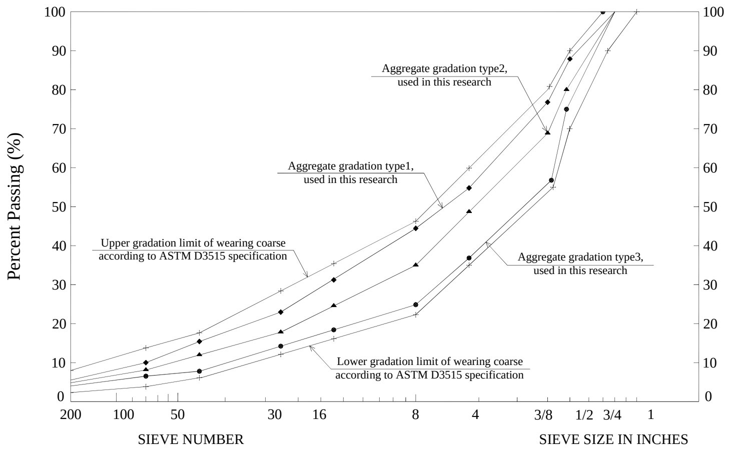


Figure 2-1: Gradation Limits of Wearing Aggregate According to ASTM D3515 and Gradation Types used in this Research

Table 2-2 Test Results of Properties of Crushed Dolomite Aggregate

No	TYPE OF TEST	Specification	Results			Average Results	Requirements of Specifications
			Spe 1	Spe 2	Spe 3		
1	Aggregate Abrasion	ASTM C131	17.96	18.74	18.5	18.4	30 max
2	Aggregate Soudness Magnesium Sulfate Sodium Sulfate	ASTM C88	 8.2 6.50	 8.2 6.55	 8.1 6.58	 8.2 m 6.54	 12 max 10 max
3	Specific Gravity of Coarse Aggregate (Passing ¾ Sieve and Retained No 4 Sieve)	ASTM C127	2.732	2.732	2.734	2.733	
4	Specific gravity of fine aggregate passing No 4 Sieve)	ASTM C128	2.754	2.753	2.753	2.753	
5	Specific gravity of filler "Passing 200 Sieves"	ASTM C120				2.788	

Table 2-3 Wearing Course Gradation Specifications Employed By" ASTM D3515 and the actual gradations (4)

Sieve Size or Sieve no.	Aggregate Gradation Types Used in this Research. "passing %"			Gradation Specification Employed by ASTM"Passing %"
	Type No. 1	Type No. 2	Type No. 3	
¾"	100	100	100	90-100
½"	87	81	75	71-90
3/8"	77	68	59	56-80
# 4	62	50	38	35-65
# 8	46	36	26	23-49
# 16	36	28	20	17-39
# 30	26	20	14	11-29
# 50	16	12	8	5-19
# 100	13	9	7	4-15
# 200	7	5	3	2-8

In preparing each specimen, graded crushed dolomite aggregates were heated to 156-160^{o}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 ^{o}C employing 75 blows on each side.

Specimens were left to cool at room temperature for one day, and then they were weighed in air and in water to determine the balk specific gravity according to ASTM D2726.

The specimens were divided into three identical groups according to the type of aggregate gradations used, and tested for Marshall Stability and Flow after being soaked in hot water for ½ hour at 60 ^{o}C. Average results of tests are given in table 2-4.

Table 2-4 Test Results of Mechanical Properties of Asphalt Concrete Mixtures

PROPERTY OF ASPHALT CONCERT MIXTURES	AGGTRGATE GRADATION TYPE		
	TYPE No 1	TYPE No 2	TYPE No 3
Percent Asphalt Content by Weight of Total Mix. "Asphalt Cement Penetration 60-70"	5.2%	4.9%	5%
Bulk Unit Weight (g/cc)	2.465	2.470	2.454
Percent Air Voids in Total Mix (% A.V)	3.9	3.9	4.2
Percent Voids in Mineral Aggregate (% V.M.A)	15.6	14.83	15.8
Marshall Stability (Kg)	1650	1530	1417
Marshall Flow (mm)	3.15	3.20	3.88
Stiffness = $\frac{\text{Stability}}{\text{Flow}}$ Kg/mm	523.8	478.125	365.2

3.Durability Testing

After finding the optimum asphalt content for each type of aggregate gradation, Marshall specimens of 4 inch diameter and 2.5 inch depth were prepared again according to Marshall method of mix design ASTM D1559.

The Asphalt cement mixture compacted in the Marshall mould at temperature of (115, 135 and 155) ± 3 ^{o}C for each gradation types employing 75 blows on each side.

Specimens were divided into three identical groups according to the type of aggregate gradation used, and tested for Marshall stability and flow after being soaked in hot water for (1, 2, 4, 8, 14 and 28) days at 60 ^{o}C. Average results of tests are given in tables 3-1, 3-2 and 3-3.

Table 3-1 Tests Results Of Mechanical Properties Of Asphalt Concrete Mixtures "Gradation Type 1"

Compaction Temperature °C	Saturation Time Days	Bulk Unit Weight g/cc	Percent Air Voids In Total Mix % A.V	Percent Voids In Mineral Aggregate % V.M.A	Marshall Stability Kg	Marshall Flow mm	Stiffness $= \frac{\text{Stability}}{\text{Flow}}$ kg/mm
115	0	2.451	4.48	15.18	1427.33	3.21	444.65
	1	2.451	4.48	15.18	1180.54	3.49	338.26
	2	2.450	4.52	15.20	1043.49	3.97	262.84
	4	2.451	4.48	15.18	940.42	4.45	211.80
	8	2.449	4.56	15.25	801.00	4.92	163.13
	14	2.450	4.52	15.20	621.39	5.20	119.49
	28	2.451	4.48	15.18	401.94	5.95	67.55
135	0	2.459	4.17	14.91	1511.75	3.06	494.03
	1	2.458	4.20	14.94	1279.92	3.24	395.03
	2	2.459	4.17	14.91	1104.43	3.51	314.65
	4	2.460	4.13	14.87	991.35	3.95	250.97
	8	2.458	4.20	14.94	843.48	4.28	197.07
	14	2.458	4.20	14.94	653.54	4.79	136.43
	28	2.458	4.20	14.94	445.22	5.34	83.37
155	0	2.460	4.13	14.87	1587.07	2.93	541.66
	1	2.461	4.09	14.84	1340.29	3.21	417.53
	2	2.460	4.13	14.87	1161.97	3.50	331.99
	4	2.459	4.17	14.91	1039.61	3.76	276.49
	8	2.460	4.13	14.87	885.26	4.04	219.12
	14	2.460	4.13	14.87	697.57	4.60	151.64
	28	2.459	4.17	14.91	504.08	5.02	100.41

