Design of a bituminous mixture for perpetual pavement

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Abstract: The flexible pavements with a design period of 50 years without requiring major structural rehabilitation and reconstructions are called as perpetual pavements. The present study aims at designing a high modulus Dense Bituminous Macadam (DBM) mixture for perpetual pavements using Industrial Grade (IG) bitumen in combination with Viscosity Grade (VG30) bitumen. Various blending combinations were tried and the ratio of 70:30 for IG: VG30 was found to fulfill the requirements. The modified Marshall hammer was used for the preparation of specimens, as the nominal size of aggregate was 25 mm. A comparative study on DBM mixture with VG30 alone and with IG: VG30 (70:30) was done and the Optimum Binder Contents obtained were 5.0 % and 5.3 % respectively at 4 % air voids. The water sensitivity tests were carried out on the bituminous specimens in accordance with AASHTO T 283 and the Indirect Tensile Strength (ITS) ratio obtained were 80.0 % and 98.3 % respectively for specimens with VG30 and IG: VG30. The stiffness modulus of DBM specimens with IG: VG30 bitumen was 3 times higher than DBM with VG30 bitumen.

1. Introduction

The flexible pavements are generally considered for 15 to 20 years of design life and to make it competitive with rigid pavements in terms of design life, it is necessary to consider the flexible pavements for a design period of 30 to 50 years. Various research works have shown that well-constructed and well-designed flexible pavements can perform for extended life times *(Mahoney, 2001; Harvey et al., 2004)*. Bituminous pavements designed as a perpetual pavement is the most cost effective alternative to the concrete pavements (*Scholz et al*. 2006; *Merrill et al*. 2006). Most of the flexible pavements that were constructed in the past are the products of full-depth bituminous pavements. These designs have shown to provide adequate strength over extended life cycles and endure unprecedented amounts of traffic growths *(APA, 2002)*. The studies carried out by Saud and Zhongyin (2016) concluded that by using reclaimed asphalt for stabilizing the base layers can reduce the asphalt layer thickness.

The basic concept of perpetual pavement was to design the bituminous pavement having higher modulus with resistance towards fatigue cracking, rutting and moisture damage (*Newcomb et al., 2010*). The Pavement structures having thick layer helps in preventing structural rutting in the subgrade by limiting them to the surface layers only (*Brown et al., 2002,* Rolt, *2001)*. The probability of failure due to bottom-up fatigue cracking in the bituminous pavements can be reduced by increasing the thickness of the bituminous layers as this can limit the maximum strain at the bottom of bituminous layers *(Newcomb et al., 2000; St. Martin et al., 2001, APA, 2002; Merrill et al., 2006;*

Romanoshci, 2008; Al-Qadi et al., 2008). Typical cross-section of a perpetual pavement is shown in Fig. 1.
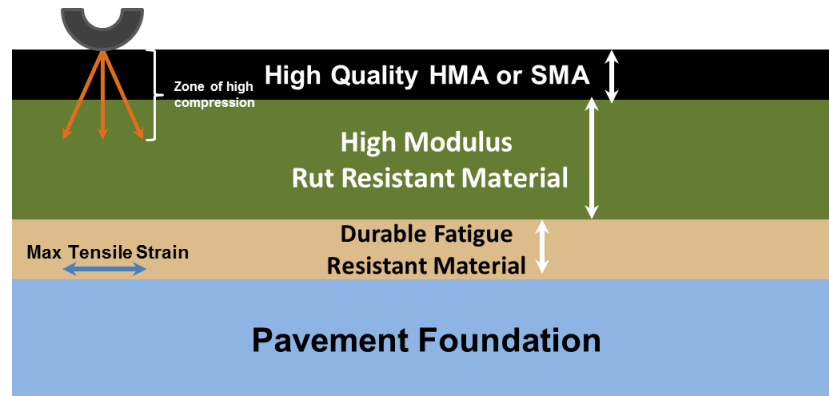

Figure 1. Cross-sectional view of perpetual pavement (source: IAPA 2017)

The present study aims at designing a high modulus DBM bituminous mixture with stiffer binder to resist moisture damage. Various tests were performed on the modified Marshall specimens in accordance with MS-2 using a 6" Marshall Hammer. The ITS test and the ITS ratio in accordance with AASHTO T 283 were carried out for finding the resistance to moisture damage.

