Effect of Compaction Temperature on Marshall Properties of Bituminous Concrete

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Abstract: The properties of Hot Mix Asphalt (HMA) paving materials depend upon the mixing temperature and compaction temperature. In determining the Optimum Binder Content (OBC) during designing of Hot Mix Asphalt (HMA) by Marshall Method, the mixing temperature and compaction temperature shall be kept 160˚C and 140˚C respectively. The density voids analysis of laboratory compacted Marshall Specimens depends upon the compaction temperature. To understand the acceptable range of laboratory compaction temperature during designing of HMA, the present study was undertaken.

The design of Bituminous Concrete (BC) which is most commonly used HMA as surface course was carried out by Marshall Stability method and Optimum Binder Content (OBC) was determined at compaction temperature of 140˚C. At OBC, Marshall Specimens at different compaction temperatures such as 140˚C, 125˚C, 110˚C, 95˚C and 80˚C were prepared and tested to find the Marshall Parameters.

On the basis of test results, it has been observed that there is minor variation in the properties of mix by decreasing the compaction temperature from 140˚C to 110˚C, however drastic change in the properties of the mix has been observed as compaction temperature falls below 110˚C. On the basis of this study it has been suggested that during evaluation of various properties of HMA in the laboratory, due consideration should be given to compaction temperature otherwise the results would not show true behavior of HMA.

Keywords: Hot Mix Asphalt, Optimum Binder Content, Marshall Stability, Compaction Temperature.

1. INTRODUCTION

India has a road network of over 5,472,144 kilometres (3,400,233 mi) as on 31 March 2015, the second largest road network in the world. In India, flexible pavements are widely used in the construction of roads, highways, bridge decks, pavements in airports and other areas with heavy wheel loads. The reasons for such a widespread utilization are lower construction cost, low curing period, the road can be used within 24 hours, good point load carrying capacity, skid resistance, ease of maintenance and repair, ability to accommodate movement of under laying layers due to climatic changes or load deformation.
Temperature is a key factor influencing viscosity of bitumen, which affects its ability to coat and provide adequate coating for the aggregates in HMA paving mixes.

Saedi Houman [1] investigated the effect of compaction temperature from 85˚C to 160˚C on Marshall Properties of HMA and concluded that best temperature for laboratory compaction is 145˚C. It was also stated that Marshall Properties change drastically over 145˚C and below 115˚C. Ahmed Hassan Youness [2] conducted Marshall Stability test at different compaction temperature ranging from 70˚C to 140˚C, with an interval of 10˚C on bituminous mixture and suggested that from temperature range of 140°C to 110°C, there is variation up to 10% in the properties of HMA. At the same time below 110°C, mixture properties changes drastically. Kori Sharanabasappa [3] studied the effect of mixing and compaction temperatures on the indirect tensile strength (ITS) of bituminous concrete mix prepared using polymer modified bitumen (PMB). It was observed by authors that ITS of BC mix increase by 36% due to increase of compaction temperature from 90°C to 140°C. Due to availability of limited literature, authors decided to take up the present study.

The objectives of the present study are as follows:
1. Characterization of aggregates and bitumen binder.
2. To finalize the job mix formula for Bituminous Concrete (Grading 1) by Marshall Stability test.
3. To investigate the effect of laboratory compaction temperature on Marshall Parameters.

2. METHODOLOGY & EXPERIMENTAL WORK

2.1 Methodology

For the present study, stone aggregates of size 20mm, 10mm, stone dust and bitumen of grade VG-30 were procured locally. The physical properties of aggregates and bitumen were determined as per relevant protocol.

Proportioning of aggregates was done as per requirement of MoRTH for BC (Grading 1) on the basis of gradation of aggregates. The design of BC was carried out by Marshall Stability method and Optimum Binder Content (OBC) was determined corresponding to maximum bulk density, maximum stability and 4% air voids.

At OBC, five series of Marshall Specimens at varying compaction temperature such as 140˚C, 125˚C, 110˚C, 95˚C and 80˚C were prepared as per method specified by ASTM D6926 [4]. The results of experimental work have been presented as follows.

