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Moisture Susceptibility by AASHTO T283

Moisture Susceptibility Testing of Asphalt Mixture using the AASHTO T283 method

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Abstract—*This paper studies the performance of HMA containing aggregate from Sargodha city of Pakistan. The AASHTO T-283 is the most widely used test for evaluating moisture susceptibility and is based on comparing tensile strength ratios. In the first step, the optimal bitumen content was determined. The optimal binder content was determined by optimization of different factors that affect the performance of the asphalt mixture. In the second step, the 7 ± 1% air voids were maintained. Finally, AASHTO T-283 was used to measure the damage in the asphalt mix caused by the moisture. The asphalt samples were evaluated in dry and wet states. The results of the test would be helpful in understanding the performance of the binder and local aggregates for the moisture susceptibility.*

Keywords- *Asphalt samples, Moisture Susceptibility, Optimum Binder Content, Pavement, Tensile Strength Ratio*

1. INTRODUCTION

The presence of the unnecessary moisture deteriorates the quality of asphalt concrete mixture leading to the early failure of the pavement system (Vargas-Nordcbeck et al., 2016; Ahmad et al, 2018). For instance, the stripping occurs when the moisture damage weakens the bond between aggregate and the asphalt binder (Buss et al., 2016). Moisture damage is the decrease in durability and strength as a result of adhesion between aggregate and binder or decrease in cohesion within a binder (Mallick et al., 2015). LaCroix et al., 2016). In Pakistan, the damage caused by moisture has affected many roads in Pakistan. The fractional or entire loss of aggregate and binder can be observed at many places in the world (Arepalli et al., 2020). The poor selection of the crush and bituminous materials contributes to the pavement system failure. Also, the compatibility between the aggregate and bitumen is essential to prevent this failure (Baldi-Sevilla et al., 2017). Moisture damage can arise from a decreasing adhesive bond between the crush sample and bitumen. This failure can be prevented through the performance testing of the asphalt mixture. The analysis of the moisture-induced damage is a challenging problem for the transportation companies. Proper testing of the asphalt mixture could save considerable resources leading to improve the economical sustainability (Kumar and Anand, 2012). This testing may be performed using AASHTO T-283 test method which determines the air voids and saturation degree of the mixture (Khosla et al., 2000; Apeagyei et al., 2006; Han and Shiwakoti, 2016).

This paper uses AASHTO T-283 to test the moisture susceptibility of the asphalt mixture containing aggregates from the hills in Sargodha city of Pakistan. In the first step, the binder content of the optimal bitumen or binder content was determined. For this purpose, the correlation was determined among the binder content and the various factors that affect the asphalt mixture. These factors include the bulk density of sample (gm/cc), air voids (%), voids in mineral aggregates (VMA) (%), voids filled with asphalt (VFA) (%), stability (kg), and flow value (0.1 inch). Air voids more than the recommended limit may cause various issues such as exposure to excessive air and water and damage with traffic loads. Air voids should be 7 ± 1%. (Khosla et al., 2000; Choubane et al., 2000). A minimum level of air voids should be maintained to prevent the instability of the pavement system. Voids in mineral aggregate (VMA) can be defined as the inter-granular voids covered by air and asphalt in the compacted mixture of asphalt (Aschenbrener and McGennis, 1994; Abd El-Hakim et al., 2019). Voids filled with asphalt (VFA) are the voids in mineral aggregate (VMA) which contain asphalt binder. Stability (in kg) represents the strength of the asphalt mixture. It is the maximum load which can be carried by the compacted asphalt at 60°C. Flow represents the flexibility of the asphalt mixture. It is the change in the diameter of the asphalt sample when the load is applied. In the second step, the 7 ± 1% air voids were maintained. In the final step, AASHTO T-283 was used to measure the damage in the asphalt mix caused by the moisture.

II. METHODOLOGY

This section describes the materials and methods used in this study. The AASHTO T-283 test procedure used in this test to analyze the moisture induced damage of asphalt mixture. This method is explained by a flow chart presented at the end of this section. This test is involved in three steps. In the first step, the asphalt mixture samples were prepared and the Marshall Mix Design method was used to identify the optimum binder content. In the second step, 7 ± 1% air voids were achieved. In the final step, AASHTO T283 was performed to test the moisture susceptibility testing of asphalt mixture.