Table 3-2 Tests Results Of Mechanical Properties Of Asphalt Concrete Mixtures "Gradation Type 2"

Compaction Temperature °C	Saturation Time Days	Bulk Unit Weight g/cc	Percent Air Voids In Total Mix % A.V	Percent Voids In Mineral Aggregate % V.M.A	Marshall Stability Kg	Marshall Flow mm	Stiffness $= \frac{\text{Stability}}{\text{Flow}}$ kg/mm
115	0	2.450	4.70	15.16	1356.65	3.39	400.19
	1	2.452	4.63	15.09	1123.23	3.74	300.32
	2	2.449	4.74	15.19	937.37	4.17	224.79
	4	2.452	4.63	15.09	876.84	4.77	183.82
	8	2.450	4.70	15.16	718.07	5.20	138.05
	14	2.453	4.59	15.05	574.13	5.86	97.97
	28	2.449	4.74	15.19	393.90	6.16	63.94
135	0	2.464	4.16	14.68	1457.92	3.29	443.13
	1	2.463	4.20	14.71	1225.75	3.54	346.25
	2	2.463	4.20	14.71	1012.65	3.87	261.66
	4	2.464	4.16	14.68	928.87	4.46	208.26
	8	2.461	4.29	14.78	798.76	5.12	156.00
	14	2.462	4.24	14.75	612.09	5.72	107.00
	28	2.464	4.16	14.68	417.54	5.98	69.82
155	0	2.465	4.12	14.64	1546.90	2.98	519.09
	1	2.465	4.12	14.64	1250.04	3.37	370.93
	2	2.466	4.08	14.60	1066.78	3.72	286.76
	4	2.466	4.08	14.60	959.32	4.10	233.98
	8	2.465	4.20	14.71	818.75	4.73	173.09
	14	2.464	4.16	14.68	659.37	5.03	131.08
	28	2.466	4.08	14.60	457.98	5.53	82.81

Table 3-3 Tests Results Of Mechanical Properties Of Asphalt Concrete Mixtures "Gradation Type 3"

Compaction Temperature °C	Saturation Time Days	Bulk Unit Weight g/cc	Percent Air Voids In Total Mix % A.V	Percent Voids In Mineral Aggregate % V.M.A	Marshall Stability Kg	Marshall Flow mm	Stiffness $=\frac{\text{Stability}}{\text{Flow}}$ kg/mm
115	0	2.446	4.63	15.10	1316.28	3.61	364.62
	1	2.445	4.67	15.14	1052.31	3.90	269.82
	2	2.446	4.63	15.10	858.56	4.35	197.37
	4	2.445	4.67	15.14	772.40	5.03	153.55
	8	2.449	4.52	15.03	674.68	5.40	124.94
	14	2.448	4.56	15.04	514.13	5.91	86.99
	28	2.446	4.63	15.10	309.00	6.82	45.30
135	0	2.453	4.36	14.86	1408.33	3.47	405.85
	1	2.454	4.32	14.83	1159.60	3.67	315.96
	2	2.451	4.41	14.93	952.98	3.98	239.44
	4	2.455	4.28	14.79	871.77	4.64	187.88
	8	2.452	4.40	14.89	739.04	5.16	143.22
	14	2.454	4.32	14.83	564.95	5.79	97.57
	28	2.455	4.28	14.79	390.00	6.24	62.50
155	0	2.457	4.21	14.72	1503.37	3.13	480.30
	1	2.456	4.24	14.76	1221.98	3.54	345.19
	2	2.456	4.24	14.76	1033.12	3.86	267.64
	4	2.456	4.24	14.76	926.06	4.51	205.33
	8	2.453	4.28	14.79	783.34	5.05	155.11
	14	2.456	4.24	14.76	644.65	5.61	114.91
	28	2.454	4.32	14.83	411.20	5.99	68.64

4- ANALYSIS AND DISCUSSION

4-1 Effect of Compaction Temperature and Gradation Types on Mechanical Properties of Asphalt Concrete Mixtures.

4-1-1 Effect of compaction temperature on unit weight of Asphalt Concrete Mixtures.

Fig 4-1 shows the relationship of compaction temperature versus unit weight of the asphalt concrete mixtures, it is noticed that unit weight increases with the increase of compaction temperature. This is true for all mixtures containing different types of gradations.

Increase in unit weight of asphalt concrete mixtures with the increase temperature was noticed in all grading because temperature decreased viscosity and made compaction easy. The increase was rapid at the beginning then it becoms slow.

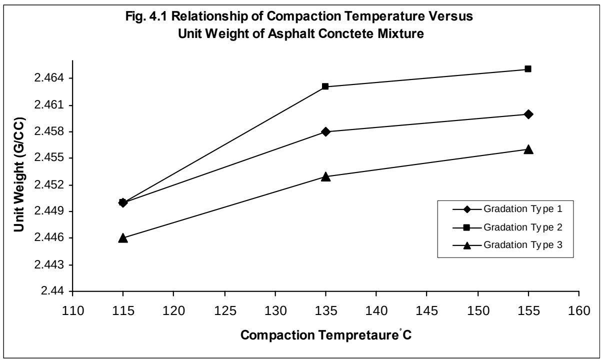


Fig. 4.1 Relationship of Compaction Temperature Versus Unit Weight of Asphalt Conctete Mixture

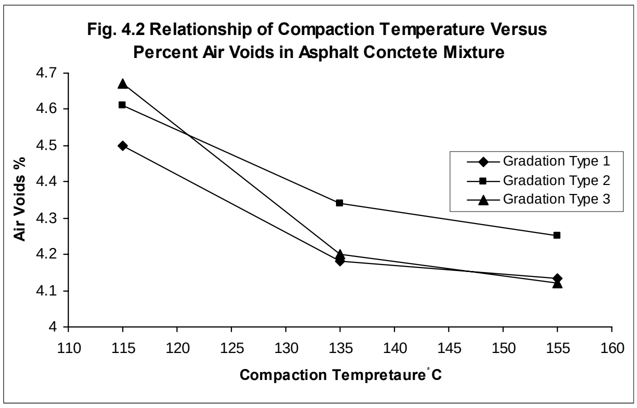
4-1-2 Effect of Compaction Temperature on Percent Air Voids in Asphalt Concrete Mixtures