2.2 Experimental Work

The physical properties of aggregates and bitumen were determined as per relevant IS codes and the test results are presented in Table 1 and Table 2 respectively.

Table – 1: Test Results of Aggregates

Properties	Test Method	Obtained Values	IS Specifications
Grain Size Analysis	IS 2386 Part 1 [5]	3.18	Maximum 5% passing 0.075mm
Flakiness and Elongation Index	IS 2386 Part 1 [5]	25.6	Maximum 35% Combined
Impact Value	IS 2386 Part 4 [6]	22.4	Maximum 24%
Abrasion Value	IS 2386 Part 4 [6]	25.7	Maximum 30%
Water Absorption	IS 2386 Part 3 [7]	0.48	Maximum 2%
Specific Gravity	IS 2386 Part 3 [7]	2.55 (20mm) 2.58 (10mm) 2.60 (Stone Dust)	2.5-3

Table - 2:Test Results of Bitumen

Test	Test Method	Test Results	Specifications as per IS 73 (2007) [12]
Ductility	IS - 1208 [8]	100cm	Minimum 40cm
Specific Gravity	IS - 1202 [9]	1.01	Minimum 0.99
Softening Point	IS - 1205 [10]	52˚C	>47ºC
Viscosity	IS - 1206 [11]	385cST	Minimum 350cST

2.3 Proportioning of Aggregates

Aggregates comprise as much as 60% to 80% of a typical bituminous mix, so they must be properly selected to be durable, blended for optimum efficiency, and properly controlled to produce consistent strength, work ability, finishing, and durability. In Jaipur City, majority area is connected by bituminous roads. Apart from construction of new roads, major work done is in the field of resurfacing of existing roads. For resurfacing, Bituminous Concrete, Grading 1 is used.

By trial and error method, the proportioning of aggregates was carried out. The achieved gradation is well in between the upper and lower limit as shown by Figure 1.

Table – 3: Composition of Bituminous Concrete Layer, Grading 1 (MoRTH-2013) [13]

Sieve Size (mm)	20mm (30%)	10mm (30%)	Stone Dust (40%)	Achieved Gradation	Desired Gradation
26.5	30.00	30.00	40.00	100.00	100
19	27.88	30.00	40.00	97.88	90-100
13.2	7.40	27.15	40.00	74.55	59-79
9.5	1.07	22.65	40.00	63.72	52-72
4.75	0.00	14.31	30.23	44.54	35-55
2.36	0.00	11.07	20.68	31.75	28-44
1.18	0.00	8.03	15.42	23.45	20-34
0.6	0.00	6.44	11.12	17.56	15-27
0.3	0.00	4.37	7.72	12.09	10-20
0.150	0.00	2.61	4.20	6.81	5-13
0.075	0.00	1.14	2.04	3.18	2-8

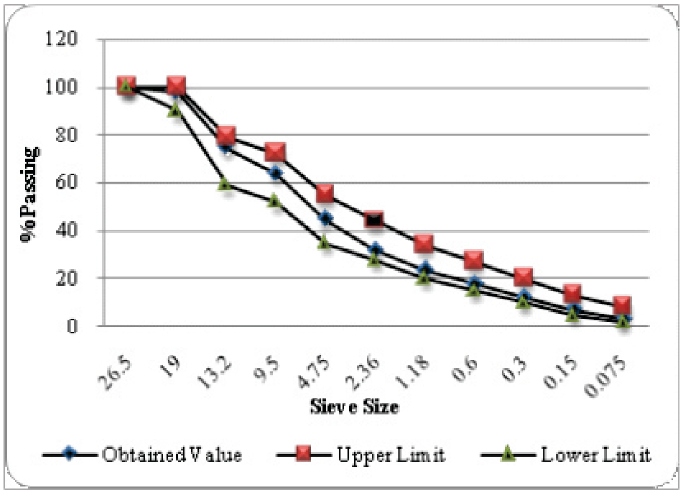

Figure 1: Gradation of aggregates

3. ANALYSIS OF RESULTS

To determine the OBC, Marshall Specimens were prepared at bitumen content of 4%, 4.5%, 5%, 5.5% and 6%. Three specimens at each bitumen content were prepared and tested. The OBC was determined on the basis of maximum Bulk Density, maximum Stability and 4% Air Voids which is shown in Table 4.