2. Materials
2.1. Aggregates
The aggregates were obtained from the quarry nearby Hyderabad and the test results of aggregates are given in Table 1. The DBM gradation with nominal aggregate size of 25 mm as per MoRT&H Specifications (*Fifth Revision, 2013*) is shown in Table-2. A coarser gradation was considered to design a rut resistant DBM mixture.

Table 1: Properties of aggregates

Test Description	Test Method	Results
Specific Gravity	Indian Standard :2386 (Part IV-1963)	2.500
Water Absorption (%)	Indian Standard :2386 (Part III-1963)	3.01
Impact Value (%)	Indian Standard :2386 (Part IV-1963)	26.1

Table 2: Aggregate gradation

IS Sieve (mm)	Grading 2 Specification (%)	Adopted Grading (%)
37.5	100	100
26.5	90-100	92
19	71-95	74
13.2	56-80	60
4.75	38-54	41
2.36	28-42	32
0.3	7-21	10
0.075	2-8	3

2.2. Bitumen
The bitumen requirement for high modulus bituminous mixtures as suggested by Laszlo and Morrasut, (2014) is shown in Table-3.

Table 3: Bitumen for high modulus mixture

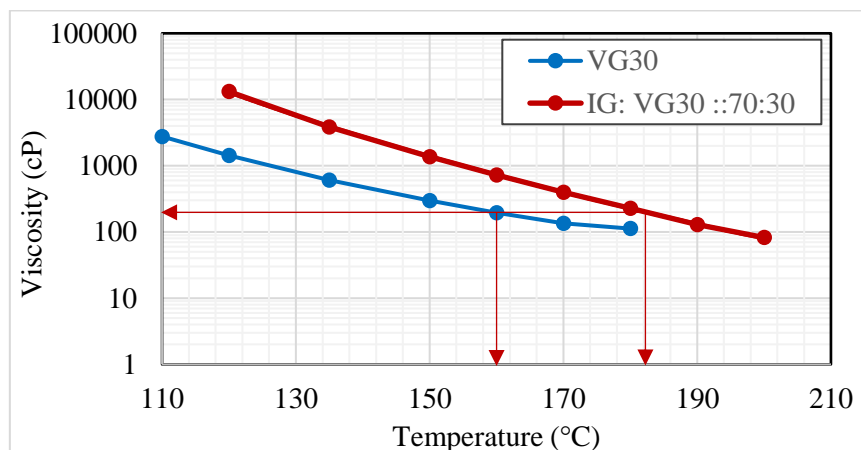| Tests on Bitumen	Requirements for bitumen
Penetration (dmm)	20/10
Softening Point (°C)	58-78
Kinematic Viscosity @135°C (Pa.s)	≥700

The bitumen with such high softening point is not readily available in India as we generally use VG30 binder for the design of bituminous mixture in flexible pavements. Hence, to obtain such stiffer bitumen, in the present study an Industrial Grade (IG) bitumen used for design of Mastic Asphalt with softening point of 85 °C and penetration of 15 dmm was obtained from Delhi. The IG bitumen was blended with VG 30 bitumen at various combinations and the ratio of 70:30 was found to fulfill our requirement for the design of high modulus DBM mixture. The bitumen test results of VG30 and the IG: VG30 are given in Table 4.