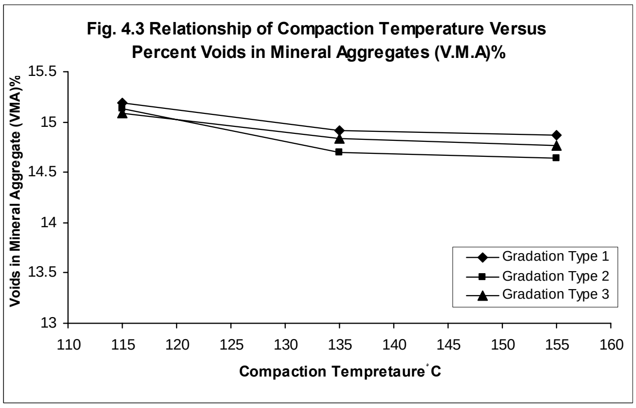
Fig 4-2 shows the relationship of compaction temperature versus percent air voids. It is noticed that the percent air voids decreases with increasing compaction temperature. This is also true for all mixes containing different types of gradations. The decrease in percent air voids with the increase in compaction temperature is due to lubricating effect of asphalt concrete keeping viscosity of the binder suitable for compaction. Gradation type 3 which is close to the coarse side exhibited highest value of percent air voids, while gradation type 1 and 2 which are close to the finer gradation and are in the middle of the gradation envelope exhibited the lowest values and they were very close to each other because there was so enough fines to fill the voids.

4-1-3 Effect of Compaction Temperature on Percent Voids in the Mineral Aggregates (% V.M.A)

Fig 4-3 shows the relationships of compaction temperature versus percent V.M.A. It is noticed that the percent V.M.A decreases with the increase of compaction temperature.

It was noticed that the initial decrease of percent V.M.A with the increase of compaction temperature is due to lubricating effect of binder, which increase the workability of the mix and improves the compaction and, consequently decreases the percent air voids and percent V.M.A.





4-1-4 Effect of Compaction Temperature on Marshall Stability

Fig 4-4, 4-5, 4-6, 4-7, 4-8, 4-9 and 4-10 shows the relationship of compaction temperature versus Marshall Stability for specimens soaked in a 60 ^{o}C water bath for 1, 2, 4, 8, 14 and 28 Days, respectively and directly tasted by Marshall method.

It is noticed that Marshall Stability increases with the increase of compaction temperature, and this is true for all mixes having different immersion time. Marshall stability increases with the increase of compaction temperature due to the more adhesive forces caused by the decrease in the viscosity of the asphalt concrete to reach the good workable and compaction condition.

Gradation type 1 exhibited the highest value of stability followed by gradation type 2 and then by gradation type 3, gradation types 1 and 2 were very close while gradation type 3 care was well bellow. It was noticed that Marshall stability decreased with the increase of the immersion time; because water effects the asphalt film adhesion to the aggregate grains. Consequently, the Marshall stability values of different samples become closer to each other (i.e. decrease of stability is directly proportional with the increase of immersion time). The loss in Marshall stability can be expressed as in equations (4-1,4-2 and 4-3) for gradation type 1, and as in equations (4-4,4-5 and 4-6) for gradation type 2 , and as in equations (4-7,4-8 and 4-9) for gradation type 3, at compaction temperature (115, 135 and 155) ± 3 °C respectively

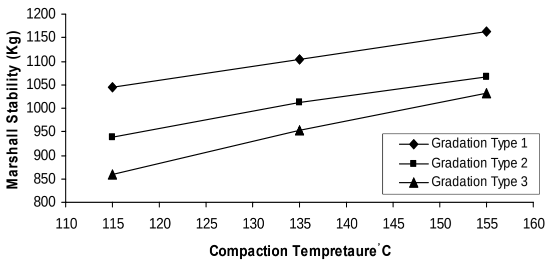
$$Y(X) = 1197.09760*0.9593{}^\wedge x \tag{4-1}$$
$$Y(X) = 1264.2790*0.96047{}^\wedge x \tag{4-2}$$
$$Y(X) = 1315.6750*0.96304{}^\wedge x \tag{4-3}$$
$$Y(X) = 1103.5760*0.96067{}^\wedge x \tag{4-4}$$
$$Y(X) = 1195.2425*0.96006{}^\wedge x \tag{4-5}$$
$$Y(X) = 1237.6499*0.96123{}^\wedge x \tag{4-6}$$
$$Y(X) = 1045.45290*0.9459{}^\wedge x \tag{4-7}$$
$$Y(X) = 1129.8946*0.95929{}^\wedge x \tag{4-8}$$
$$Y(X) = 1211.6318*0.95953{}^\wedge x \tag{4-9}$$

Where:

Y- The expected Marshall stability value.

X- The immersion time in days.

Fig. 4.6 Relationship of Compaction Temperature Versus Marshall Stability of Asphalt Concrete Mixture Being Soaked in water for 2 Day at 60°C



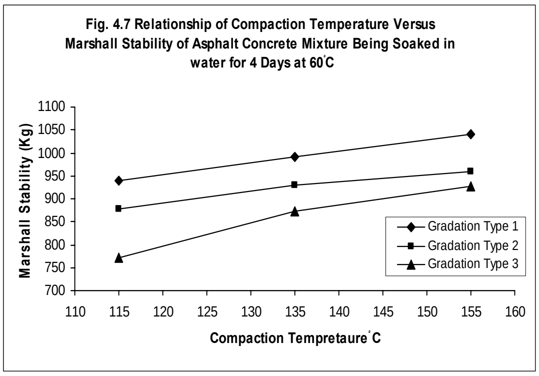


Fig. 4.7 Relationship of Compaction Temperature Versus Marshall Stability of Asphalt Concrete Mixture Being Soaked in water for 4 Days at 60°C

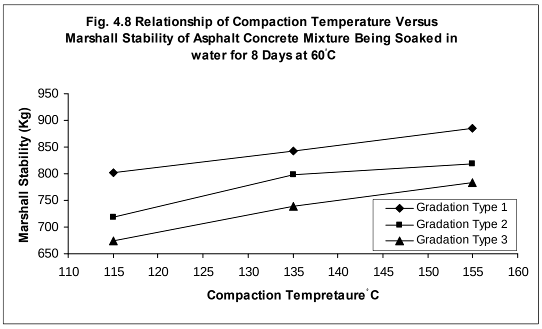


Fig. 4.8 Relationship of Compaction Temperature Versus Marshall Stability of Asphalt Concrete Mixture Being Soaked in water for 8 Days at 60°C

