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Laboratory Study on effect of Air voids on performance of Bituminous mixes

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Abstract — *India is one of the countries having the largest road network where majority of the roads are paved with bitumen-based macadamized roads with a thin bituminous surfacing or a premix carpet as a wearing course. Bituminous roads are mainly composed of naturally available aggregates and hot bitumen/asphalt, where aggregate makes up 90-95 percent by weight of Hot Mix Asphalt (HMA). There are variations in aggregate gradation during preparation of bituminous mixes in hot mix plant to leads to variation in air voids in mix. Hence it is required to study the effect of these variations in air voids on performance of bituminous mixes. Among the various type of bituminous paving mixes in India, Bituminous Concrete (BC) mix having dense grading specification (as per Ministry of Road Transport and Highways (MoRTH))has been used as a wearing course in a pavement structure to distribute stresses caused by heavily trafficked loading and to protect underlying unbound layers from the effects of water. Hence, is important to analyze that how the variation in aggregate gradation within the specified limits can affect the essential mix design properties of bituminous mix.*

Keywords- *Bituminous concrete, hot mix asphalt**,** Marshall method of mix design, Air voids.*

I. INTRODUCTION

Today, road transport is the major leading mode of transportation in India and by any reckoning it proves to be the lifeblood of India's economy because of the industrial developments and economic benefits associated with a road development project. Due to these motives, development of a modern road network has become one of the vital agendas of various countries. India is currently having a road network of 4.69 million kilometers [1], where the total road length of India has increased more than 11 times during the 60 years between 1951 and 2011. From 3.99 lakh kilometer as on 31 March 1951, the road length has increased to 46.90 lakh kilometers as on 31 March 2011.Majority of roads in India are flexible pavements having primarily bitumen-based macadamized roads with a thin bituminous surfacing or a premix carpet as a wearing course and Hot Mix Asphalt (HMA) is widely used bituminous material from many years for construction of flexible pavements. As per the layer to layer choice of materials and it's sizes get changed after doing gradation. Designing a bituminous mix to meet the desired requirements of a particular paving project requires careful selection of the compatible aggregate source, aggregate gradation and bitumen grade to sustain till its design life. Basically in a batch mix or in a drum mix plant, aggregates and binder are added in designated amounts to make up one batch, where the aggregates are obtained from the nearest quarry. In a quarry, the gradation of each stock pile aggregate material is determined first and then gradations are analyzed to determine in what proportion the aggregates from different stock piles can be combined to produce a specific gradation which lies with the specified gradation limit of MoRTH. This variation in gradation limit tends to affects almost all the vital properties of HMA, including stiffness, stability, durability, permeability, workability, fatigue resistance and resistance to moisture damage. Therefore, it is important to analyze that how the variation in aggregate gradation of Indian bituminous paving mixes (Bituminous Concrete) can affect the essential mix design properties within the specified limits of Ministry of Road Transport and Highways (MoRTH) **-**(Fifth Revision) 2013.

II. OBJECTIVE

The present paper aims to highlight the variability involved in the aggregate gradation of laboratory and field produced mixes. The primary purposes of the research are the following:

i. To determine the Optimum Binder Content (OBC) of bituminous mixes for the various aggregate gradations by using Marshall Method of mix design.
ii. To evaluate Marshall Stability, Marshall Flow and Volumetric properties of consists different Air Voids Of bituminous mixes.

III. PROBLEM STATEMENT

Bitumen are widely used in road construction largely because they are relatively inexpensive and generally provide good durability in paving mixtures. In addition, bituminous pavements are generally characterized by their immediate serviceability, good riding quality and absence of joints. However, bitumen is not a panacea. As an organic substance, bitumen can age harden, i.e. increase in viscosity, which results in significant deterioration of the serviceability of bituminous paving materials. When the bitumen is hardened, the asphalt mixture will become brittle and its ability to support traffic-induced stresses and strains may significantly reduce, leading to deterioration of the pavement by readily-induced cracking. In addition, excessive hardening can also weaken the adhesion between the bitumen and aggregate, resulting in loss of materials at the surface layer and generate weakening of the asphalt mixture.

IV. NEED OF STUDY

There are variations in aggregate gradation during preparation of bituminous mixes in hot mix plant to leads to variation in air voids in mix. Hence it is required to study the effect of these variations in air voids on performance of bituminous mixes.