Table – 4: Optimum Binder Content

Maximum Bulk Density	6%
Maximum Stability	5%
Bitumen Content corresponding to 4% Air Voids	5.75%
Average Bitumen Content	5.6%
Bitumen Content corresponding to total mix	5.3%

At OBC, specimens were prepared for all five series of compaction temperature. In this way a total of thirty Marshall Specimens were prepared and tested for Marshall Parameters.

The average of three specimens was taken for laboratory investigations. The results of laboratory investigations are as reported below.

3.1 Bulk Density

Bulk Density is involved in most key mix design calculations including air voids, VMA and VFB. Relation between compaction temperature and bulk density is shown in Figure 2. It has been observed that by decreasing the compaction temperature from 140°C to 110°C, there is very minor decrease (0.87%) in bulk density. On further reducing of compaction temperature from 110°C to 80°C, there is huge decrease (10.18%) in bulk density, which might be due to the reason that below 110˚C, the viscosity of bitumen increases. At high viscosity workability of mix decreases and hence results in decrease of density.

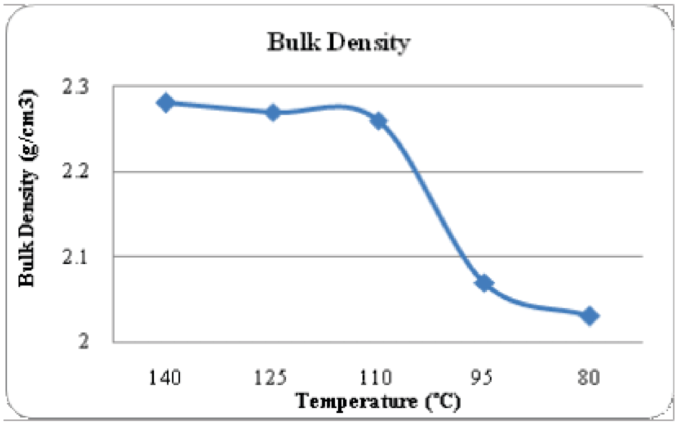

Figure – 2: Graphical representation of Bulk Density

3.2 Air Voids

Air voids are small air spaces or pockets of air that occur between the coated aggregate particles in the final compacted mix. A certain percentage of air voids is necessary in all bituminous mixes to allow some additional pavement compaction under traffic and to provide spaces into which small amounts of asphalt can flow during this subsequent compaction. Relation between compaction temperature and air voids is shown in Figure 3. It is observed that when compaction temperature reduces from 140˚C to 110˚C, percentage air voids increases by 16.94%. The values up to 110˚C are still under the specifications of MoRTH. But on further reducing the temperature from 110°C to 80˚C, air voids increased by 201%. This is because at low temperature, the resistance to compaction offered by the mix increases which results in increase in air voids

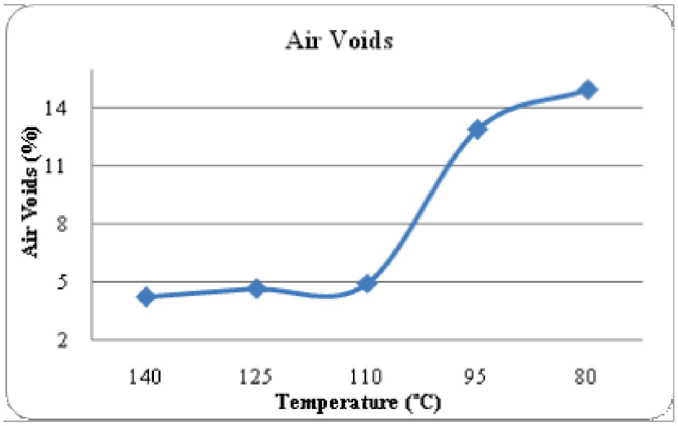

Figure – 3: Graphical Representation of Air Voids

3.3 Volume of Bitumen (V_b)

The volume of bitumen is the percent of volume of bitumen to the total volume. Relation between compaction temperature and V_b is shown in Figure 5. The value of V_b has a very slight decrease of 0.7% when compaction temperature reduces from 140˚C to 110˚C but on further reducing in compaction temperature from 110˚C to 80°C, the values decreases by 11.15%. This is because the percentage of bitumen used is same at all compaction temperatures but the value of total volume is increasing on decreasing compaction temperature. So, the value of V_b is decreasing.

