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Influence of Construction Parameters on Performance of Dense Graded Bituminous Mixes

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Abstract: *This paper investigates the influence of construction parameters on the properties and performance of dense graded bituminous mix. Construction and process control parameters such as bitumen content, air voids content and compaction in bituminous concrete mix were varied and their influence on pavement performance were ascertained.In this study Bituminous concrete and Dense Bituminous Macadam were selected to effectively represent both the wearing course and binder course as these two mixes are popularly used in National Highway projects in India. The samples were prepared according to Marshall mix design method. Marshall Test was performed at optimum binder content and under varying number of compaction to identify the influence of density/varying air voids on Marshall stability, flow value and volumetric properties of mixes. Indirect tensile strength test (ITS) was performed to estimate the properties of the bituminous mixes and to ascertain their potential for rutting and cracking. The main factors considered were bitumen binder content, varying compaction effort and percent air voids. Wheel tracking tests were performed to study the influence of the above mentioned parameters on rut susceptibility of bituminous mixes. Binder characterization was carried out by traditional as well as through dynamic mechanical analysis. Relationship was developed between bitumen content, air voids and indirect tensile strength of the bituminous mixes.Finally, influence of these properties on pavement performance by estimating fatigue and rutting performance of pavements was estimated using the mechanistic empirical pavement design guide.*

Keywords: *Hot Mix Asphalt, Indirect Tensile Strength Test, Air Void, Bitumen Binder Content, Pavement Performance, Rutting, Fatigue.*

I. Background

Presently, there is a proliferation of bituminous paving mixes in India. For heavily trafficked roads, Bituminous Concrete (BC) grading II is being widely used as a wearing course whereas Dense Bituminous Macadam (DBM) grading II is being used as a binder course. Although various methods are available for the design of bituminous mixes however, Marshall mix design is most widely followed in India and hence, it has been adopted for mix design in this study. Marshall mix design for bituminous concrete is based on the guidelines provided in the Asphalt Institute (USA) Manual MS-2. 'Mix Design Method for Asphalt Concrete and other Hot Mix Types'.

Marshall test was performed as part of Marshall mix design procedure adopted for optimizing the design asphalt content. Further, Marshall test was performed at varying number of compaction blows to estimate the influence of density on Marshall stability, flow value and volumetric properties of the mixture. Indirect tensile strength (ITS) test were conducted to estimate the performance of bituminous mixes and to ascertain their potential for rutting and cracking. ITS was performed on specimens prepared at optimum binder content as well as at binder content higher and lower than optimum value. To study the significance of air voids in mix performance, indirect tensile strength (ITS) were conducted on specimens prepared at optimum binder content but under varying compaction. Wheel-Tracking machine was used to evaluate the rutting potential of bituminous mixes. In the absence of sufficient field pavement performance/distress data, Mechanistic-Empirical Pavement Design Guide (MEPDG), because of its ability to estimate initiation and progression of pavement distresses, was used to provide valuable information in qualitatively establishing the relationship between construction parameters and pavement performance.

Through this study, it has been attempted to capture the influence of fatigue and rutting performance of flexible pavements, considering the variation in construction parameters such as, binder content, air voids/density and layer thickness and through ITS test results. Presently, this study lacks the field performance data and thus, performance prediction have been suggested, based on simulations, however, it could not undermine the significance of actual field performance of these mixes. The conceptual framework developed

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under this study is based on the relationship among the variables that characterize the design, construction, and performance of the pavement.

II. Objectives And Scope

The objective of this study are to assess the influence of construction parameters such as; bitumen content, density/air voids and layer thickness on performance of dense graded bituminous mixes considering rutting and fatigue cracking as the major pavement distresses.

2.1 Methodology

The following methodology has been adopted in the present study:

1. Construction and process control parameters such as difference in bitumen content, air voids content and compaction in bituminous concrete mixes were varied and their influence on physical strength tests such as Marshall stability, Flow value and indirect tensile strength tests (ITS) were investigated.
2. Using MEPDG, fatigue and rutting life for all the mixes were evaluated and its relationship with regard to HMA layer thickness, density, variation in air void content, binder content and ITS results as well as dynamic modulus of the mix were studied.

III. Literature Review

The goal in any pavement design and construction project is to produce a pavement that is durable and performs satisfactorily throughout its expected design life. Well calibrated design and good construction quality are the two most significant factors contributing towards pavement performance. Root[1] observed that many pavement failures are not caused by poor mix design methods but are the manifestation of poor specification control during production and construction. The HMA material in a pavement is composed of three components, namely aggregate, binder, and air voids. Many parameters are used to measure or give an indication of the state or variations of these three components. These parameters include aggregate gradation, HMA layer density, Voids in Mineral Aggregate (VMA), voids filled with asphalt (VFA), binder content, air voids content etc.

The significance of closely monitoring asphalt binder content in hot mix asphalt mixes to obtain optimum serviceability and durability cannot be overemphasized. Previous studies have shown that a bituminous pavement can ravel or crack if it is deficient in asphalt binder content by as little as 0.5 percent, whereas, even 0.5 percent excessive binder content can cause bleeding and rutting. Brosseaud et al.[2] stated that asphalt binder film thickness should be adequate for coating the aggregate and providing cohesion, but too much binder can have a lubricating effect, reducing the effectiveness of the aggregate skeleton and creating an unstable mix that is prone to premature rutting. Binder grade can also affect rutting performance. In general, the higher the binder grade, the stiffer the binder, and the greater the rutting resistance (Stuart and Izzo[3] and Netemeyar[4]). In order to construct a stable and durable pavement, proper compaction of hot mix asphalt mixture is an essential pre-requisite. Robert et al.[5] concluded that initial in-place air voids in a mixture should not fall below approximately 3 percent, nor should it exceed above approximately 8 percent. They observed that while lower percentage of air voids may result in rutting and shoving, higher percentage may allow water to penetrate into the pavement causing raveling and cracking. While low in-place voids are generally related to mix problem, high in-place voids are generally caused by inadequate compaction. Huber and Helman[6] looked at a number of causes of rutting in asphalt mixtures in Canada and concluded that one of the primary causes of rutting was low air voids (below 3 percent) in those asphalt mixtures. Brown and Cross[7] in a study of rutting of asphalt pavements, showed significant rutting was likely to occur once in-place voids reached lower than 3 percent. Monismith et al.[8]stated that air void content is an important factor which affects fatigue life of an asphalt mixture and it should be as small as possible (but not less than a minimum limit of 3 percent) to obtain the greatest fatigue life.

Maupin[9] indicated existence of correlation between asphaltic concrete tensile stiffness and fatigue life and that the fatigue susceptibility of a mixture could be predicted with a simple indirect tension test. Khosla and Harikrishnan[10] observed that the fatigue life of the mixture decreases exponentially with decreasing tensile strength. They also showed that the mixtures with lower tensile strength exhibited higher rut depths indicating that rut susceptibility of mixtures increased with decreasing tensile strength.