2.1. Materials

The granite is used as an aggregate obtained from Karana Hills located at 16 kilometers distance from Sargodha city of Pakistan. The aggregate gradation met the requirements of National Highway Authority (NHA) Class B. This study used asphalt as a binder or bitumen without any additive. Table 1 enlists some physical properties of aggregate and binder along with their results.

Table 1. Physical Properties of Aggregate and binder

Aggregate			Binder		
Property	**Standards**	**Results**	**Property**	**Standards**	**Results**
Abrasion	ASTM C-131	23%	Penetration	ASTM D5	67 dm
Elongation	ASTM D4791	16.7%	Softening point	ASTM D36	47°C
Bulk spec. gravity	AASHTO T-166	2.64	Flash point	ASTM D92	320°C
Water absorption	AASHTO T-166	18%	Solubility	ASTMD2042	99.9%

2.2 Determination of stability and flow value

For the sample preparation, 1250 gm of aggregate crush was heated at appropriate temperature. First of all, 3% binder was heated at 120°C temperature. The binder and aggregate sample were completely blended in a mixer and placed in an oven at 163°C. The mixture was placed in a mould firmed by a rammer with 50 blows. The mass of mix aggregates was compacted to the thickness of 2.5 inches. The same procedure was repeated for the binder contents of 3.5%, 4.0%, 4.5%, and 5.0%. The optimum value of binder or bitumen was 4.2%. The prepared samples were placed in a water bath at 60°C temperature. Then, the stability and flow were determined using Marshall Stability and flow test. In the Marshall Stability and flow test, the recommended limit for the stability is > 330 kg and the recommended limit for the flow value is 9-18 mm.

2.3 Attainment of 7% air voids

After the determination of the optimum value of bitumen contents (4.2%), the samples were prepared for the determination of the number of blows which should gain 7 ± 1% air voids. For this purpose, many trials were performed with different number of blows such as 25, 30, 35, 40, 45, 50, and so on.

2.4 The application of in-house AASHTO T-283

The nine samples of the asphalt mixer were taken for the testing with in-house AASHTO T-283. Six samples were needed for two sub groups (three sample each) one sample in loose for calculations of G_{mm} (if not given) and remaining two samples are for trial purposes. The asphalt mixture was cooled for 100-130 minutes at room temperature and placed in the oven for 16 hours for curing at 60°C. Then, the sample was placed in the oven for 120 minutes at 130-140°C before the compaction. Then, the sample was compacted at required number of blows (calculated earlier) to obtain 7 ± 1% air voids. One specimen was reserved in loose form for the calculation of G_{mm}. The samples are detached from the moulds and placed for 3-4 days at room temperature (Figure 1).

After the four days of curing, the assessment and tests of every sample is given below.

1. Calculation of G_{mm} as per standard of AASHTO T-209
2. Measurement of thickness (t) and diameter (D)
3. Calculation of (G_{mb}) as per standard of AASHTO T-166 (Figure 2)

The volume (E) of sample is calculated by subtracting the sample mass in water from the saturated, surface-dry weight of the sample.

Figure 1. Samples for Curing

Figure 2. Calculations of G_{mb}

Percentage air voids of each sample is measured and grouped them in two subsets (three specimens each) such that both the subgroups have average air voids are approximately equal. One subset will be tested as dry ITS and the other subset will be tested as wet (conditioned) ITS. The volume of the air voids (V_a) in cubic centimeters is calculated as follows.

$$V_a = \frac{PV'}{100}$$

Here $\mathbf{V_a}$ volume of air voids in cm^3, **P** air voids in percentage and **V'** volume of the sample in cm^3.

After the grouping, the dry subset samples are folded with plastic/tape in a waterproof plastic bag. Then, the specimens were put in a water bath 25°C for 110-130 minutes as shown in Figure 3.

Figure 3. Samples in Water Tub

Samples of conditioned subgroup are positioned in a vacuum pot supported at least 1 inch over the container base. (Figure 4). The container is full of distilled water at room temperature such that the samples have minimum 1 inch of water over their top side. A vacuum of 10-26 inch of Hg is exercised for about 10 minutes (Figure 5). The vacuum is detached and the sample is remaining submerged in water for at least 10 minutes.