Table 4: Test results of bitumen

Property	VG30	IG: VG30
Penetration (dmm) @ 25°C	66	25
Softening Point (°C)	50	76
Specific Gravity	1.02	1.02
Absolute Viscosity (Poise) @ 60°C	2443	NA
Kinematic Viscosity (Pa.s) @ 135°C	608	985

3. Temperature-viscosity relationship

The temperature-viscosity relationship were plotted (see Fig. 2) after testing the viscosity of VG30 and IG: VG30 bitumen using Brookfield Viscometer. The relationship showed that the blended bitumen was stiffer than the VG30 bitumen. The mixing temperatures for VG30 and IG: VG30 binders at 2 poise viscosity were 163 °C and 185 °C respectively.

Figure 2. Temperature-Viscosity Relationship

4.Modified Marshall mixture design

The modified Marshall mixture design was carried out in accordance with Asphalt Institute's Manual Series 2 using 6" Marshall hammer. The Marshall specimens were prepared at the binder contents of 4.5, 5.0, 5.5, and 6.0 % by weight of mixture with VG30 and IG: VG30 binders. The bulk specific gravity, Marshall Stability and the flow values of the specimens were measured and the volumetric properties like percentage air voids, Voids in Mineral Aggregates (VMA) and the Voids Filled by Bitumen (VFB) were calculated. The bituminous mixture properties at different binder contents are given in Table 5. The OBC were 5.0 and 5.3 % respectively for VG30 and IG: VG30 binders at 4 % air voids. The other properties were verified at the OBC. The plots for DBM with VG30 and IG: VG30 are shown from Figures 3 to 8.

Table.5: Calculated values from volumetric readings

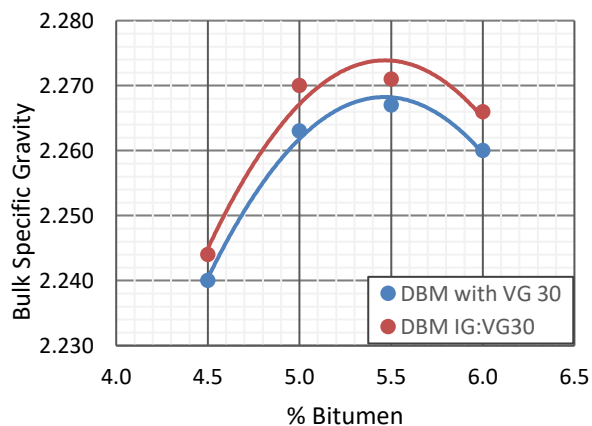| Bitumen %	Bulk Density(g /cc)	Air-voids (%)	VMA (%)	VFB (%)	Marshall Stability(kN)	Flow(mm)
DBM with VG30 Bitumen						
4.5	2.240	5.6	14.4	60.9	25.2	3.6
5.0	2.263	4.0	14.0	71.3	28.5	4.4
5.5	2.267	3.2	14.3	77.7	31.0	5.1
6.0	2.260	2.8	15.0	81.1	27.4	6.0
DBM with IG:VG30::70:30						
4.5	2.244	6.3	13.5	53.0	39.1	3.2
5.0	2.270	4.6	12.9	64.6	55.8	4.2
5.5	2.271	3.9	13.3	71.1	61.2	4.6
6.0	2.266	3.4	13.5	75.0	55.7	5.2

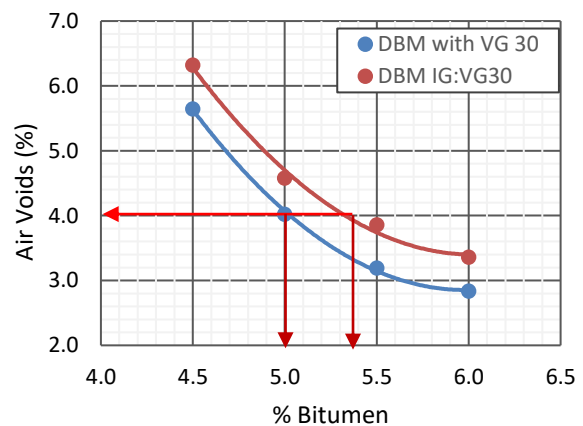**Figure 3**. Bulk specific gravity Vs Binder content