Wheel tracking tests, are being increasingly used to predict the rut performance of asphalt pavements and to rank mixes during the design phase, but these tests are expensive and have limited availability. However, the disadvantage of the wheel tracking type of tests is that they are empirical strength tests and their output results only in accept or reject decision based on experience and the correlation of the tests to real pavement conditions. Cooley et al.[11] observed that wheel tracking devices correlate reasonably well to actual field performance when the in-service loading and environmental conditions of that location are considered.

Based on the literature review it can be inferred that construction parameters significantly influence the overall performance of bituminous mixes and there is a need to study the extent of this influence. In this study, it has been attempted to evaluate the influence of bitumen content, air void content/compactive effort and layer thickness on properties of bituminous mixes using simple and readily available test setups.

IV. Materials And Testing

Bituminous Concrete (BC) grading II and Dense Bituminous Macadam (DBM) grading II are the most widely used wearing course and binder course used in National Highway projects in India and thus have been selected for this study. Mid-gradations of the aggregate composition recommended in Ministry of Road Transport and Highways (MORTH) specifications[12] were selected (Table 1).

A VG30 asphalt binder was used with a mixing and compaction temperature of 160^0C and 150^0C, respectively. BC grading II samples were prepared for a range of bitumen content by total mass of the mix and for varying air void content (by varying compaction effort of Marshall hammer). Volumetric properties such as air voids, voids in mineral aggregate (VMA) and voids filled with bitumen (VFB) were evaluated. The maximum load and corresponding deformation gauge readings were recorded after conditioning the specimens for 2 hours in an oven maintained at 60 ± 1^0C (AASHTO T245-94). Optimum binder content was computed as per Asphalt Institute MS-2. In order to understand the influence of increased compaction blow and reduced air void content on Marshall mix properties, samples were also prepared at 50 and 100 blows. The binder content variation was achieved by using higher and lower percentage of the bitumen content deviated from the design binder content. MORTH specifications, permits a deviation by ± 0.3% from optimum binder content for wearing and binder course. The effect of further lowering of binder content on mix properties were ascertained by preparing specimens at lower than MORTH permitted binder content deviations.

Table 1.Aggregate Mid-Gradation for BC Grading II and DBM II

IS Sieve Size(mm)	BC II	DBM II
37.5	---	100
26.5	---	95
19	100	83
13.2	90	68
9.5	79	---
4.75	62	46
2.36	50	35
1.18	41	---
0.6	32	---
0.3	23	14
0.15	16	---
0.075	7.0	5.0

Further, in order to understand the influence of increased compaction on volumetric properties and more conspicuously, on ITS, samples at optimum binder content were compacted at 75, 100, 150 and 200 compaction blows. Indirect tensile strength test was selected since it has been shown to be a rational and practical test procedure, and could be conducted using relatively simple testing equipment, generally available in laboratories that conduct usual Marshall stability tests. Prior to ITS testing, the specimens were conditioned in an air bath for a minimum of 4 hours (ASTM D6931-12). The specimen was taken out from air bath, and tested immediately at a deformation rate of 50 mm/min. IDT strength was calculated as

$$\mathbf{S_t = \frac{2000\,P}{\pi t D}}$$

S_t = IDT strength, kPa; P = maximum load, N; t = specimen height immediately before test, mm; D = specimen diameter, mm

The dynamic moduli of the samples were computed using the Hirsch model[13], which is based on the theory of composite material which combines series and parallel elements of the phases. It is considered relatively simpler than Witczak model[14],[15]and relates the dynamic modulus of the bituminous concrete (|E*|) with binder modulus (G*), voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA).

$$\mathbf{|E^*| = Pc[\ 4{,}200{,}000(1-VMA/100) + 3|G^*|_{binder} \times \{(VFA \times VMA)/10{,}000\} + (1-Pc) \times [(1-VMA/100)\ /\ 4{,}200{,}000\} + (VMA\ /\ VFA \times 3|G^*|)\ ]^{-1}}$$

$$\mathbf{Pc = \frac{[20 + VFA \times 3|G^*|_{binder}/\ VMA]^{0.58}}{650 + [\ (VFA \times 3|G^*|_{binder})/VMA]^{0.58}}}$$

Where;
|E*| = dynamic modulus, psi
|G*|binder = binder dynamic modulus, psi
VMA= voids in the mineral aggregate, %
VFA = voids filled with asphalt, %
Pc = aggregate contact factor

In these equations, the binder modulus can be determined experimentally using the dynamic shear rheometer (DSR) or can be estimated through mathematical models. The binder modulus should be computed at the same temperature and loading time, as that selected for the mixture modulus and in consistent units[15]. If facilities are available, the dynamic modulus values can be determined experimentally. If the experimental facilities are not available, the above empirical equation may be used.

V. Results

Various tests were performed on the bitumen (VG 30). The data pertaining to bitumen are shown in Table 2. Note that the bitumen was also tested with the dynamic shear rheometer for the complex modulus data that were later utilized for predicting dynamic modulus of the mixes.In order to estimate the effect of number of compaction blows on the Marshall mix properties, samples were prepared and tested at 50 blows, 75 blows and 100 blows. Marshall stability and flow value obtained under different compactive effort are summarized in Table 3. ITS test results obtained under different compaction effort have been summarized in Table 4 and Table 5 shows the summary of the mix test data.

Table 2. Conventional bitumen test results

Test	**Units**	**Aging Condition**	**Recommended Value as per IS:73-2006**	**Result**
Penetration	dm	Unaged	50-70	70.5
		Short term aged		38
Softening Point	°C	Unaged	47 (minimum)	49
		Short term aged		56
Absolute Viscosity	Poise	Unaged	2400 (minimum)	2660.1
		Short term aged		3555.0
Kinematic Viscosity	cSt	Unaged	350 (minimum)	473.2
		Short term aged		649.25
Viscosity (Using Rotational Viscometer)	CentiPoise	Short term aged		544.44
Specific gravity		Unaged	0.99 (minimum)	1.051

Table 3. Marshall Test Results Performed under different Compaction Blows

Binder content %	4.5			5.0			5.5			6.0		
No of blows	50	75	100	50	75	100	50	75	100	50	75	100
Unit wt(gm/cc)	2.28	2.36	2.36	2.33	2.38	2.40	2.54	2.52	2.36	2.97	2.66	2.47
Marshall stability (KN)	17.72	24.93	16.95	21.14	22.74	24.91	19.87	21.05	24.97	18.32	18.21	14.54
Flow value(mm)	2.17	2.01	1.78	2.37	2.34	1.89	2.54	2.52	2.35	2.97	2.66	2.47
Air voids (%)	9.32	7.78	7.22	7.79	5.82	5.43	5.88	3.98	3.87	5.22	3.78	2.30
VMA (%)	13.73	12.27	11.73	13.36	11.51	11.15	13.14	11.43	11.33	13.55	12.23	11.52
VFA (%)	32.18	36.69	38.48	41.72	49.51	51.29	55.77	65.23	65.84	61.46	69.10	73.97