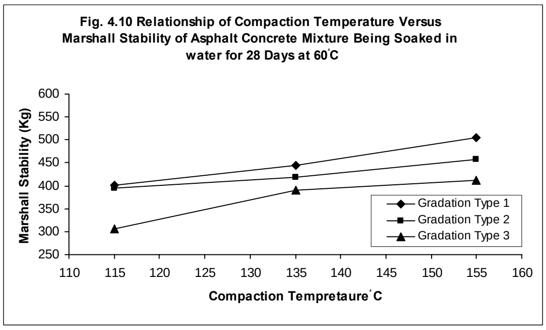


Fig. 4.10 Relationship of Compaction Temperature Versus Marshall Stability of Asphalt Concrete Mixture Being Soaked in water for 28 Days at 60°C

4-1-5 Effect of Compaction Temperature on Marshall Flow

Fig 4-11, 4-12, 4-13, 4-14, 4-15, 4-16 and 4-17 shows the relationship of compaction temperature versus Marshall flow for specimens immersed in a 60 ^{o}C water bath for 0, 1, 2, 4, 8, 14 and 28 days respectively. It is noticed that Marshall Flow decreases with the increase of compaction temperature and this is also true for all mixes containing different gradations. The increase of compaction temperature increased the workability; which increased the asphalt coating of the aggregate grains, and the filling of the micro pores with asphalt, theirfor the density of the mix increased which allowed flowing to decrease.

It was also noticed that Marshall Flow increases with the increase of the immersion time.

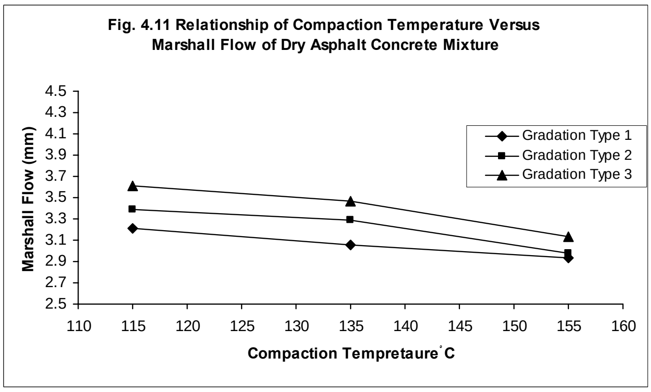


Fig. 4.11 Relationship of Compaction Temperature Versus Marshall Flow of Dry Asphalt Concrete Mixture

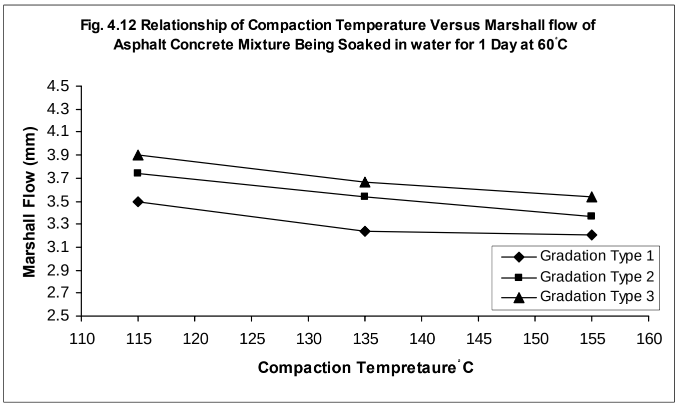


Fig. 4.12 Relationship of Compaction Temperature Versus Marshall flow of Asphalt Concrete Mixture Being Soaked in water for 1 Day at 60°C

Fig. 4.13 Relationship of Compaction Temperature Versus Marshall flow of Asphalt Concrete Mixture Being Soaked in water for 2 Days at 60°C

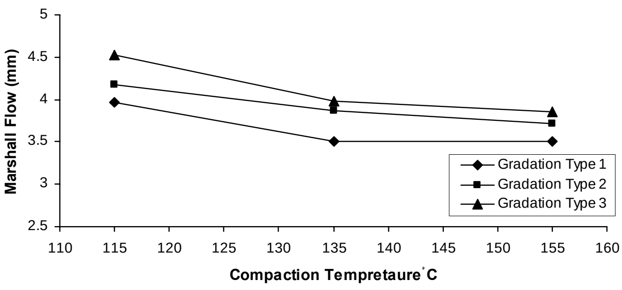


Fig. 4.14 Relationship of Compaction Temperature Versus Marshall flow of Asphalt Concrete Mixture Being Soaked in water for 4 Days at 60°C

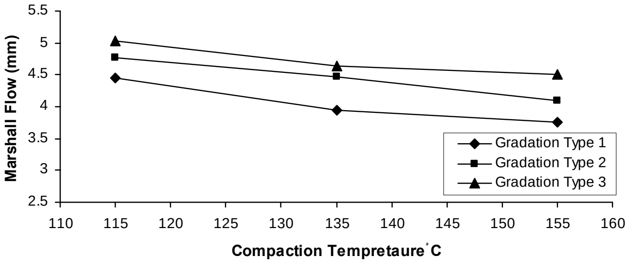


Fig. 4.15 Relationship of Compaction Temperature Versus Marshall flow of Asphalt Concrete Mixture Being Soaked in water for 8 Days at 60°C

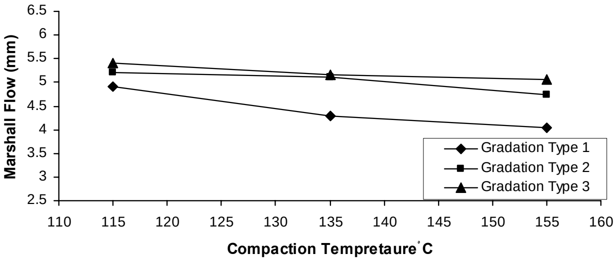


Fig. 4.16 Relationship of Compaction Temperature Versus Marshall flow of Asphalt Concrete Mixture Being Soaked in water for 14 Days at 60°C

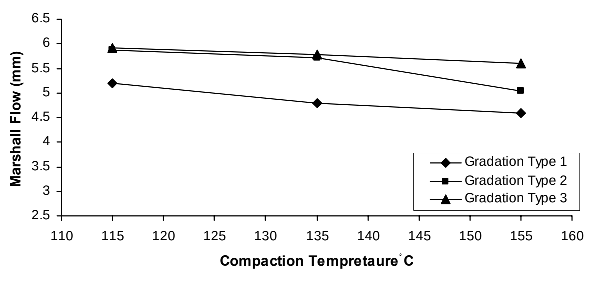
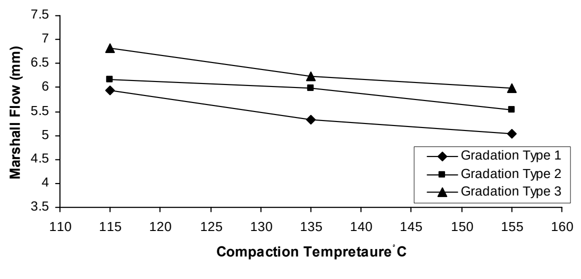