Figure 4. Samples in vacuum bottle

Figure 5. Application of vacuum

The volume of immersed water (V_i) in cm^3 is measured by the given formula.

$$V_i = M_{SSD} - M_D$$

Where, $\mathbf{M_{SSD}}$ is mass of the SSD sample after vacuum application in gm and $\mathbf{M_D}$ is mass of the dry sample in air in gm.

The extent of saturation in % ($\mathbf{S^d}$) is measured by using the given formula:

$$S^d = 100\ V_i/V_a$$

As per standard of AASHTO T283 the value of $\mathbf{S^d}$ ranges between 55-80. The Asphalt Institute advises the $\mathbf{S^d}$ ranges between 70 to 80 percent.

Due to the following of AASHTO standards, range of 55-80% is considered in the experiment. AASHTO T283 says if S^d

- $\mathbf{S^d}$ value is within the range then the experiment should proceed further.
- $\mathbf{S^d}$ value is less than 50%, the vacuum practice is done with more vacuum/time.
- $\mathbf{S^d}$ value is greater than 80% then the sample is useless and should be removed and vacuum process repeated with another sample.

Samples, with 55-80% degree of saturation, are covered with a plastic layer and place them in a water tight plastic bag (having 10 ml water) and sealed the bag. These covered samples are then put in a freezer at temperature of -18°C for one day (Figure 6). The samples were taken from the freezer and the plastic cover was removed. (Figure 7).

Figure 6. Samples in the freezer

Figure 7. Sample taken out from the freezer

Then, the samples were placed in a water bath for one day at 60°C. Finally, the water bath was filled in such a way that the water top surface is one inch of the samples (Figure 8).

Figure 8. Wet subset samples in water bath at 60°C

After 24 hours in the water bath, the samples are removed and then put in a 25°C water bath for 110-130 minutes. After the conditioning, the wet samples were fixed diametrically in the steel bearing plates of testing machine (Figure 9). A consistent force was applied at a rate of 2 inches/minutes.

Force was applied till the sample cracked. After the loading the machine loading was stopped and loading pattern against the deformation can be taken from the computer system attached with the machine (Figure 10). Broken pieces of sample can be taken for visual inspection.

Figure 9. Sample in Testing Machine

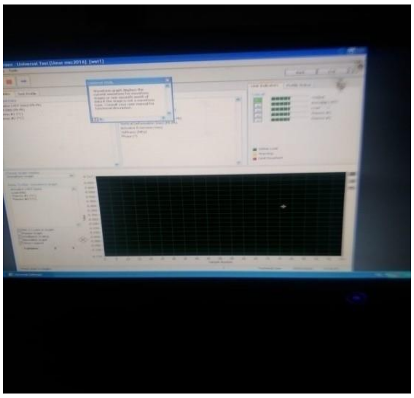


Figure 10. Display layout of computer

Moisture damage can be controlled through attainment of particular limits of the tensile strength ratios (Lee et al., 2015). The tensile strength is calculated using the following equation:

English units:

$$S_t = \frac{2F}{\pi t D}$$

S_t = tensile strength, psi
F = maximum load, lbs
t = specimen thickness, in.
D = specimen diameter, in.