Table 4. Summary of ITS Results for BC-II at Different Compaction Blows

Mix	No. of Blows	Average Air voids %	Average Density (%G_{mm})	Average IDT (kPa)
BC II	75	3.794	96.207	1013.226
	100	3.374	96.626	1042.668
	150	2.817	97.183	1077.384
	200	2.348	97.652	1089.668

Table 5. Result of ITS Test performed on BC grading II and DBM grading II

BC II				DBM II			
Binder Content %	Average Air voids %	Average ITS (kPa)	Coeff. of Varia-tion CV, %	Binder Content %	Average Air voids %	Average ITS (kPa)	Coeff. of Varia-tion, %
4.3	5.97±0.27	1206.44	2.72	3.8	4.69±0.29	1078.24	2.96
4.5	5.89±0.69	1147.09	4.19	4.0	4.26±0.15	1107.77	2.15
4.7	4.52±0.58	1162.76	2.60	4.2	3.66±0.36	897.76	1.03
5.0	4.12±0.81	1075.77	1.44	4.5	3.25±0.08	897.77	8.40
5.3	3.16±0.19	1045.00	3.99	4.8	2.40±0.06	814.91	4.56

Dynamic modulus values were estimated using Hirsch model. In order to evaluate the rutting potential of asphalt mixtures, Wheel-Tracking Machine was used. This equipment assesses the susceptibility of a bituminous material to deformation by measuring the rut depth formed by repeated passes of a loaded wheel at a constant temperature. BC grading II samples were tested at 4.5%, 4.7%, 5.0% and 5.3% binder content by mass of the total mix whereas, rut susceptibility of DBM grading II samples were evaluated at 4.0%, 4.2%, 4.5% and 4.8% binder content by mass of the total mix.

Results are summarized in Table 6. Four specimens of 150mm diameter and 50mm height were made for each sample type. Since specimens were prepared manually through Modified Marshall method and permissible variation in height of the specimens is 50±2 mm, about 20% of the specimens made were discarded due to unacceptable dimensions. All samples were tested at 60^0C and under a wheel load of 720N. A limiting value of 5 mm rut depth or 5000 load cycles was assigned for BC grading II samples whereas, a limiting value of 4mm rut depth or 5000 load cycles was designated for DBM grading II samples. Table 7 summarizes the average number of passes for specified rut depths for BC grading II and DBM grading II samples.

Table 6. Estimated Dynamic Modulus values of BC-II and DBM-II Mixes

BC-II				DBM-II			
Binder content %	Air void %	Dynamic modulus (MPa)	Number of passes to 5mm rut depth	Binder content %	Air void %	Dynamic modulus (MPa)	Number of passes to 4mm rut depth
		At 45°C	At 60ºC			At 45°C	At 60ºC
4.5	5.0	1760	7400	4.0	3.0	2283	8350
4.5	5.2	1732	6150	4.0	4.1	1965	7350
4.7	3.4	2139	2550	4.2	3.0	2212	7200
4.7	3.7	2072	2350	4.2	4.0	1952	6700
5.0	3.6	1965	2350	4.5	2.6	2245	2750
5.0	4.4	1852	2150	4.5	3.2	2080	2550
5.3	2.1	2365	1300	4.8	2.7	2144	1600
5.3	2.5	2270	1000	4.8	2.8	2120	1600

Table 7. Average number of passes to specified rut depth for BC II and DBM II

Mix Type	Binder Content %	Average Number of Passes to 5mm Rut depth	Mix Type	Binder Content %	Average Number of Passes to 4mm Rut depth
BC II	4.5	6566	DBM II	4.0	7000
	4.8	2633		4.2	6866
	5.0	2250		4.5	2633
	5.3	1166		4.8	1950

VI. Analysis

6.1 Development of Indirect Tensile Strength Predictive Model

When time and resources are limited, it is convenient to refer to some predictive models to compare properties of mixes that are of interest. A number of multiple regression models for predicting indirect tensile strength were developed using results of this study. A number of independent variables were used to express the dependent variable. The individual effects of air void content and asphalt binder content on ITS values and their combined influence have all proven to be significant to a mixture’s ITS properties. The results of tests from BC-II and DBM-II mixes are shown in Fig. 1.Baskandi et al.[16] have suggested predictive model for ITS for BC-II and DBM-II mixes.

For BC-II mixes:

$$\mathrm{ITS(kPa)} = 2272.9 - 17.7 * \mathrm{AV} - 90.2\mathrm{P_b} \quad (1)$$

For DBM-II mixes:

$$\mathrm{ITS(kPa)} = 3281.1 - 424.7 * \mathrm{AV} + 353.7 * \mathrm{P_b} - 73.7 * \mathrm{VFA} \qquad (2)$$

Where,

ITS = indirect tensile strength, kPa
AV = air void content, percentage
P_b = binder content, percentage
VFA = Voids Filled with Asphalt (bitumen)

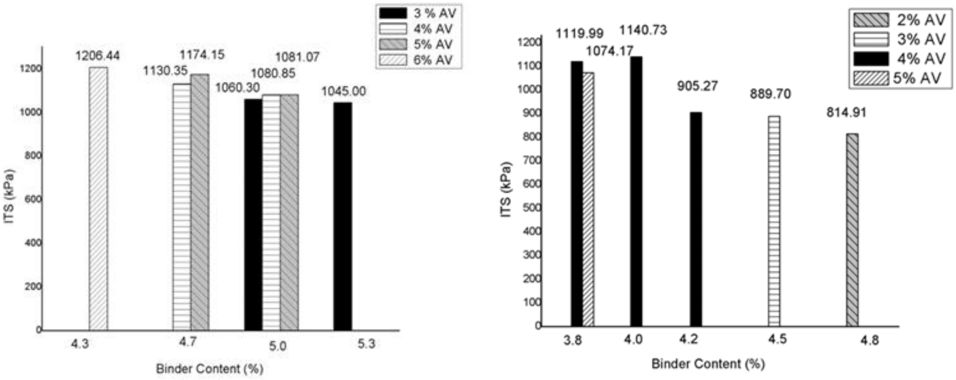


Figure 1. Indirect Strength Test (ITS) results from BC-II (top) and DBM-II (bottom) mixes at 25^{o}C; AV – air voids.

The predicted ITS values from the predicted equation for BC-II and DBM-II mix were plotted against the experimentally measured ITS values and are shown in Fig. 2. Overall, the data are scattered on both sides of the line of equality.