Fig. 4.17 Relationship of Compaction Temperature Versus Marshall flow of Asphalt Concrete Mixture Being Soaked in water for 28 Days at 60°C



4-1-6 Effect of Compaction Temperature on Stiffness

Fig 4-18, 4-19, 4-20, 4-21, 4-22, 4-23 and 4-24 shows the relationship of compaction temperatures versus stiffness. Stiffness is defined as the ratio of Marshall Stability to Marshall Flow. It is noticed that the stiffness increases with increase of compaction temperature, but decreases with immersion time, and this is true for all mixes containing different gradations. Stiffness is directly proportional to Marshall Stability and inversely proportional to Marshall Flow. Consequently, stiffness increased for all aggregate gradation types with the increase of compaction temperature.

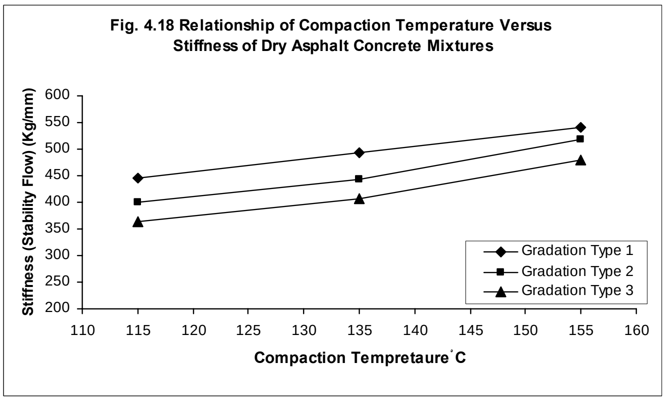
It could be concluded that gradation type 1 exhibited the highest value of stiffness, while gradation type 3 exhibited the lowest values of stiffness. In addition, it could be concluded Marshall Stiffness decreased with the increase of the immersion time. The loss in Marshall Stiffness can be expressed as in equations (4-10,4-11 and 4-12) for gradation type 1 , and as in equations (4-13,4-14 and 4-15) for gradation type 2 , and as in equations (4-16,4-17 and 4-18) for gradation type 3 ,at compaction temperature (115, 135 and 155) ± 3 ^{o}C respectively

$$Y(X) = 321.5676*0.94053^{x} \quad (4\text{-}10)$$
$$Y(X) = 372.8350*0.94241^{x} \quad (4\text{-}11)$$
$$Y(X) = 398.2961*0.94621^{x} \quad (4\text{-}12)$$
$$Y(X) = 277.3071*0.94186^{x} \quad (4\text{-}13)$$
$$Y(X) = 316.6231*0.94036^{x} \quad (4\text{-}14)$$
$$Y(X) = 351.8399*0.94320^{x} \quad (4\text{-}15)$$
$$Y(X) = 252.0891*0.93515^{x} \quad (4\text{-}16)$$
$$Y(X) = 288.9044*0.93988^{x} \quad (4\text{-}17)$$
$$Y(X) = 325.2235*0.93940^{x} \quad (4\text{-}18)$$

Where:

Y- The expected Marshall Stiffness value.

X- The immersion time in days.



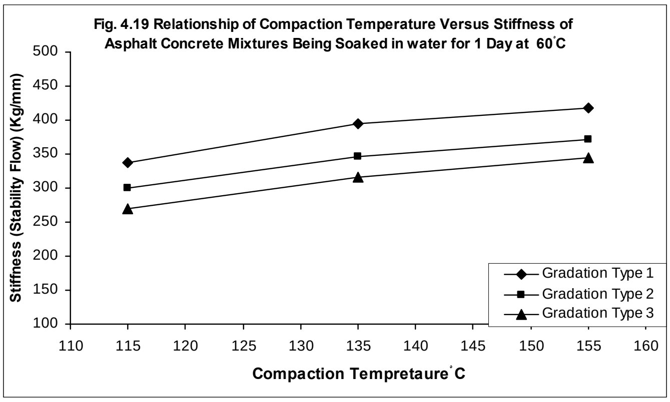


Fig. 4.19 Relationship of Compaction Temperature Versus Stiffness of Asphalt Concrete Mixtures Being Soaked in water for 1 Day at 60˚C

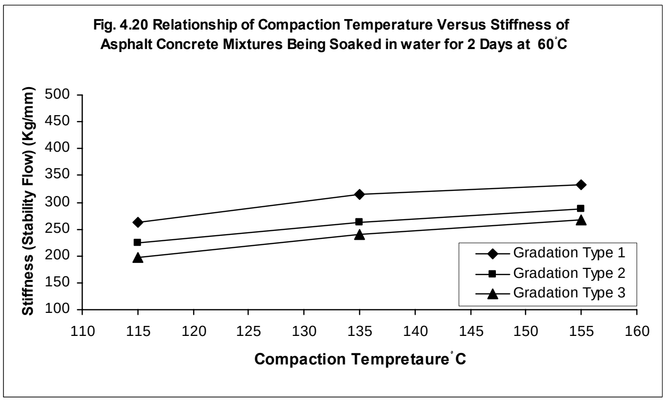


Fig. 4.20 Relationship of Compaction Temperature Versus Stiffness of Asphalt Concrete Mixtures Being Soaked in water for 2 Days at 60˚C

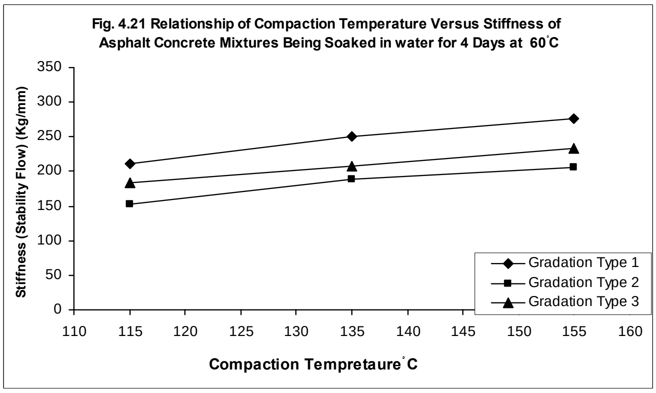


Fig. 4.21 Relationship of Compaction Temperature Versus Stiffness of Asphalt Concrete Mixtures Being Soaked in water for 4 Days at 60˚C