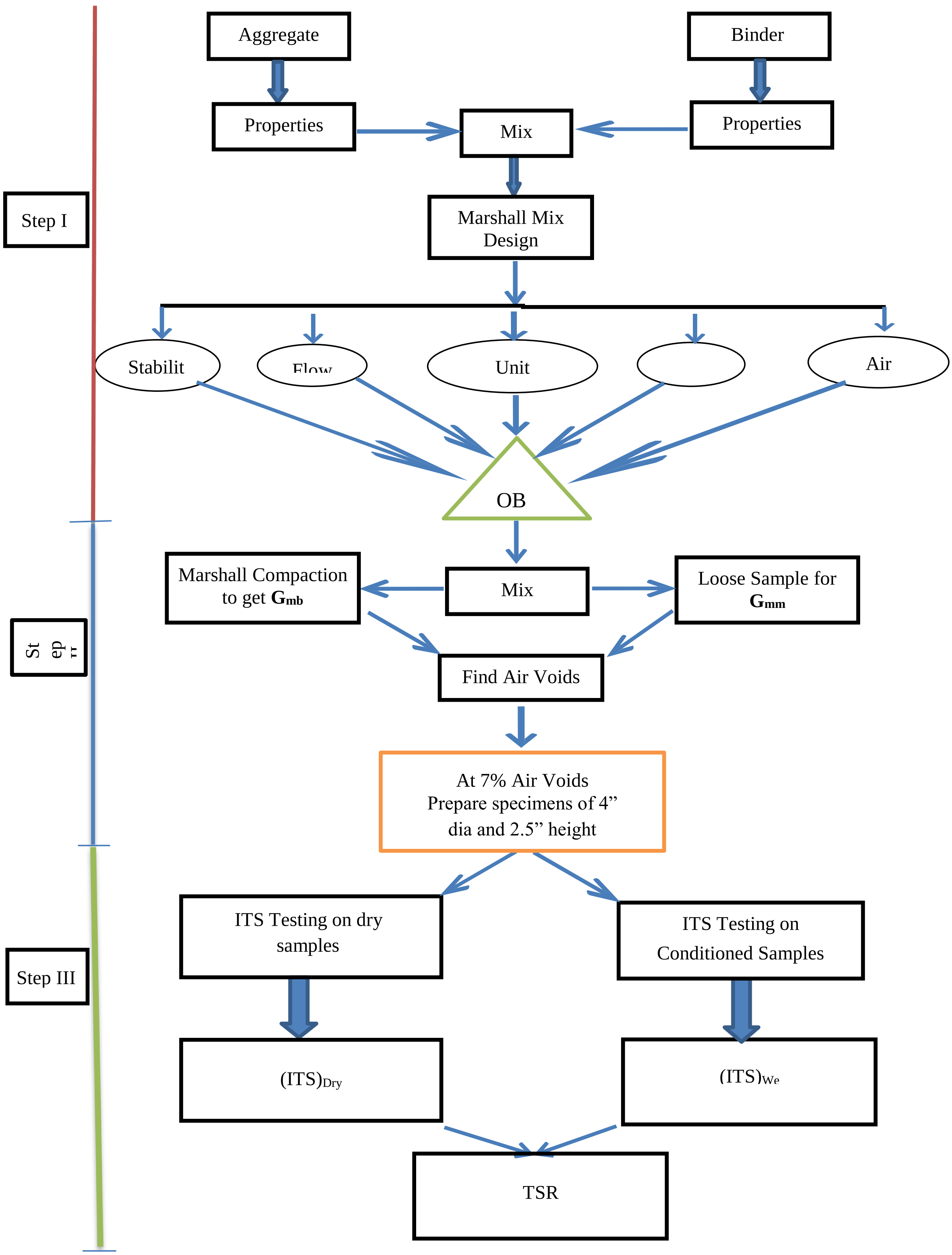
SI units:

$$S_t = \frac{2000F}{\pi t D}$$

St = tensile strength, kPa
F = maximum load, N
t = specimen thickness, mm
D = specimen diameter, mm

The TSR is resulted as follows:

$$\text{Tensile Strength Ratio (TSR)} = \frac{S'}{S''}$$



Flow Chart Diagram of Complete Experiment

III. RESULTS AND DISCUSSION

This section discusses the key results of this study.

3.1 Optimization of binder contents

Table 2. Different Factors that Affect the Asphalt Mixture

Binder content (%)	Bulk density of sample (gm/cc)	Air voids (%)	Voids in mineral aggregates (VMA) (%)	Voids filled with asphalt (VFA) (%)	Stability (kg)	Flow value (0.1 inch)
3.0	2.41	7.4	14.4	46	1372	2.5
3.5	2.43	6.3	14.1	55	1500	2.6
4.0	2.46	4.4	13.5	67	1640	3.0
4.5	2.45	3.9	14.2	72	1599	3.2
5.0	2.44	3.7	15.1	75	1490	3.7

The key results can be interpreted as follows.