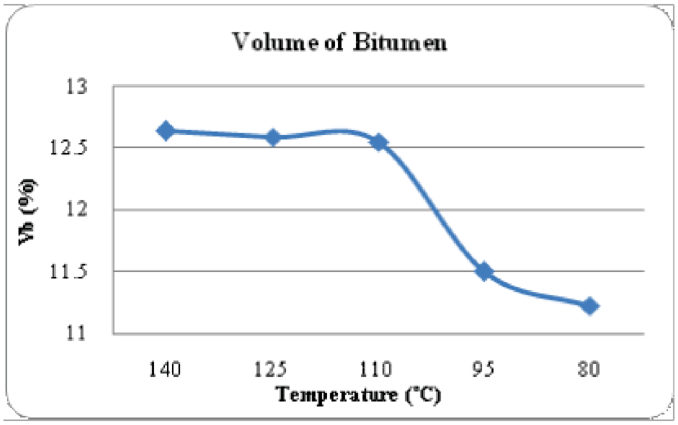

Figure – 4: Graphical Representation of V_b

3.4 Voids in Mineral Aggregates (VMA)

Voids in mineral aggregates is the volume of intergranular void space between the aggregate particles of a compacted mix that includes the air voids and bitumen content, expressed as a percent of the total volume of the sample. Relation between compaction temperature and VMA is shown in Figure 5. The value of VMA has a very slight increase of 3.7% when compaction temperature reduces from 140˚C to 110˚C but on further reducing in compaction temperature from 110˚C to 80°C, the values increases by 55.06%. This is because VMA is significantly affected by compaction temperature below 110˚C. The bituminous mix is difficult to compact as the temperature decreases because the viscosity of bitumen significantly increases.

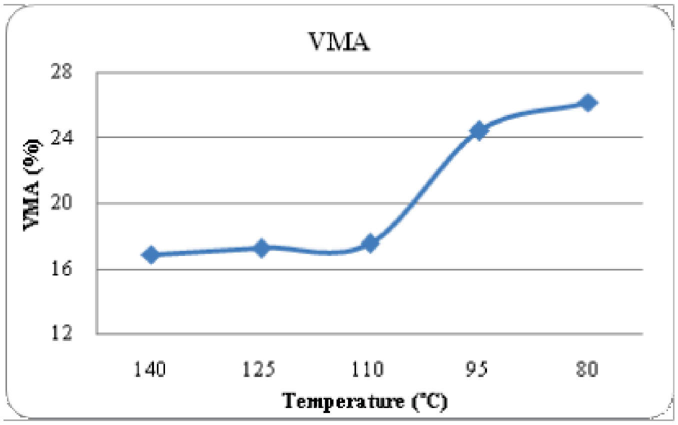

Figure – 5: Graphical Representation of VMA

3.5 Voids Filled with Bitumen (VFB)

Voids filled with bitumen is portion of the volume of intergranular void space between the aggregate particles (VMA) that is occupied by bitumen. Relation between compaction temperature and VFB is shown in Figure 6. Same scenario is seen here also. The value of VFB has a small change of 4.26% when compaction temperature reduces from 140˚C to 110˚C. But on further decreasing the temperature from 110˚C to 80°C, the value falls by 42.68%. This is because VFB is the percentage volume of bitumen in VMA. As the value of VMA increases, the value of VFB decreases.