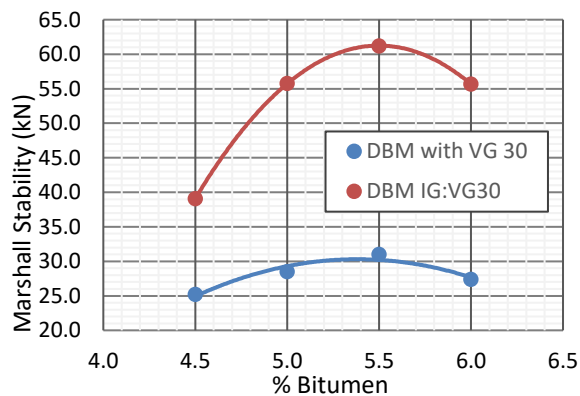**Figure 4**. Air voids Vs Binder content

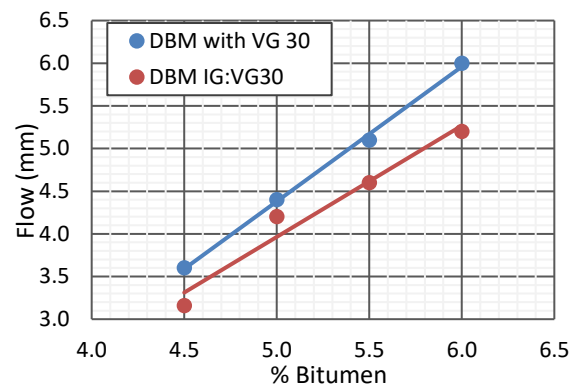**Figure 5**. Marshall Stability Vs Binder content
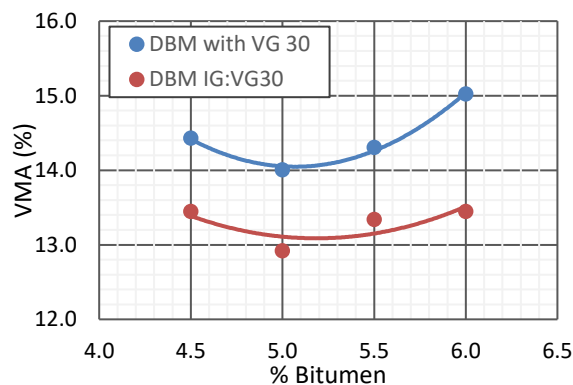
Figure 6. Flow Vs Binder content
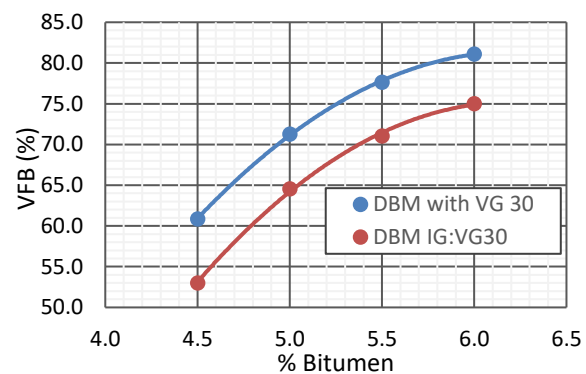
Figure 7. VMA Vs Binder content

Figure 8. VFB Vs Binder content

5.Indirect Tensile Strength Ratio (AASHTO T 283)

As per the Asphalt Institute's Manual Series 2, the OBC was considered at 4 % air-voids and the mixture properties at OBC are given in Table 6. At OBC, nine specimens were prepared to carry out the water sensitivity tests as per AASHTO T 283. The Indirect Tensile Strength (ITS) dry at 25 °C was carried out on the 3 unconditioned specimens and the other 3 specimens were conditioned by placing in water bath at 60 °C for 24 hours and in air at 25 °C for 4 hours before testing for ITS and the ratio of conditioned specimens to unconditioned specimens was calculated and the ratio obtained was 98.3 %.