- Bulk density of the sample was maximum 2.46 at 4% binder content (Figure 11). Further increase in the binder quantity resulted in a decrease in density.
- Air voids percentage was maximum 7.4 at 3% binder content. Further increase in binder quantity resulted in a decrease in air voids (Figure 12). This shows that the air voids decrease with an increase in binder content (Kar et al., 2019).
- Voids in mineral aggregates (VMA) percentage was minimum 13.5 at 4% binder content. Further increase in binder quantity resulted in decrease in VMA (Figure 13).
- Voids filled with asphalt (VFA) were maximum 75% at 5% binder content. Further increase in binder quantity resulted in a decrease in VFA (Figure 14).
- Stability was maximum 1640 at 4% binder content (Figure 15). Further increase in the binder quantity resulted in a decrease in stability. In the Marshall Stability and flow test, the recommended limit for the stability is > 330 kg and the recommended limit for the flow value is 9-18 mm. Flow value increased with an increase in binder content (Figure 16).

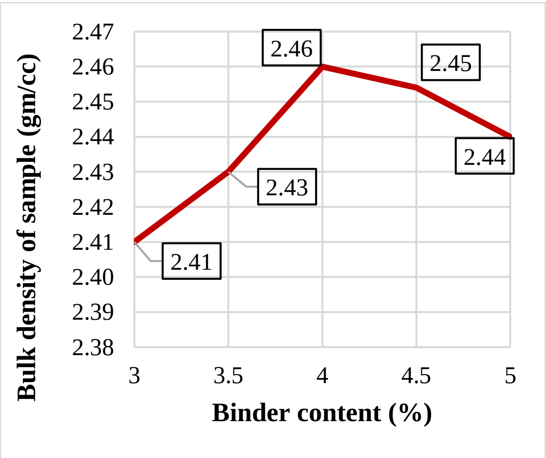


Figure 11

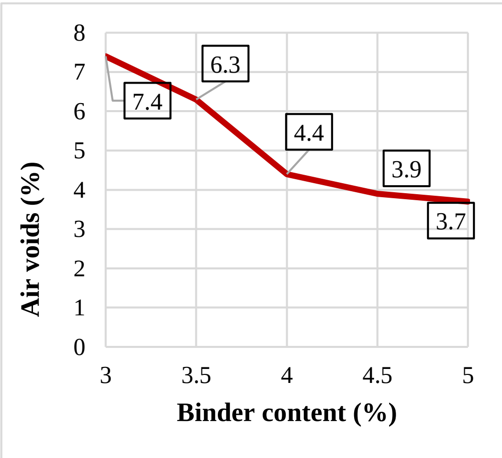


Figure 12

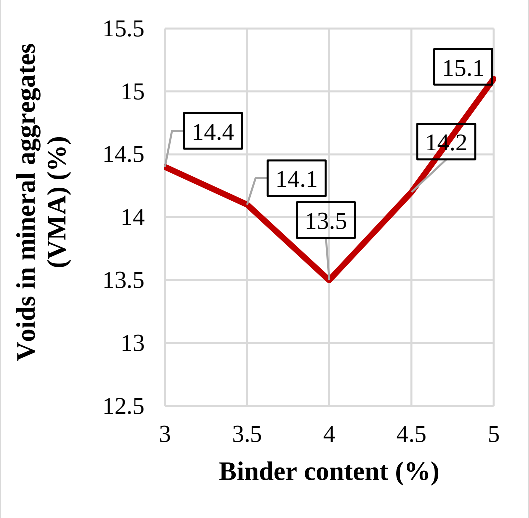


Figure 13

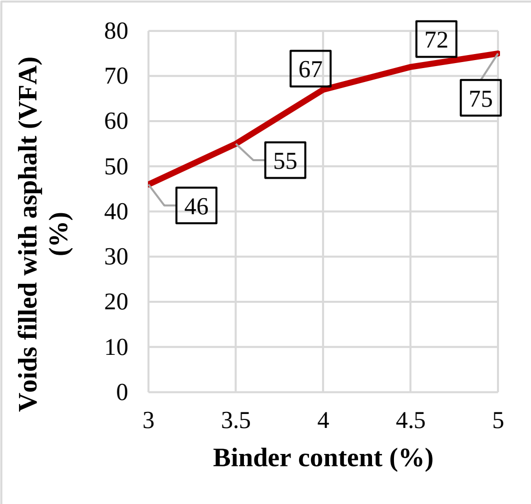


Figure 14

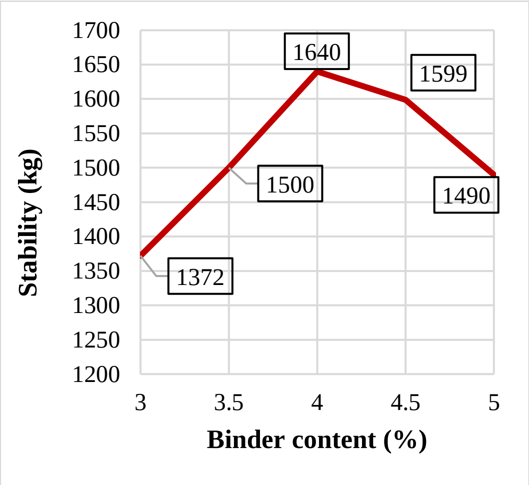