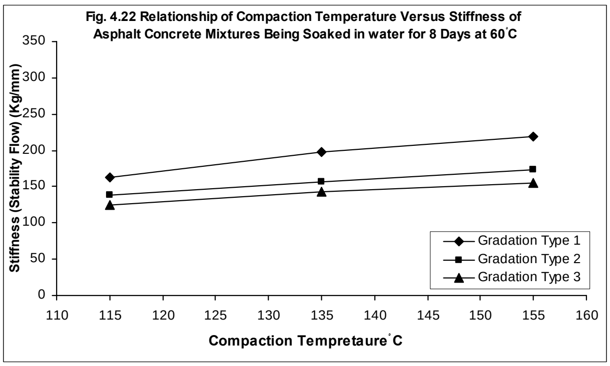


Fig. 4.22 Relationship of Compaction Temperature Versus Stiffness of Asphalt Concrete Mixtures Being Soaked in water for 8 Days at 60°C

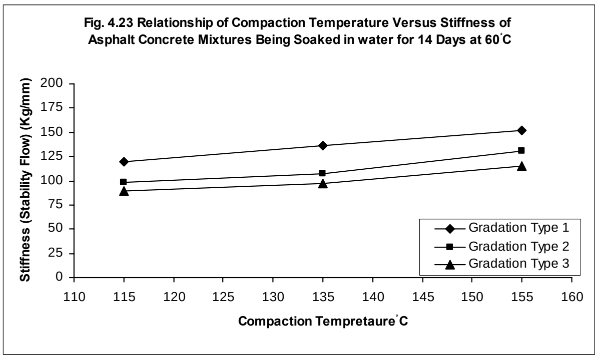


Fig. 4.23 Relationship of Compaction Temperature Versus Stiffness of Asphalt Concrete Mixtures Being Soaked in water for 14 Days at 60°C

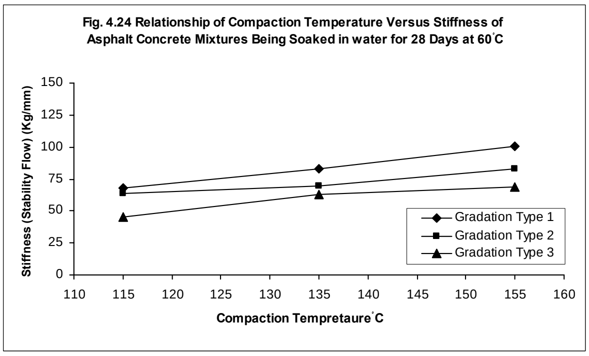


Fig. 4.24 Relationship of Compaction Temperature Versus Stiffness of Asphalt Concrete Mixtures Being Soaked in water for 28 Days at 60°C

4-2 Effect of Different Gradation Types of Aggregate and Compaction Temperature on the Durability of Bituminous Mixtures

4-2-1 Durability Curves.

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 temperature. High durability potential usually implies that the mechanical behavior of the mixture will endure for a long service life (5).

The durability potential of a given mixture was assessed by testing the mixture after immersion in a 60 ^{o}C water bath for 1, 2, 4, 8, 14 and 28 days. The mechanical criteria for durability in this research are retained Marshall Stability.

Based on these tests, a durability curve shows the relationship of retained Marshall stability versus log immersion time was plotted for each given mixture, as can be seen in Figures 4-25, 4-26, and 4-27 for three gradations.

The retained strength obtained by these tests has been adopted by some agencies as the criterion index for the durability potential of the mixture (6).

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 mechanical tests. In these research works, 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 conditions.

It was generally found that the one-day immersion criterion does not always reflect the durability behavior of the mixture after longer periods of immersion. Moreover, it was found by the researchers that different mixtures could reach a similar level of retained strength in a different manner after a given period of immersion, i.e. Some may keep a high level of strength during most of the immersion period, but deteriorate on the last day of the period, while other mixtures may deteriorate sharply on the first day or the second. But then keep the particular level of retained strength for a long period (4).

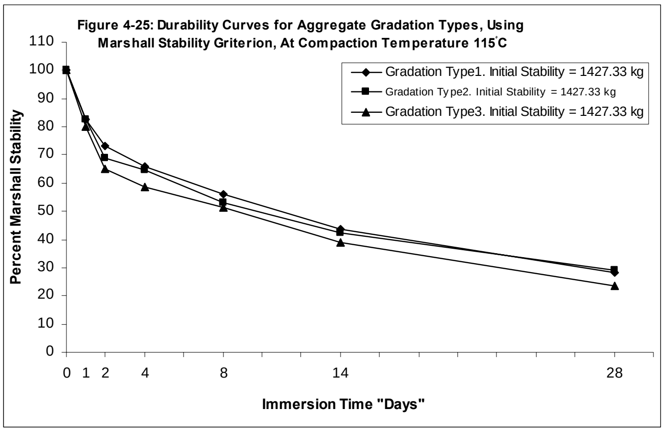


Figure 4-25: Durability Curves for Aggregate Gradation Types, Using Marshall Stability Griterion, At Compaction Temperature 115°C

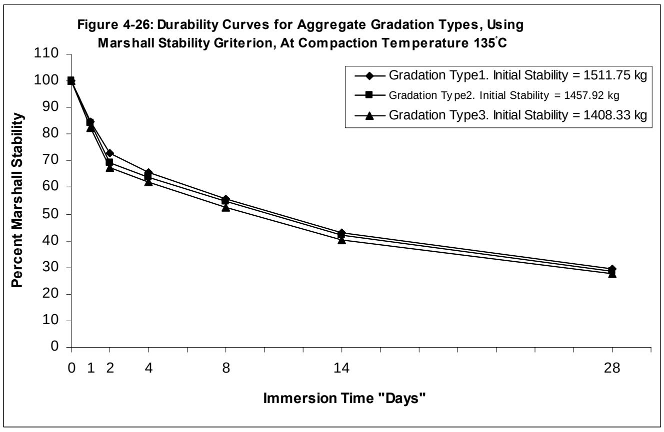


Figure 4-26: Durability Curves for Aggregate Gradation Types, Using Marshall Stability Griterion, At Compaction Temperature 135°C