Table.6: Obtained readings at OBC

Mixture Properties	DBM with VG30	DBM with IG:VG30
Air-voids,%	4.0	4.0
Bulk Specific Gravity	2.263	2.272
Stability, kN	28.5	60.0
VMA, %	14.0	13.1
VFB, %	71.3	69.5
Flow, mm	4.4	4.5

As the DBM mixture was designed for the perpetual pavement with design life of 50 years, the remaining 3 specimens were further conditioned in the water bath at 60 °C for 48 hours and in air at 25 °C for 4 hours before testing for ITS. The ratio of conditioned specimens to the dry specimens was

calculated and the ratio obtained was 97.7 %. The ITS values for dry and conditioned specimens are given in Table 7. The main failure in the flexible pavement is generally due to water damage. The ITSR results showed that there was marginal reduction in strength even after conditioning the specimens for 48 hours due to the use of stiffer binder in the DBM mixture.

Table.7: ITS values for wet and dry specimens

Specimens	Stiffness (MPa) DBM with stiffer bitumen	Stiffness (MPa) DBM with VG30 bitumen
Testing at 25 °C with 7 % air voids		
Dry 1	3.08	1.02
Dry 2	3.36	0.98
Dry 3	3.04	0.96
Average	3.22	0.99
Testing at 25 °C after soaking in water at 60 °C for 24 hours with 7 % air voids		
Wet 1	3.24	0.77
Wet 2	3.08	0.80
Wet 3	3.17	0.83
Average	3.17	0.80
Testing at 25 °C after soaking in water at 60 °C for 48 hours with 7 % air voids		
Wet 1	3.20	0.50
Wet 2	3.11	0.46
Wet 3	3.15	crumbled
Average	3.15	0.48

The results showed that the DBM bituminous mixture, designed using IG: VG30 bitumen had the stiffness value of 3.2 MPa which is 3 times higher than the stiffness values of the conventional DBM bituminous mixtures designed using VG 30.

6. Cost Analysis
The cost analysis was worked out to find the increase in cost of DBM mixture with the use of IG: VG30 binder. Considering the operation cost, it was calculated and found that the cost of DBM mixture designed using IG: VG30 binder is approximately 50 % costlier than the DBM with VG 30 bitumen as shown in Table 8. Hence, considering the life cycle cost analysis for 50 years design period the DBM mixture with IG: VG30 binder will be economical.

Table.8: Cost analysis

Mixture Cost	DBM with VG30 bitumen @ OBC 5.0%	DBM with blended bitumen @ OBC 5.3%
Bitumen Cost (Rs)	30,000/ton	48,000/ton
DBM Cost (Rs)	6000/m^3	9000/m^3

7. Conclusions
- High modulus DBM bituminous mixture prepared using IG: VG30 was found to have high stiffness when tested for indirect direct tensile strength. The ITS value was 3 times higher for IG: VG30 binder when compared to VG 30 bitumen. The higher Marshall Stability value results in less plastic deformation and hence, lesser rutting during the design life.

- The indirect tensile strength ratio, as per AASHTO T 283, for IG: VG30 binder after conditioning for 24 hours and 48 hours at 60 °C in water was 98.3 and 97.7 % respectively. From the results it can be concluded that the DBM bituminous mixture prepared using IG:VG30 binder has marginal or no loss in strength even when tested under adverse conditions while the DBM with VG30 binder showed nearly 50 % loss due to moisture damage.
- From the cost analysis it can be concluded that the DBM mixture prepared using IG: VG30 is 1.5 times the cost of conventional DBM mixture prepared using VG30 binder. Considering the benefits and the life cycle cost analysis, the DBM mixture prepared using IG: VG30 is feasible for the construction of perpetual pavements.

8.References

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