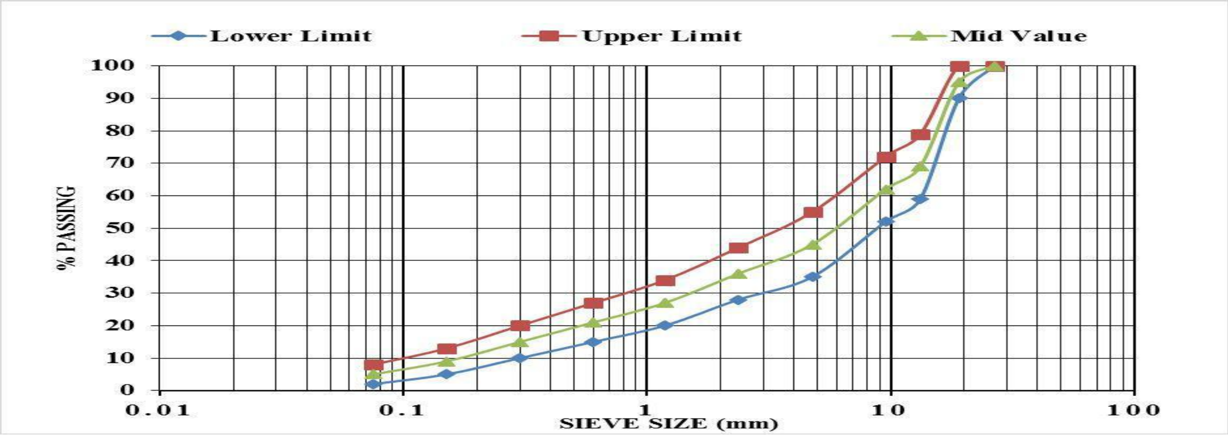
V. LETRATURE REVIEW

The performance of a bituminous mixture depends on external and internal conditions; the external conditions being traffic load and environmental and the internal conditions being properties of the materials, structure of the mixture, design of the mixture, and process of the construction (Chowdhury et al., 2001). Bituminous mixture consists of bitumen binder, aggregates and air voids. The properties of a bituminous mixture depend on the quality of its components, the construction process, and the mix design proportions (Coree and Hislop, 2000). Gradation is defined as the distribution of particle sizes expressed as a percent of the total weight. If the specific gravities of the aggregates used are similar, the gradation in volume will be similar to the gradation in weight. Roberts et al. (1996) suggested that gradation is perhaps the most important property which affects almost all the important properties of a bituminous mixture, including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage. Permanent deformation in bituminous pavements, commonly referred to rutting, usually consists of longitudinal depressions in the wheel paths, which are an accumulation of small amounts of unrecoverable deformation caused by each load application (Sousa et al., 1991). Bitumen binders are visco-elastic materials whose resistance to deformation under load is very sensitive to loading time and temperature (Ramond et al., 1999). The bitumen viscosity directly affects the strength of bituminous concrete in compression (rutting) for the practical range of temperatures. The log of pavement resistance and of cohesion varies directly with the log of asphalt viscosity. Modulus of elasticity in compression was influenced by the type of asphalt, temperature and amount of lateral confinement (William et al., 1967). Brown and Snaith (1974) suggested that the increase in deformation is related to the decrease in binder viscosity at high temperatures (40^{o}C), thereby leading to a lower interlock between the aggregates. The contribution of the aggregate skeleton towards the behavior of the mixture becomes more significant at higher temperatures.

VI. EXPERIMENTAL PROGRAMME

Bituminous paving mixes (BM, DBM, SDBC & BC) specified in the MORTH Specifications (2013) only BC-1 mix design is carried out. There is bitumen binder (VG-30) used to prepare the bituminous mixture specimens. Extensively, the properties of three aggregate gradations limit (upper limit, mid-point range and lower limit) for BC-1 grading was studied to signify the influence of variation on the mix design properties of bituminous mixes using Marshall Method of mix design. Further, verification of aggregate and binder specification is done according to MoRTH-2013 (Fifth revision) and IS: 73- 2006 [9]. Crushed stone aggregates (coarse, fine and filler) were used to prepare the bituminous mixture specimens. Maximum size and aggregate grading are directly controlled by the specifications (MORTH -2013). Three aggregate gradations for each mix as described below were selected:

- Gradation U: Upper limit of gradation range. The nominal size of this gradation is 13 mm for BC-1 mix.
- Gradation M: Midpoint of gradation range. The nominal size of this gradation is 19 mm for BC-1 mix.
- Gradation L: The lower limits of gradation range. The nominal size of this gradation is 19 mm for BC-1 mix.