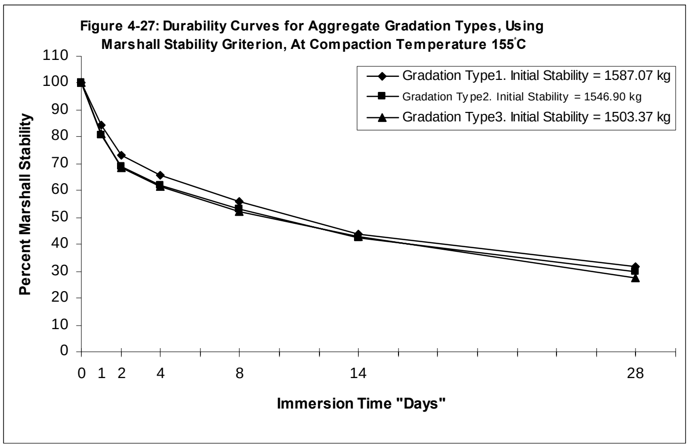


Figure 4-27: Durability Curves for Aggregate Gradation Types, Using Marshall Stability Griterion, At Compaction Temperature 155̊C

4-2-2 Basic Requirements for a Proposed Durability Index

From this 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”.

1-It should be rational and physically defined.

2-It should express both present retained strength and its absolute value.

3-It should define the durability potential for a flexible range immersion periods.

4-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 deferent mixtures. Two indices were found to satisfy most of the criteria listed above. They were adopted for the analysis of the durability test data in this research.

4-3 Durability Indices

4-3-1 First Durability Index

The first 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 4.28, this Index (r) is expressed as follows (5):

$$r = \sum_{i=0}^{n-1} \frac{s_i - s_{i+1}}{t_{i+1} - t_i} \qquad (4\text{-}19)$$

s_{i+1} - Percent retained strength at time t_{i+1}

s_i - Percent retained strength at time t_i

t_i, t_{i+1} - immersion periods (from beginning of test) specifically, when strength measurements were taken after 1, 2, 4, 8, 14, and 28 days of immersion, equation (4-19) was as follows (4):

$$r = \frac{s_0 - s_i}{1} + \frac{s_1 - s_2}{1} + \frac{s_2 - s_3}{2} + \frac{s_3 - s_4}{4} + \frac{s_4 - s_5}{6} + \frac{s_5 - s_6}{14} \qquad (4\text{-}20)$$

Practically, the first durability index expresses the percentage loss in strength as weighed for one day. Positive values of (r) indicate strength loss, while negative values indicate strength gain.

It is also possible to define the first durability index in terms of the absolute values of the weighed loss in strengths (R) as follows (5):

$$R = \frac{r}{100} s_0 \qquad (4\text{-}21)$$

Where:

s_0 - is the absolute value of the initial strength.

The units of (R) are the same units of (s_0), i.e. The units of the specific strength parameter used (Lb., Kg).

4-3-2 Second Durability Index

The second durability index is defined as average strength loss area enclosed between the durability curve and the line $s_0 = 100$ percent. Based on Figure 4-28 this index (a) is expressed as follows (5):

$$a = \frac{1}{t_n} \sum_{i=1}^{n} a_i = \frac{1}{2 t_n} \sum_{i=0}^{n-1} \left(s_i - s_{i+1}\right)\left[2 t_n - \left(t_i + t_{i+1}\right)\right] \qquad (4\text{-}22)$$

Where all the terms are defined in the Figure 4-28, or in Equation 4-1.

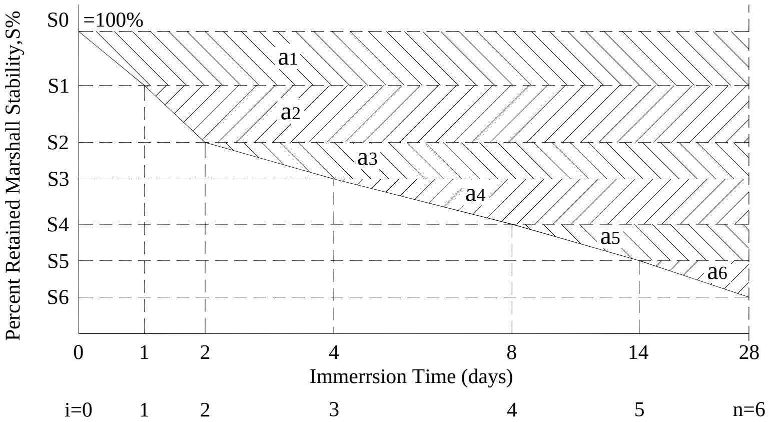


Figure 4.28: Schematic Description of Durability Curves, with the Parameters Defining the Durability Indices

It should be noted that the area increments a_i are defined and partitioned horizontally. Since they express the relative contribution of the immersion-period increments to the total loss on strength. In this respect, the relative weight of the early time increments is much higher than that of later ones.

The second durability index (a) also express an equivalent 24 hours strength loss. Again, Positive values of (a) indicate strength loss, negative values indicate strength gain. Under its definition, $a < 100$. Consequently, it is possible to express the percentage 24 hours equivalent retained strength (s_a) as follows (5):

$$s_a = (100 - a) \qquad (4\text{-}23)$$

It is also possible to define the second durability index in terms of the absolute values of the equivalent loss or retained Marshall stability (A and $\bar{S}_a$, respectively), as follows (5):

$$A = \frac{a}{100} s_0 \qquad (4\text{-}24)$$

$$\bar{S}_a = s_0 - A \qquad (4\text{-}25)$$

Figures 4-25, 4-26 and 4-27 present the durability curves as a function of aggregate gradation type, immersion time, compaction temperature and Marshall Stability criterion. These curves serve as a basis for the analysis of the various factors, which influence the durability characteristics of the mixtures.

It is meant here to point out that the decrease of stability percentage after one day of water immersion was less than that percentage decrease during the four and more days of water immersion.

Table 4-1 presents the values of the two durability indices as defined in Equation 4-19 through 4-25 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.

In general, both indices reflect a similar trend in their variability with gradation type and bitumen content. For any given gradation, however the second index seems to be more sensitive to higher values and higher-range strength loss at a given range of bitumen content.

Another advantage of the second index is its versatility in defining the values of the equivalent retained strength, by either percentage or the absolute values of the strength parameter “durability indices values”.

Figures 4-29, 4-30 and 4-31 show the relationship of the percentage of retained Marshall Stability versus the compaction temperature for different immersion periods. These Figures also show the relationship of the durability curve, as expressed by the durability index (a), to compaction temperature. As can be seen in Figures 4-29, 4-30, and 4-31 this curve is maintained throughout the entire immersion period, and is also reflected in the durability index.