Figure 15

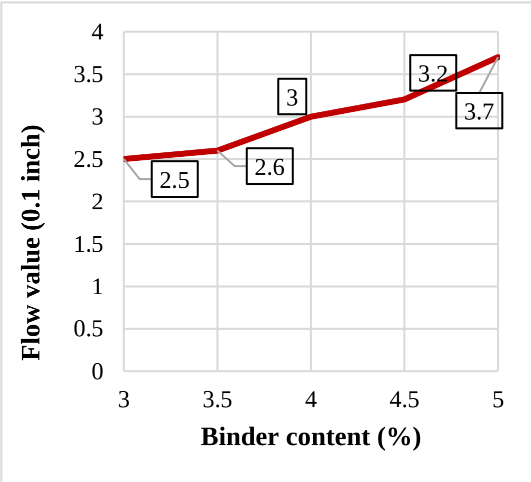


Figure 16

3.2 Attainment of air voids at 7 ± 1%

Air voids should be 7 ± 1% (LaCroix et al., 2016). In the following, the air voids have been attained to this limit.

3.2.1 Calculation of G_{mb}

$$G_{mb} = \frac{A}{C-B}$$

Table 3. Calculations of G_{mb}

Sample Number	Dry weight (gm)	Sub weight (gm)	SSD weight (gm)	G_{mb}
25-1	1190.7	695.9	1206.5	2.332
25-2	1202.1	705.1	1225.9	2.308
40-1	1157.1	676.0	1174.2	2.323
40-2	1170.4	685.8	1191.7	2.314
50-1	1239.0	735.6	1243.0	2.442
50-2	1246.1	733.8	1266.7	2.338
75-1	1240.6	740.1	1246.7	2.449
75-2	1252.3	741.2	1259.5	2.416

3.2.2 Calculation of G_{mm} and Air Voids

$$G_{mm} = \frac{A}{A+D+E}$$

$$\text{Air Voids (\%)} = (1 - G_{mb}/G_{mm}) \times 100$$

Table 4. Calculations of G_{mm} and Air Voids

Sample Number	Sample Dry weight (A) (gm)	Sample + Flask+ H_2O (D) (gm)	Flask + H_2O (E) (gm)	G_{mm}	G_{mb}	Air Voids	Average
25-1	1182.0	2761.5	2048.4	2.521	2.332	7.460	7.29
25-2	1188.0	2758.3	2048.4	2.485	2.308	7.123	
40-1	1147.4	2735.0	2048.4	2.490	2.323	6.707	6.61
40-2	1156.2	2734.0	2048.4	2.457	2.314	6.505	
50-1	1242.0	2811.7	2048.4	2.595	2.442	5.896	6.04
50-2	1232.0	2786.0	2048.4	2.492	2.338	6.179	
75-1	1236.2	2801.0	2048.4	2.556	2.449	4.186	4.25
75-2	1242.8	2799.0	2048.4	2.525	2.416	4.317	