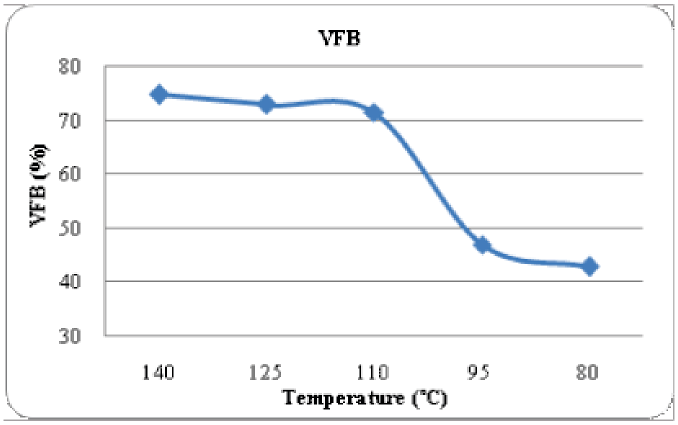

Figure – 6: Graphical Representation of VFB

3.6 Marshall Stability

Stability is the maximum load sustained by the bituminous mix. Relation between compaction temperature and Stability is shown in Figure 7. Marshall Stability value reduces by 24% on reducing compaction temperature from 140˚C to 110˚C. When compaction temperature further reduces from 110˚C to 80°C, marshall stability decreases by 74.8%. This is because at low temperature proper lubrication of aggregate particle doesn't takes place which in turn results in improper bonding between the aggregates.

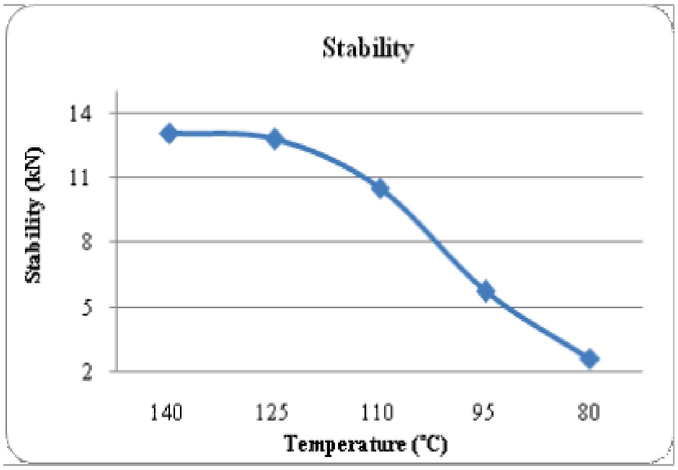

Figure – 7: Graphical Representation of Stability

3.7 Flow

Flow is the deformation of Marshall specimen under load. Relation between compaction temperature and flow is shown in Figure 8. It is shown that the flow value is increased by 43% as temperature reduced from 140˚C to 110˚C, but the value is within the limits specified by MoRTH. When the compaction temperature is further decreases from 110°C to 80°C, the flow value increases by 59.5%. This is attributed to that, at low temperature the percentage of voids of total mixture is high than that at higher temperature. This causes air space for the aggregate particle to deform and this increases flow value.

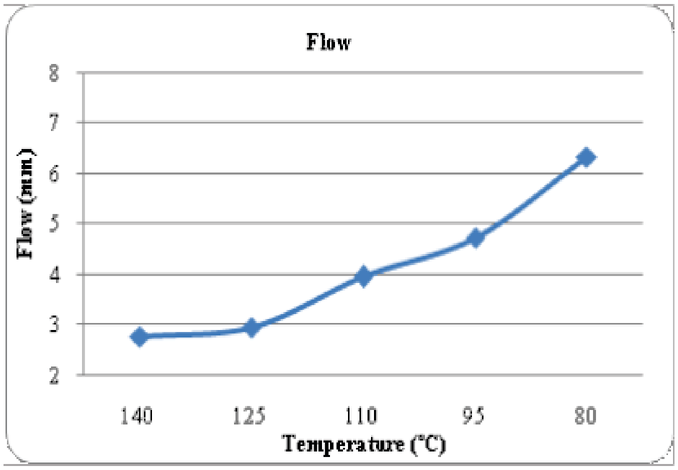

Figure – 8: Graphical Representation of Flow

4. CONCLUSIONS

On the basis of above study, it is concluded that best suitable laboratory compaction temperature for Bituminous Concrete is 140˚C but in any circumstances it should not go below 110˚C. The properties of bituminous mixes in the range of compaction temperature from 140˚C to 110˚C are within the permissible limits specified by MoRTH but below 110˚C, there is a drastic change in the properties of the mix.

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