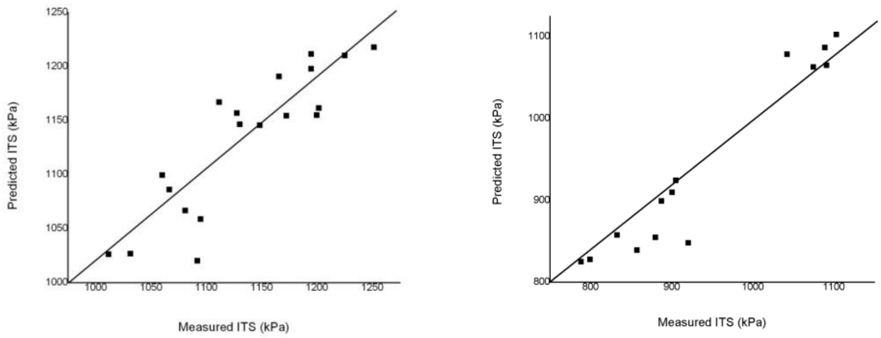
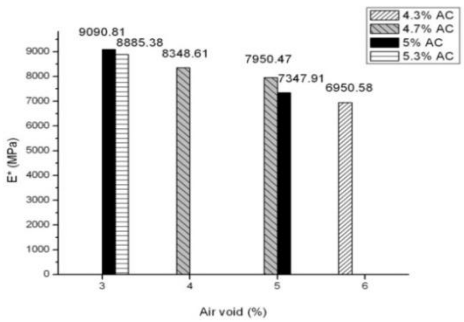


Figure 2. Measured versus Predicted Indirect Tensile Strength for BC-II and DBM-II Mixes

6.2 Combined Influence of Air Voids and Bitumen Content on Dynamic Modulus and Rut Wheel Tracking Results

Treating asphalt binder content, and air void content as categorical variables having two and three levels, respectively, analysis of variance (ANOVA) was employed to establish the significance of both main effects and two-factor interactions on the single dependent variable, the dynamic modulus values. Further, Tukey's test was used in conjunction with ANOVA to understand whether the means were significantly different from each other? Tukey's test showed that the mean difference is not significant at 0.05 levels. ANOVA results indicated that air void content and asphalt binder have significant influence on the E* results, both individually as well as through their interaction. It is important to note here that Tukey's follow up test is conservative because it attempts to control the overall α level. The results of tests from BC-II and DBM-II mixes (conducted at 25ºC) are shown in Fig. 3.

Table 6. signifies the influence of asphalt binder content and air void content on the number of load passes to critical rut depth for BC-II and DBM-II mixes. It clearly indicates that the number of load passes to critical rut depth decreases with an increase in asphalt binder content and the rutting susceptibility in the mixes is more pronounced when asphalt binder content increases beyond its optimum value. It is evident that at a constant binder content, the dynamic modulus of the mix decreases and numbers of load passes to limiting rut depth decrease with an increase in air void content, which shows that rut susceptibility of the mix increases, with an increase in air void content and decrease in dynamic modulus of the mix.



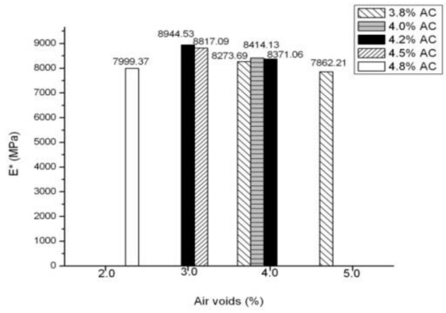


Figure 3. Combined Influences of Bitumen Content and Air void Content on Dynamic Modulus for BC-II and DBM-II Mix.

6.3 Evaluating Pavement Performance Using Mechanistic-Empirical Pavement Design Guide

The MEPDG provides a uniform and comprehensive set of procedures for the analysis and design of new and rehabilitated flexible and rigid pavements. It employs common design parameters for traffic, materials, subgrade, climate, and reliability for all pavement types, and may be used to develop alternative designs using a variety of materials and construction procedures. The output from the MEPDG is predicted pavement distresses at the selected reliability level. Thus, it is not a direct thickness design procedure, but rather an analysis tool for the designer to use in an iterative mode (MEPDG- A Manual of Practice, 2008). It provides a direct linkage between construction variables and pavement performance. The parameters utilized in the use of MEPDG for this study are shown in Table 8.

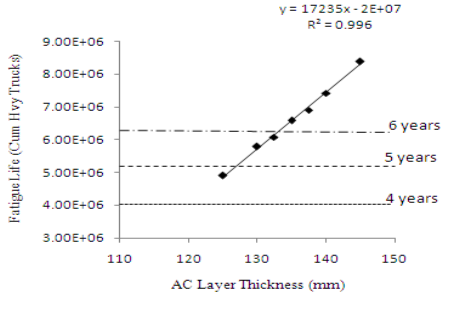
Table 8. Design parameters

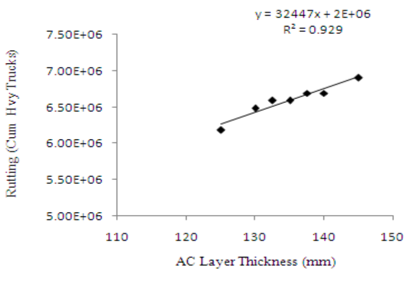
Parameter	Type/Data
Pavement type	New, Flexible
Pavement Structure	Based on IRC: 37 (2012); for 30 msa and subgrade CBR 10 percent; 250mm thick Wet Mix Macadam (WMM) base and another 200 mm of Granular Sub-Base (GSB).
Critical pavement distresses	AC bottom-up fatigue cracking of 20 percent; Permanent deformation (AC layer only) of 10mm; Other distresses criteria have been taken as per default values provided in DARWin-ME. The reliability limit has been set at 90 percent.
Terminal IRI limit	4m/km
Traffic	29 msa of cumulative heavy trucks for a design life of 20 years
Climate	Miami Airfield, Florida, USA (equivalent location in US)

6.4 Influence of HMA layer Thickness on Pavement Performance

Presently, as per specifications, agencies impose a direct penalty on the contractor for deviating from the specified HMA layer thickness based on the reduced amount of hot mix asphalt being provided, ignoring the more severe loss to it due to reduced pavement life. In this study, the thickness of HMA layer has been varied from the recommended thickness of 135mm (40mm BC-II and 95mm DBM-II) for HMA layer with the thickness of other layers being kept constant as per IRC:37, 2012 guidelines for traffic up to 30 msa and subgrade CBR of 10%. Fig. 4 shows the relationship between pavement fatigue life and variation in BC-II layer thickness whereas, the relationship between pavement rutting life and BC-II layer thickness is presented in Fig. 5. The relationship is linear with adjusted R-square values being 0.996 and 0.929 respectively. This clearly shows that with reduction in HMA layer thickness; there is a corresponding reduction in the overall fatigue and rutting life of the pavement. A ± 25mm variation in layer thickness of BC-II mixture resulted in reduction in fatigue life by up to 1 year.