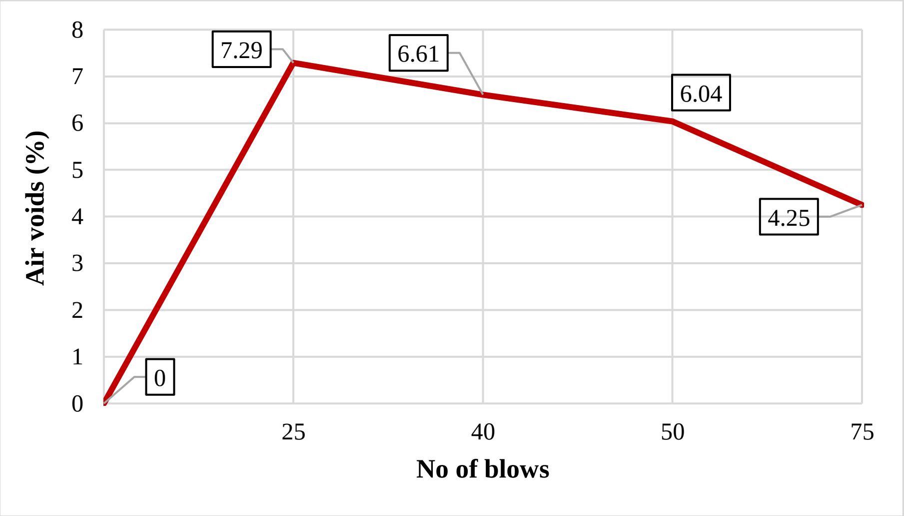


Figure 17. Correlation between No. of Blows and Air Voids

3.3 Application of AASHTO T-283

In the following, the AASHTO T-283 has been used to test the moisture susceptibility.

3.3.1 Calculation of G_{mm}

$$G_{mm} = \frac{A}{A+D+E}$$

A = 962.1 gm
D = 1975.9 gm
E = 2556.3 gm

$$G_{mm} = 2.521$$

3.3.2 Calculation of Air Voids

Table 5. Calculations of Air Voids

Sample No.	Thickness (cm)	Dia (cm)	Volume (cm^3)	Dry wt (gm)	Sub wt (gm)	SSD wt (gm)	G_{mb}	Air Voids (%)
1	6.25	10	490.6	1132.9	664.4	1146.2	2.351	6.706
2	6.27	10	492.2	1123.0	657.3	1133.9	2.356	6.508
3	6.23	10	489.1	1146.8	668.7	1158.7	2.340	7.143
4	6.2	10	486.7	1140.0	668.0	1151.2	2.359	6.389
5	6.33	9.9	487.1	1146.3	666.6	1158.7	2.329	7.579
6	6.27	10	492.2	1138.1	662.6	1151.0	2.330	7.539
7	6.21	10	487.5	1144.5	668.6	1157.6	2.340	7.143
8	6.2	10	486.7	1151.8	669.0	1162.1	2.336	7.302

All the samples were so arranged in two subsets of three sample each. The average air voids of both the sub-groups was almost same as per directions of standard.

Subset of samples for dry ITS having sample number 3, 7 and 8

Subset of samples for wet ITS having sample number 4, 5 and 6

3.3.2 Calculations for degree of saturation (S^d)

The following are some formulae used in Table 6.

$$S^d = 100\, V_i/V_a$$

$$V_i = M_{ssd} - M_d$$

$$V_a = \frac{PV'}{100}$$

Table 6. Degree of Saturation

Sample No.	Volume (V')	Air voids (P)	Volume of air voids (V_a)	Dry mass (M_d)	SSD mass (M_{ssd})	Volume of absorbed water (V_i)	Degree of saturation (S^d)	Status
4	486.7	6.389	31.10	1140	1166	26	83.61	Rejected
5	487.1	7.579	36.92	1146.3	1175	28.7	77.74	OK
6	492.2	7.539	37.11	1138.1	1166.5	28.4	76.54	OK
1	490.6	6.701	32.88	1132.9	1152.7	19.8	60.23	OK

4.3.6 Calculations of indirect tensile strength and tensile strength ratio

$$S_t = \frac{2000F}{\pi t D}$$

Table 7. Indirect Tensile Strength

Sample		P (N)	D (mm)	t (mm)	S_t (kPa)
Dry	3	10886	100	62.3	1112.963
	7	11186	100	62.1	1147.317
	8	11485	100	62	1179.885
Wet	1	8395	100	62.5	855.5414
	5	8595	99	63.3	873.5893
	6	8495	100	62.7	862.971

$$\text{Tensile Strength Ratio (TSR)} = \frac{S'}{S''}$$

S’ = S_t of the dry subgroup, psi (kPa)

S” = S_t of the wet subgroup, psi (kP)