"Fig. 1 Aggregate Gradation of Bituminous Concrete (BC)-1 Mix"

VII. MATERIALS CHARACTERIZATION

1. AGGREGATE

Aggregate used in this study is crusher aggregate from Chikhli Quarry. The sizes of aggregate used are 20 mm, 10mm and Stone Dust (SD) as per recommendation of MORTH Section 509 for nominal size of aggregate 19 mm. The physical properties of aggregate are shown in **Table 1.1** which satisfies the MoRTH 2013 specifications.

"Table 1.1 Properties of Aggregates"

Property	Test Method	Stone Dust	10 mm	20 mm	MoRTH, 2013 Specifications
Aggregate Impact Value	IS 2386 (Part IV)-2002	8.75			24% max
Water Absorption	IS 2386 (Part III)-2002	1.96	1.76	1.00	2% max
Specific Gravity	IS 2386 (Part III)-2002	2.614	2.766	2.877	2.5-3.0
Flakiness and Elongation Index	IS 2386 (Part I)-2002	27.93			35% max
Stripping Value Test	IS : 6241-1971	98%			Minimum retained coating 95%

2. BITUMEN

Bitumen is often referred to as visco-elastic materials, behaving as elastic solids at low temperature and viscous liquids at high temperature. In the present study, VG-30 grade of bitumen has been used. Physical tests are conducted to check the suitability of binder for the preparation of bituminous mix. Results obtained from laboratory testing are presented in **Table 1.2** and it satisfies the requirements as per IS 73:2013.

"Table 1.2 Properties of Bitumen (VG-30)"

Property	Test Method	Test Results	Repeatability	Requirements as per IS 73:2013 for VG 30
Penetration 25°C ,100 g, 5 s, 0.1mm	IS 1203-1978	54	3%	Min 45
Softening point (R & B),°C	IS 1205-1978	48	1°C	Min 47
Ductility Test, 25°C, cm	IS 1208-1978	100+	10%	Min 75
Absolute viscosity at 60°C, Poises	IS 1206 (Part 2)-1978	2732	7%	2400-3600

VIII. PERFORMANCE EVALUATION OF BITUMINOUS MIXES

1. TENSILE STRENGTH RATIO (TSR) TEST

The degree of susceptibility to moisture damage is determined by preparing a set of laboratory-compacted specimens conforming to the job-mix formula. It measures the splitting tensile strength by the application of a diametric compressive force on cylindrical bituminous mix specimen placed with its axis horizontal. Tensile strength ratio is determined according to AASHTO T283, which is the ratio of wet tensile strength to dry tensile strength of Marshall Specimens. For conditioning of dry samples, Marshall Samples are soaked in water for 30 minutes at 25^{0}C or are put in air chamber for 4 hours at 25^{0}C. For the conditioning of wet samples, the samples are placed in water bath for 24 hours at 60^{0}C and then placed in water bath at 25 °C for 2 hours. Then using Marshall Stability apparatus, Marshall Samples are loaded with compressive load and load at which specimen fails is measured as shown in **Figure 2**.

The tensile strength is calculated as given below:

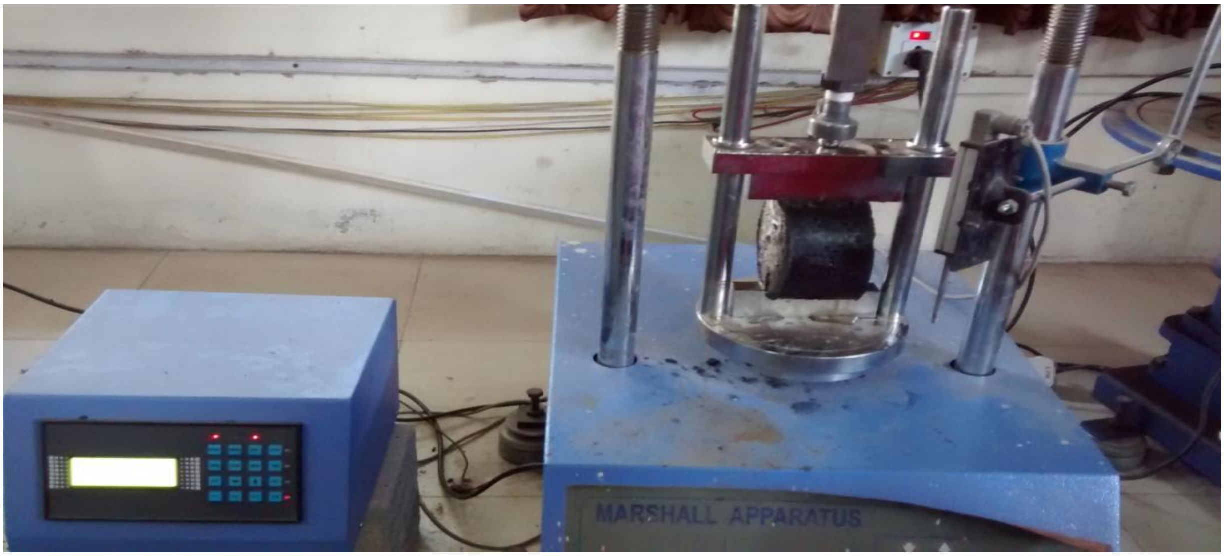
$$S\_t = 2P/\pi tD$$

Where:
S_t = tensile strength, kg/cm^2
P = maximum load, kg
t = specimen height immediately before test, cm
D = specimen diameter, cm
The Tensile Strength Ratio (TSR) is calculated as per below equation

$$TSR = \left(\frac{S_{tw}}{S_{td}}\right) * 100$$

Where:

TSR = tensile strength ratio
S_{tw} = average tensile strength of the moisture conditioned subset
S_{td} = average tensile strength of the dry subset



"Figure 2 A View of Test setup of Indirect Tensile Strength"

2. RETAINED MARSHALL STABILITY TEST

This test is conducted as per ASTM D 1075 specifications. The standard Marshall specimens of 100 mm diameter and 63.5 mm height are prepared. Marshall Stability is determined using the standard procedure i.e after conditioning the one set of specimen at 60^0 C for 30-40 minutes. Another set of specimen is kept for conditioning in water bath maintained at 60°C for 24 hours, and thereafter tested for Marshall Stability value. The results are reported as the percentage ratio of soak stability to standard stability. This test is conducted to know that the mix is susceptible to moisture damage or not. The minimum value of Retained Stability of bituminous mixes is 75% specified by the MORTH section 500 clause 509.

IX. TEST RESULTS AND DISCUSSION

1. THEORETICAL SPECIFIC GRAVITY OF AGGREGATES

"Table 1.3 Theoretical Specific Gravity of Aggregates"

Gradation Type	Proportion			Theoretical specific gravity of aggregates
	20mm Aggregate	**10 mm Aggregate**	**Stone Dust**	
ML	0.34	0.28	0.38	2.741
LL	0.445	0.25	0.305	2.764
UL	0.29	0.28	0.43	2.728
PUL	0.22	0.2	0.58	2.698
PLL	0.55	0.25	0.2	2.793

2. VOLUMETRIC ANALYSIS AND MECHANICAL TEST OF THE MARSHALL SPECIMENS

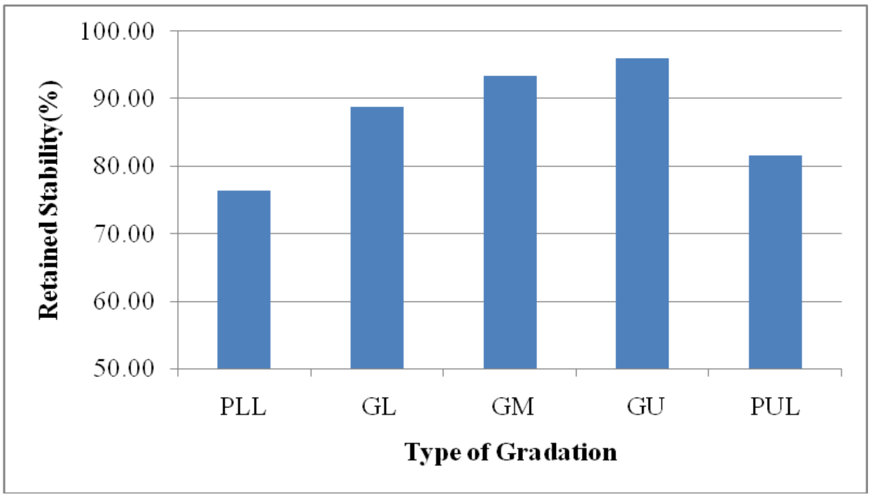
"Table 1.4 Volumetric Properties at OBC"