Figure 4. Fatigue life and Layer Thickness **Figure 5.** Rutting and Layer Thickness





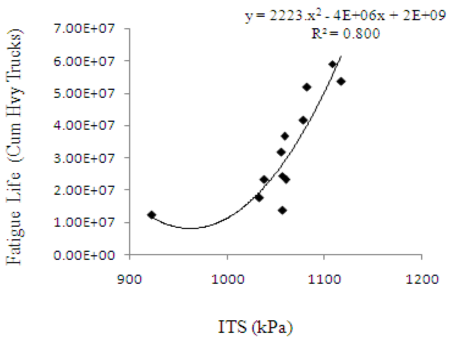
6.5 Influence of HMA Layer Density on Pavement Performance

Density or degree of compaction is an important component of asphalt pavement quality and its performance. To highlight the influence of degree of compaction on HMA layers and on its performance, the BC-II mix prepared at optimum binder content were compacted under varied number of Marshall compaction blows. Density in terms of percent of theoretical maximum specific gravity of the mix and its corresponding influence on fatigue and rutting performance of the mix were studied and as expected, it was found that with an increase in compaction effort, there was a consistent reduction in air void content and an increase in both the indirect tensile strength of the mixture and its fatigue life. Fig. 6. shows the polynomial relationship between the ITS values of the mixture and its estimated fatigue life. The adjusted R-square value was 0.800. Fig.7 captures the effect of variation in mix density (measured as percentage of ratio of mixtures bulk specific gravity to its theoretical maximum specific gravity) on its fatigue performance. Although, with an increase in density, the rut resistance of the mixture also improved, however, the trend was not as clear and significant as with fatigue cracking.

6.6 Relationship between ITS Results and Pavement Performance

The indirect tensile strength test is one of the most popular tests used for HMA mixture characterization and in evaluating pavement structures. Past studies have shown that there exists a relationship between the indirect tensile strength of a mixture and its estimated fatigue and rutting life. The indirect tensile strength values of the mixtures, measured from IDT test, were compared with the fatigue and rutting life of the mixture (as estimated through MEPDG).

Fig. 8 shows the relationship between the fatigue life estimated for the various BC-II mixtures and their corresponding ITS values. The polynomial relationship was developed between fatigue life and ITS values for the mixture as this relationship had the highest adjusted R-square value of 0.717. All the specimens prepared with asphalt binder content lower than MoRTH specified permissible variation from optimum binder content developed more than 20 percent bottom up cracking in less than 5 years whereas, specimens prepared with less than optimum binder content, even though within the permissible range of ± 0.3% binder content specified by MoRTH, failed in fatigue cracking in less than 8 years. As expected, maximum fatigue life was observed in HMA mixtures having higher asphalt binder content and lower air void content. Further, the results indicated that there exists an optimum ITS value for best performing HMA mixtures. Fig. 9 shows the relationship between rutting calculated for BC-II mixture and their ITS results. The linear relationship was developed as this had the highest adjusted R-square value of 0.744. None of the specimen reached the limiting rut depth of 10mm within 5 years, however, mixtures with asphalt binder content higher than optimum value reached the limiting rut depth in earliest timeframe (within 8 years). Considering the fatigue cracking and rut susceptibility for all the mixtures together, it was observed that the mixtures prepared at optimum binder content were best performing.



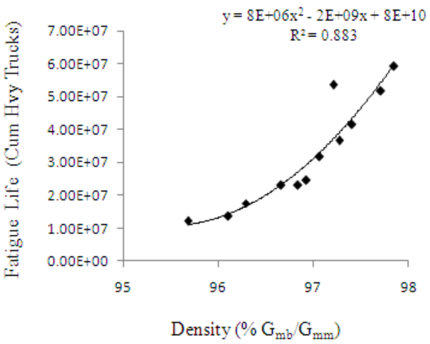


Figure 6. Fatigue life and ITS results for BC-II Mixtures Prepared Under Varied Compaction **Effort**
Figure 7. Fatigue life versus Density of the Mixture

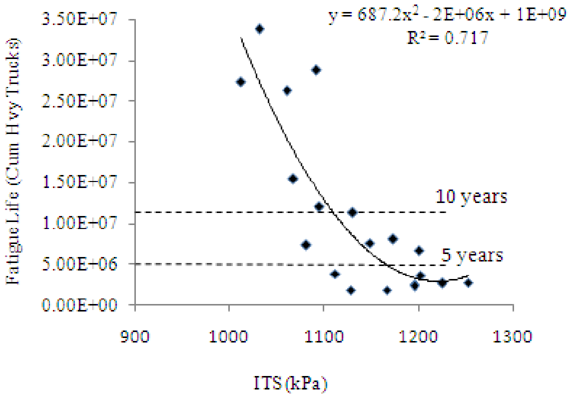


Figure 8. Fatigue Life and Indirect Tensile Strength for BC-II Mixture

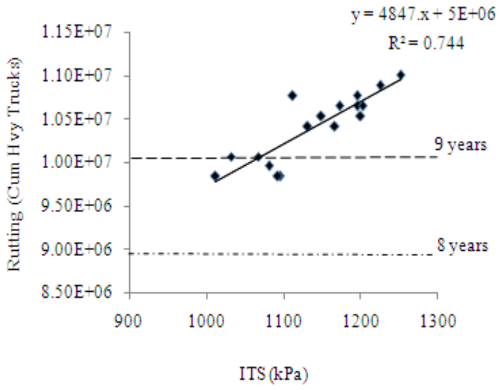


Figure 9. Rutting and Indirect Tensile Strength for BC-II Mixture

Fig. 10 shows the relationship between fatigue life for DBM-II mixture and their corresponding ITS values. The highest adjusted R-square value of 0.761 was observed for a polynomial relationship. As in case with BC-II mixture, here also it was observed that the fatigue life is more for mixtures prepared with higher asphalt binder content and lower air void content. The mixtures prepared with optimum and higher than optimum binder content reached limiting rutting value earlier than mixtures prepared with lower than optimum asphalt binder. However, limiting value was not reached prior to 7 years and hence; fatigue life was found to be critical among the two pavement distresses under study. Fig. 11 shows the progression of rutting in DBM-II mixtures and its relationship with ITS results. The relationship between rutting and ITS results was found to be linear with adjusted R-square value of 0.800.