Table 8. Tensile Strength Ratio

Sample Group	Load (Dry) kN	ITS (Dry) kPa	Load (wet) kN	ITS (Wet) kPa	TSR (%)
1	10.89	1112.49	8.40	855.15	76.87
2	11.19	1146.77	8.50	854.40	74.50
3	11.49	1179.37	8.60	872.73	74.00

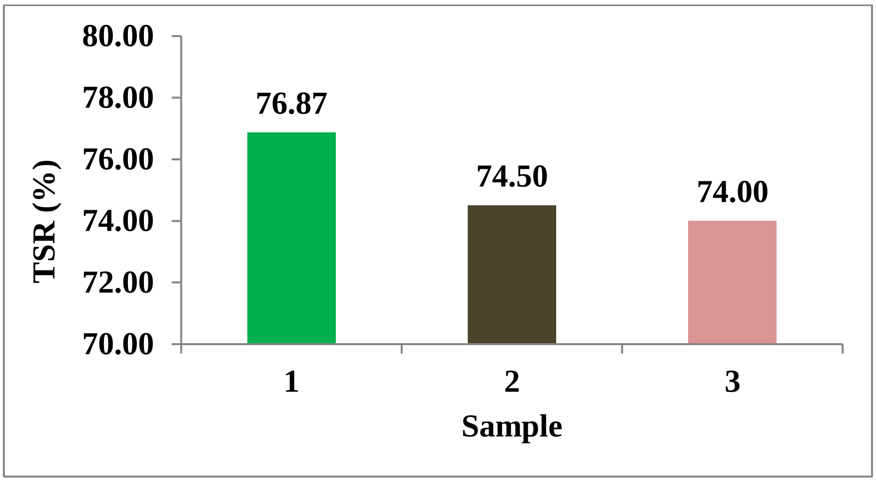


Figure 22. TSR of Mix Design

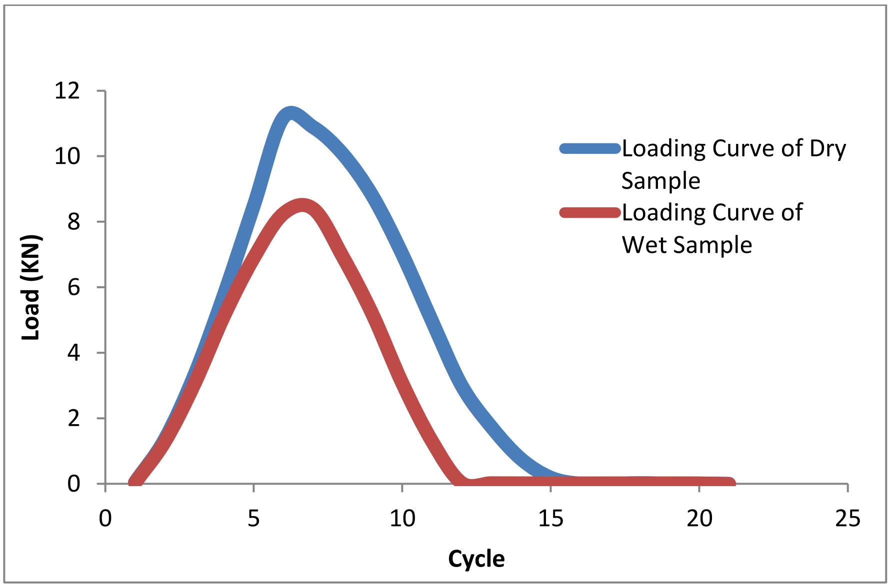


Figure 23. Comparison of Average Loading Curves of Dry and Conditioned Samples

IV. CONCLUSION

This paper performed the AASHTO T283 procedure to test the moisture susceptibility of the asphalt mixture containing the local aggregate of Sargodha crush. The average tensile strength ratio achieved was 75% which is less than the recommended value (i.e. 80%). Hence, the aggregate is somewhat susceptible to moisture damage. The test was performed to understand the AASTO T283 procedure within the limited resources of the lab. The variation of the results from the standards value of 80% may be due to some reasons. It may be due to the compaction issue, as test was performed on Marshall Test apparatus so chances of variation in application of load during compaction and handling the samples while placement.

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