Property	PLL	GL	GM	GU	PUL	Specified Values as per MORT&H, 2013
Corrected Stability, KN	14.38	15.35	13.11	14.57	15.99	> 9
Avg Flow, mm	3.67	3.14	2.71	2.89	3.56	2 - 4
Marshall Quotient	3.91	4.88	4.83	4.80	4.49	2-5
Air Voids, %	3.88	4.60	4.44	4.79	4.75	3 - 5
Voids Filled with Bitumen, %	71.38	73.49	74.14	72.71	73.87	65 – 75
Avg Density, gm/cc	2.511	2.412	2.398	2.377	2.342	-

3. RETAINED STABILITY TEST

"Table 1.5 Results of Retained Stability Test"

Type of Gradation	Normal Stability @ 60^0C for 30 mins	Soaked Stability @ 60^0C for 24 hours	Retained Stability (%)	MoRTH 2013 Specifications
PLL	14.38	10.89	75.74	Note*
GL	15.35	13.45	87.62	75% minimum
GM	13.11	12.09	92.16	
GU	14.57	13.82	94.84	
PUL	15.99	14.21	88.84	Note*

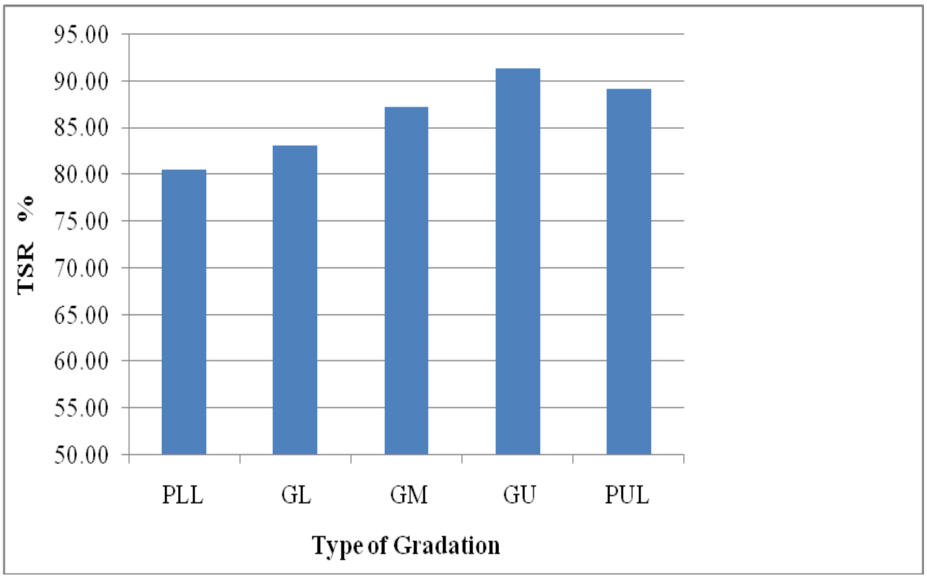


"Figure 3 Retained Stability Results"

4. INDIRECT TENSILE STRENGTH TEST

"Table 1.6 Indirect Tensile Strength Results"

Type of Gradation	Indirect Tensile Strength @ 60°C for 24 hours and @ 25°C for 2 hours, S_{tw}, (N/mm^2)	Indirect Tensile Strength @ 25°C for 2 hours, S_{td}, (N/mm^2)	Tensile Strength Ratio (TSR), %	MoRTH 2013 Specifications
PLL	0.329	0.409	80.5	Note*
GL	0.397	0.478	83.1	80% minimum
GM	0.517	0.593	87.2	
GU	0.603	0.660	91.3	
PUL	0.580	0.650	89.2	Note*



"Figure** Error! No text of specified style in document. **Tensile Strength Ratio"

X. CONCLUSIONS

Based on the detailed study carried out on effect of different gradations on performance of bituminous mixes, the following conclusions are drawn:

1. Bituminous concrete prepared by adopting different mix gradations as mentioned in Table 4.3 satisfies the requirements of mix given in Table 3.3. Though, the gradations GUOM and GLOM are taken outside the gradation limits as specified for BC-1 by MORTH (2013), the mixes prepared by adopting these gradations satisfy the mix specification values.

2. Looking the values of retained stability and tensile strength ratio for all gradations adopted for present study, it is found that the gradation GU has good resistance to damaging effect of water submergence conditions, whereas the gradation LL has relatively low resistance.
3. The performance parameters are correlated with gradation parameter Gradation Ratio (GR) and good to excellent correlations are obtained for different mix gradations.

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