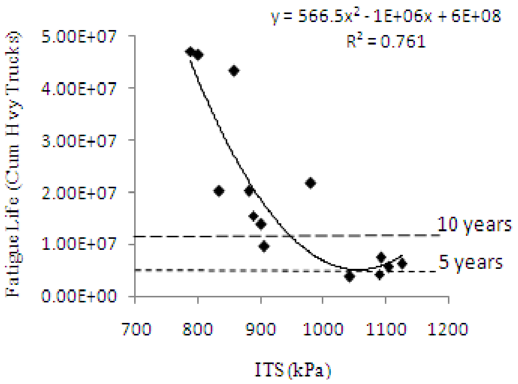


Figure 10. Fatigue versus IDT for DBM-II Mixtures

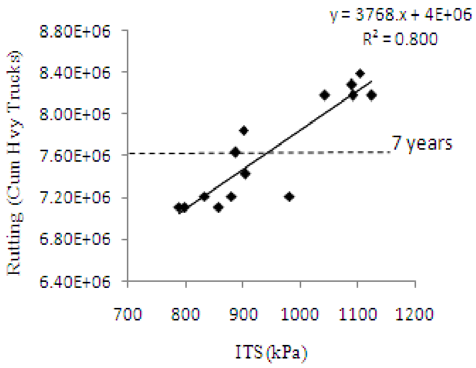


Figure 11. Rutting versus IDT for DBM-II Mixtures

6.7 Influence of Construction Parameters on Performance of BC-II Mix

Using MEPDG it was observed that BC-II mixtures prepared with less than permitted asphalt binder content deviation of -0.3% (as per MoRTH), resulted in excessive bottom up cracking making the pavement fail in fatigue in less than 4 years. Also, mixtures prepared with less than optimum binder content but within the permitted MoRTH specified deviation of -0.3% asphalt binder by weight of total mix, developed excessive bottom up cracking in less than 8 years. Again, it was also observed that mixtures prepared at and more than optimum binder content failed under excessive rutting in less than 9 years however, the rutting observed at higher than optimum binder content was slightly more than that observed in mixtures prepared at optimum binder content. This rutting happened, even though the variation in binder content was within the +0.3 % deviation permitted under MoRTH specifications.

It is to be noted that small deviations in construction parameters are permitted under MoRTH guidelines considering the difficulty in maintaining absolute precision during construction, however; these deviations does affect the overall HMA layer performance. Earlier, it was established that asphalt binder content significantly influences the ITS results and the same has been captured in the ITS predictive equation1. In order to qualitatively establish the influence of asphalt binder content on the HMA layer performance, the binder content of mixes (which were earlier prepared and tested at laboratory under optimum binder content) were varied by ±0.2% and up to ±1% by volume, keeping air void content constant and there fatigue and rutting performance were ascertained using MEPDG. ITS value was predicted using equation 1 and was plotted against fatigue life. A strong polynomial relationship was observed with fatigue life consistently increasing with an increase in asphalt binder content. The rutting life and predicted ITS value (capturing the influence of variation in asphalt binder content) also showed a strong polynomial relationship with rutting life decreasing with an increase in binder content % by volume of the total mix(decrease in predicted ITS value). However, it remained well below the limiting rutting in HMA layers. Although asphalt binder content significantly affected the fatigue life of HMA layer, however; minor deviations in the same was not a limiting criteria as long as mixtures are prepared at or close to optimum binder content. Fig.12 and 13 shows the relationship between predicted ITS values and fatigue life and between predicted ITS values and HMA layer rutting respectively. It was seen that by increasing the asphalt binder content by up to 1% by volume of the total mix, the fatigue life of the mixture increased by 1 year, however; overall, the pavement remained well above its limiting distress value. The plot shows that for sample3, the air void content is least among the three samples prepared at optimum binder content and thus, for the same asphalt binder content in the three samples, it shows the maximum ITS values and also maximum fatigue and rutting life. However, within the same sample, with the decrease in asphalt binder content (air void content being kept constant), the ITS value increases and correspondingly the fatigue life decreases whereas the rut life increases.

As per equation 1, ITS values are dependent on asphalt binder content and air void content. Earlier we have seen that at optimum binder content, pavement performance is best and it can even accommodate minor fluctuations in binder content (from optimum value) without an alarming loss in performance. For the estimation of pavement performance, influence of air void content is equally important. Thus, in order to ascertain its influence on pavement performance, air void content in BC-II mixture prepared at optimum binder content were varied and their corresponding fatigue and rutting life were determined using MEPDG. Fig. 14 shows the exponential relationship between predicted ITS values and fatigue life of the BC-II mixtures. The variations within the specimen were incorporated by varying the air void content. It is evident from the figure and from the table that in all the cases when the air voids increased beyond 5.5%, the HMA layer reached its limiting fatigue life before 5 years and it reached limiting rut depth at and above 7.0% air voids. Also, in all the cases excessive distress developed at ITS value below 1060 kPa. Fig. 15 depicts the plot between predicted ITS value and rutting life observed in BC-II mixture.

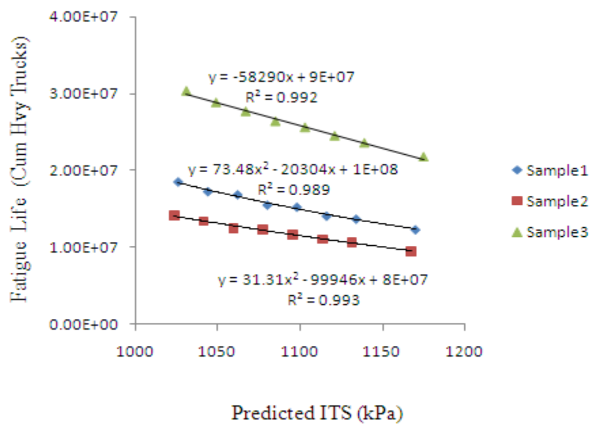


Figure 12. Fatigue life versus Predicted ITS (under Varying Bitumen Content for BC-II Mix)

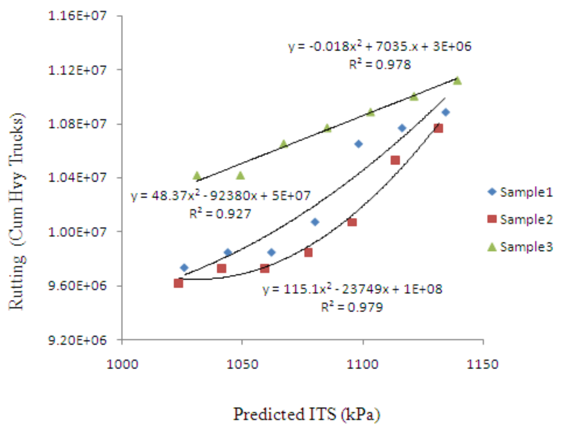


Figure 13. Rutting versus Predicted ITS (under Varying Bitumen Content for BC-II Mix)

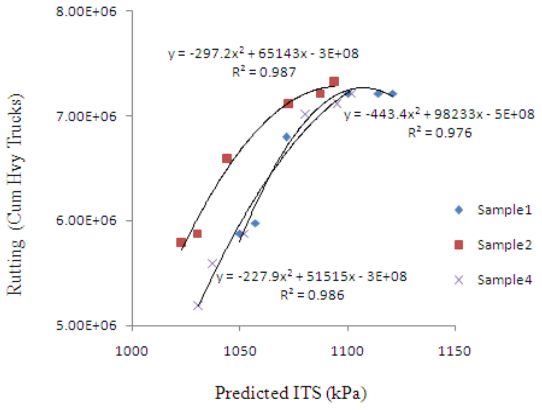


Figure 14. Fatigue life versus Predicted ITS (under Varying Air Void Content for BC-II Mix)