Table 4-1 Values Of The Durability Indices For The Various Gradations

Gradation Type	Compaction Temperature °C	Basic Initial Marshall Stability (Kg)	First Durability Index		Second Durability Index			
			r (%) Eq.(4.19)	R (Kg) Eq.(4.21)	a (%) Eq.(4.22)	Sa (%) Eq.(4.23)	A (Kg) Eq.(4.24)	$\bar{S}_a$ (Kg) Eq.(4.25)
1	**115**	**1427.33**	**36.14**	**515.83**	**51.68**	**48.32**	**737.64**	**689.69**
	135	**1511.75**	**36.21**	**547.40**	**51.48**	**48.52**	**778.24**	**733.51**
	155	**1587.07**	**35.91**	**569.75**	**50.66**	**49.34**	**804.00**	**783.07**
2	**115**	**1356.65**	**38.81**	**526.51**	**52.82**	**47.18**	**716.58**	**640.07**
	135	**1457.92**	**38.74**	**564.79**	**52.73**	**47.27**	**768.76**	**689.16**
	155	**1546.90**	**39.43**	**609.94**	**52.91**	**47.09**	**818.46**	**728.44**
3	**115**	**1316.28**	**43.05**	**566.65**	**56.60**	**43.40**	**745.01**	**571.27**
	135	**1408.33**	**40.52**	**570.65**	**54.40**	**45.60**	**766.13**	**642.20**
	155	**1503.37**	**39.86**	**599.24**	**53.58**	**46.42**	**805.5**	**697.87**

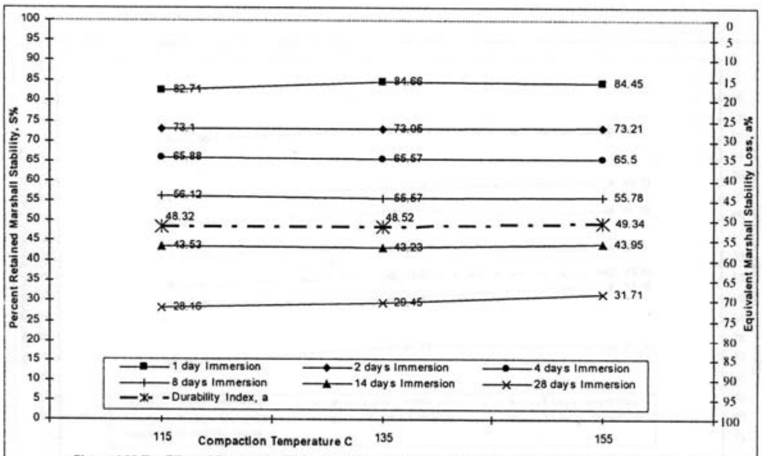


Figure 4-29 The Effect of Compaction Temperature on the Durallity Potential of the Mixtures Type 1 at Different Periods of Immersion, uning Marshall Stability Criterion

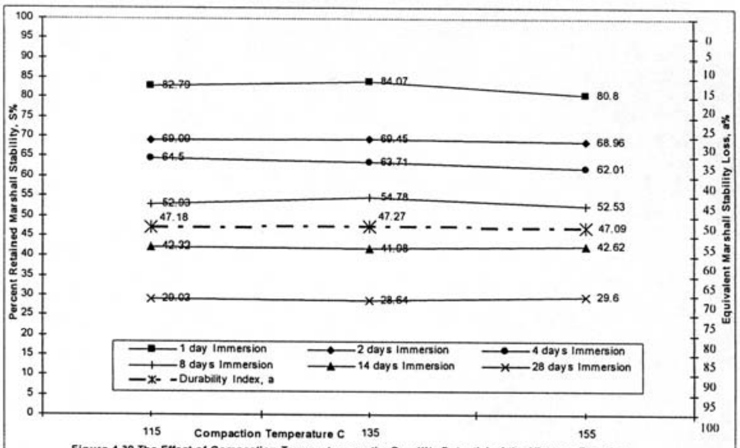


Figure 4-30 The Effect of Compaction Temperature on the Duraility Potential of the Mixtures Type 2 at Different Periods of Immersion, uning Marshall Stability Criterion

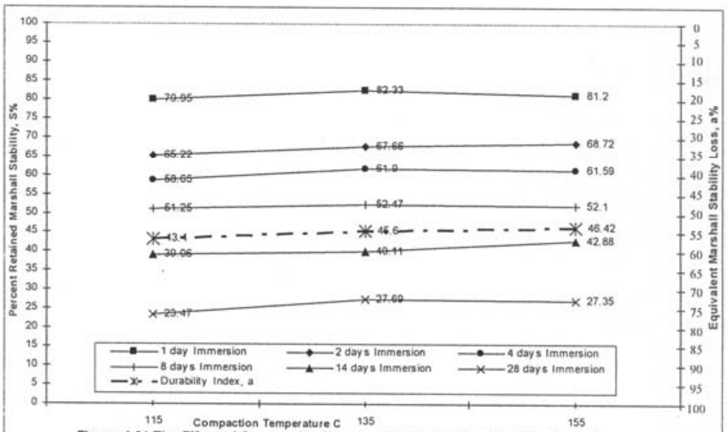


Figure 4-31 The Effect of Compaction Temperature on the Duraility Potential of the Mixtures Type 3 at Different Periods of Immersion, uning Marshall Stability Criterion

5- CONCLUSIONS AND RECOMMENDATIONS

This laboratory investigation presented a study of the influence of gradation types, compaction temperatures, and immersion times on the durability of asphalt concrete mixtures, using dolomite aggregates. It was clear that both compaction temperatures and immersion times greatly affect the durability of these mixes.

1-It was found that the bulk unit weight, Marshall stability and stiffness values of asphalt concrete mixtures increase with increase of compaction temperatures, while percent of air voids, percent of voids in the mineral aggregate (% V.M.A) decrease with increase of compaction temperatures at optimum bitumen contents.

2-Results show that the standard Marshall Stability values of mixtures at optimum binder contents are not useful for the prediction of the durability performance of these mixes when compared with immersion Marshall Stabilities.

3-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 gradually in the first day and rapidly after that.

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 8 days. It was evident that the 8 days water immersion period was more applicable than the one-day period on calculating the durability indices (R) and (S_a); 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 gradation type 1, for a longer period of immersion time.

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Received, 4 April, 2006.