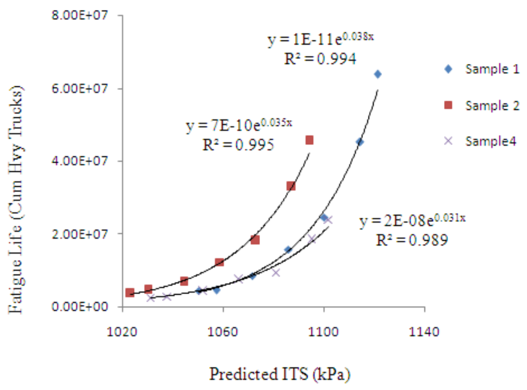


Figure 15. Rutting versus Predicted ITS (under Varying Air Void Content for BC-II Mix)

It is known from past studies (Brown et al., 1988; Huber et al., 1997; Ford, 1998) that in-place air void should not fall below 2.5%. Although, MEPDG provides a warning when the in-place air voids are reduced below 2.0%, however; in this case, it could not effectively capture the influence of the same on rut susceptibility of the HMA layer. However, it is recommended that air void content in a mix should not be allowed to fall below 2.5%.

6.7 Influence of Construction Parameters on Performance of DBM-II Mix

Pavement life was predicted using MEPDG and it was observed that DBM-II mixtures prepared with less than permitted asphalt binder content deviation(from optimum binder content value) of -0.3% (as per MoRTH), resulted in excessive bottom up cracking making the pavement fail in fatigue in less than 6 years. Further, mixtures prepared with less than optimum binder content but within the permitted MoRTH specified deviation of -0.3%, developed excessive bottom up cracking in 8 to 12 years. It was observed that mixtures prepared at, and more than optimum binder content failed under excessive rutting in less than 7 years as against the rutting life of 8 years at lower than optimum binder content. From the wheel tracking test results, it was seen that rut susceptibility of mixture prepared with higher than optimum binder content was more than the mixtures prepared with optimum/lower than optimum binder content.

To assess the influence of asphalt binder content on DBM-II mix and consequently on the HMA layer performance, the binder content of mixes prepared at optimum binder content were varied at by ± 0.2% by volume and up to ±1%, keeping air void content constant. ITS value was predicted using equation 2 and was plotted against fatigue life. A strong polynomial relationship was observed with fatigue life consistently increasing with an increase in asphalt binder content and ITS value. The rutting life and predicted ITS value (capturing the influence of variation in asphalt binder content) also showed a strong polynomial relationship with rutting life decreasing with an increase in binder content % by volume of the total mix. However, it remained well above the limiting rutting in HMA layers. Although asphalt binder content significantly affected the fatigue life of HMA layer, however; minor deviations in the same was not a limiting criteria as long as mixtures are prepared at or close to optimum binder content. Fig. 16 and 17 shows the relationship between predicted ITS values and fatigue life and between predicted ITS values and HMA layer rutting respectively. It was seen that by increasing the asphalt binder content by up to 1% by volume of the total mix, the fatigue life of the mixture increased by over 2 years whereas only a negligible increase in rutting was observed, however; overall, the pavement remained well above its limiting distress value. It is evident that with an increase in ITS value, the fatigue life of the mixture and thereby of the pavement is increasing, whereas, it's rutting resistance is decreasing with an increase in ITS value. Thus, there is an optimum value of ITS for best performing bituminous concrete mixtures.

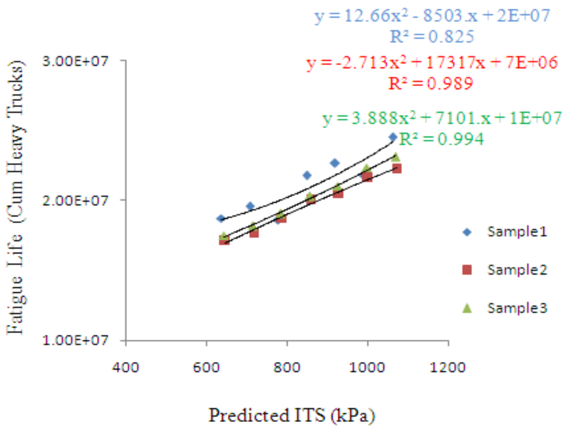


Figure 16. Predicted Fatigue Life versus Predicted ITS for DBM-II Mix under Varying Bitumen Content (by Volume of Total Mixture)

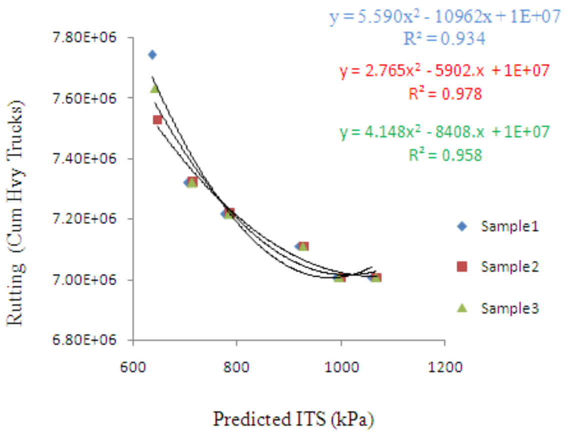


Figure 17. Predicted Rutting versus Predicted ITS for DBM-II Mix under Varying Bitumen Content (by Volume of Total Mixture)

For the realistic estimation of influence of construction parameters on pavement performance, influence of air void content on it is equally important. Thus, air void content in DBM-II mixtures prepared at optimum binder content were varied and their corresponding fatigue and rutting life were determined using MEPDG. Fig. 18 shows the relationship between predicted ITS values and fatigue life of the DBM-II mixtures while Fig. 19 depicts the plot between predicted ITS value and rutting life observed in DBM-II mixture.

The variations in performance (within the specimen), were incorporated by varying the air void content. It was noticed from the results that in all the cases when the air voids increased beyond 5.5%, the HMA layer reached its limiting fatigue life in less than 5 years and it reached limiting rut depth of 10mm at and above 7.0% air voids. Also, it indicated that there exists an optimum value of ITS which has to be considered in conjunction with the asphalt binder content of the bituminous concrete mixture and more importantly, with its air void content.

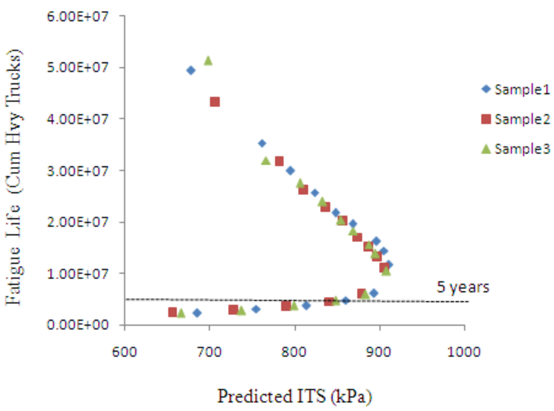


Figure 18. Fatigue Life versus Predicted ITS (under Varying Air Void Content) for DBM-II

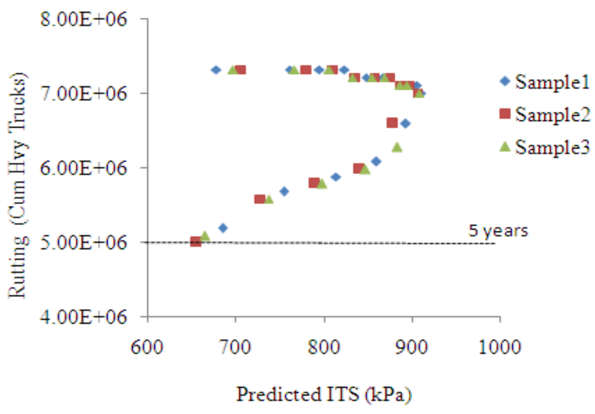


Figure 19. Rutting versus Predicted ITS (under Varying Air Void Content) for DBM-II

VII. Summary And Conclusions

7.1 Summary

The objective of this study was to relate construction quality to pavement performance by identifying and quantifying those properties of HMA mixes that influence the rutting and cracking in HMA layers. The scope of this study has been restricted to two types of HMA mixes namely, BC grading II and DBM grading II as these two are the most widely used bituminous concrete paving mixes in India, particularly, for heavily trafficked roads. The main consideration while preparing experimental investigations methodology was to capture the influence of variation in asphalt binder content, compaction, and air-voids on mix performance.

DARWin-ME was used to provide a link between material, structural design, construction parameters, climate, traffic, and pavement performance.

7.2Conclusions

On the basis of work that has been carried out in this study, the following conclusions can be drawn.

7.2.1 Marshall Test

With increase in number of compaction blows, the density of the mix is found to increase and air void content is found to decrease.

7.2.2 Indirect Tensile Strength Test

- Contrary to expectation, the observed ITS values decrease with increase in binder content. It may however be noted that binder content alone cannot completely dictate the ITS results.
- With decrease in air void (keeping constant asphalt binder content), ITS values were found to increase.
- Higher average ITS values were obtained at higher number of compaction blows, and with increase in compaction effort the air voids decreased resulting in higher mix density.

7.2.3 Rut Wheel Tracking Test

- The number of load passes to critical rut depth decreases with an increase in asphalt binder content and the rutting susceptibility in the mixes was more pronounced when asphalt binder content increased beyond its optimum value.
- At constant binder content, numbers of load passes to limiting rut depth are decreasing with an increase in air void content, which shows that rut susceptibility of the mix increases, with an increase in air void content.
- At binder contents higher than optimum binder contents, air voids content fell below 3 percent and increased rutting was observed in both the mixes.

7.2.4 Predicting Pavement Performance through Dynamic Modulus of the Mix

- A strong correlation was obtained between progression of Fatigue cracking (calculated through MEPDG) and dynamic modulus for both the mixes (estimated through Hirsch predictive model).
- Again a reasonably strong negative linear correlation was observed between the progression of rutting in the asphalt concrete layer and its dynamic modulus value, as estimated through Hirsch predictive model.
- It was noticed that mix dynamic modulus could provide a good indication of the pavement performance in terms of initiation and progression of bottom up-cracking and rutting in the asphalt concrete layer (when measured under same temperature and loading frequency).

7.2.5 Predicting Pavement Performance in terms of ITS

- A negative correlation was reported between progression of Fatigue cracking (calculated through MEPDG) and ITS results for both the mixes.
- Rutting in HMA layer (prepared with both the mixes) and ITS results (experimentally derived) indicates that, ITS results could provide important information regarding rut susceptibility of the mix.

7.2.6 Influence of HMA Layer Thickness on Pavement Performance

- With reduction in HMA layer thickness; there was a corresponding reduction in the overall fatigue and rutting life of the pavement. A ± 25mm variation in layer thickness of BC-II mixture resulted in reduction in fatigue life by up to 1 year.

7.2.7 Influence of HMA Layer Density on Pavement Performance

- As expected, it was observed that with increase in compaction effort, there was a consistent reduction in air void content and an increase in both the indirect tensile strength of the mixture and its fatigue life.
- Although, with an increase in density, the rut resistance of the mixture also improved, however, the trend was not as clear and significant as with fatigue cracking.

7.2.8 Influence of Construction Parameters on Performance of BC-II Mix

- BC-II mixtures prepared with more deviation than permitted value of -0.3% asphalt binder content (as per MoRTH), resulted in excessive bottom up cracking making the pavement fail in fatigue in less than 4 years.

- Mixtures prepared with less than optimum binder content but within the permitted MoRTH specified deviation of -0.3% asphalt binder by weight of total mix, developed excessive bottom up cracking in less than 8 years.
- Again, it was also observed that mixtures prepared at and more than optimum binder content failed under excessive rutting in less than 9 years. The rutting observed at higher than optimum binder content was slightly more than that observed in mixtures prepared at optimum binder content.
- Fatigue life increased whereas, rutting life decreased consistently with an increase in asphalt binder content in the mix (under constant air void content). However, as long as the deviation in binder content was not much from the optimum value, the distresses remained below the critical limits.
- It was observed that as the air voids in the mix increased beyond 5.5%, the HMA layer reached its limiting fatigue life before 5 years and it reached limiting rut depth at and above 7.0% air voids. Although the ill-effects of excessively low air content could not be completely captured in this study however, based on past studies carried out by various researchers, it has been recommended that air void content below 2.5 % needs to be avoided.

7.2.9 Influence of Construction Parameters on Performance of DBM-II Mix

- DBM-II mixtures prepared with less than permitted deviation of -0.3% asphalt binder content (as per MoRTH), resulted in excessive bottom up cracking making the pavement fail in fatigue in less than 6 years.
- It was also noticed that mixtures prepared with less than optimum binder content but within the permitted MoRTH specified deviation of -0.3%, developed excessive bottom up cracking in 8 to 12 years.
- Mixtures prepared at, and more than optimum binder content failed under excessive rutting in less than 7 years as against the rutting life of 8 years at lower than optimum binder content thus, reconfirming the earlier wheel tracking results which also highlighted that the rut susceptibility of HMA mixes increases with increase in binder content.
- With increase in binder content and under unchanged air void content, the fatigue life consistently increased whereas, the performance of the mix against rutting decreased.
- With an increase in ITS value, the fatigue life of the mixture and thereby of the pavement increased, whereas, it's rutting resistance decreased with an increase in ITS value. Thus, there is an optimum value of ITS which has to be considered in conjunction with the asphalt binder content of the bituminous concrete mixture and more importantly, with its air void content.
- Like in case of BC-II mix, it was observed that as the air voids in the mix increased beyond 5.5%, the HMA layer reached its limiting fatigue life before 5 years and it reached limiting rut depth at and above 7.0% air voids.

Acknowledgements

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