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APPLICATION OF THE DISSIPATED ENERGY CONCEPT TO THE FATIGUE CRACKING IN ASPHALT (BITUMINOUS) PAVEMENT

[1]Rahil Ashraf, [2]Dr. Rakesh Gupta
[1]M.Tech Scholar, Civil Dept., SRMIET, Bhurewala, Ambala, Haryana, India
[2]Professor, Director of Civil Engineering, SRMIET, Bhurewala, Ambala, Haryana, India

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Abstract- Highway pavements, once constructed will not last forever. After a time, signs of wear will appear. These signs include cracking, rutting and polishing of the road pavement. Loss of skidding resistance and loss of texture are forms of pavement maintenance. The structural purpose of the pavement is the support of vehicle wheel loads applied to the carriageway and the distribution of them to the subgrade immediately underneath. One of the principal mechanisms causing failure in Flexible (Bituminous) Pavements is the development of fatigue cracking on a bituminous surface due to repeated cycles of tensile stresses generated by vehicle loading. The long life of pavements can also be achieved by the removal of any cracked or severely rutted material, before the defects has progressed too deeply, and its replacement with the new material. A constant load is applied to a flexible pavement material, the strain of the material is proportional to the applied stress and when the load is withdrawn, thus there is a complete regain to the original position. The behavior of flexible pavement material in which a constant stress increases the strain over a long time and when the applied stress is removed, the material fails to attain its original position leading to permanent deformation. Fatigue can be minimized by controlling the dissipated energy. In the present study, various types of bitumen available for the flexible pavement purposes are being compared and discussed in respect of bitumen content, strain level, and testing temperature on dissipated energy on NH-1 and testing the material properties like softening point ,penetration, bitumen concrete extraction gradation, flakiness and elongation index test, Bump integrator Test, flexural beam fatigue test

Keywords: Rutting, skidding, resistance, Crumb Rubber modified Bitumen, Conventional Bitumen

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I. INTRODUCTION

The ability of a material to withstand repeated application of stress generally at a level below the tensile strength of a material without fracture. The importance of testing asphalt mixtures for fatigue performance was first recognized in the 1950's (Hveem.1955) due to increasing concern with the pavement cracking. Since that time, significant process has been made with regard to the understanding of fatigue behavior of asphaltic mixtures. Fatigue cracking can be generally be considered as occurring in two stages.

- •The formation of cracks (crack initiation)
- •The growth of crack (crack propagation)

In Hot Mix bituminous pavements, fatigue cracking occurs when repeated traffic loads ultimately cause sufficient damage in a flexible pavement t. A number of factors can influence a pavement's ability to withstand fatigue, including pavement structure (thin pavements or those that do not have strong underlying layers are more likely to show fatigue cracking than thicker pavements or those with a strong support structure), age of the pavement, and the materials used in construction. The flexural fatigue test is used to investigate fatigue as it relates to Hot Mix bituminous construction materials.

Fatigue Life Concept

The concept of a fatigue life centers on the universal idea that most materials undergo a gradual deterioration under repeated loads that are much smaller than the ultimate strength of the material. A paper clip can be broken by repeatedly bending it just as a large pressure vessel can fail after being subject to many thousands of pressure cycles. Hot Mix bituminous pavements are similar.

A classic fatigue crack starts at the bottom of a Hot Mix bituminous pavement layer (or structure) and grows towards the surface. Its development is directly proportional to the strain level at the bottom of the layer. This strain level changes with Hot Mix bituminous thickness (thicker pavements give lower strain values), stiffness and other properties.

Asphalt Mixture Characterization

For the laboratory study, aggregate of sizes 20 mm, 10 mm, stone dust and lime were used and tested as per IS Standards. Bitumen of Viscosity CRMB 60 as well as conventional bitumen of various grades have been considered for the test purposes to obtain the results and many other types of bitumen such as Conventional Bitumen CB (80/100), CB (60/70) and so on are available. CRMB 60 and CB (60/70) are used and tested as per Bureau of Indian Standards (BIS). The results of tests performed on asphalt for the study are shown in Table 1 and Table 2. The basic tests on aggregates performed during the study are shown in Table 3 as per BIS limits and as per the specifications of Ministry of Road Transport and Highways (MORTH) 2005. The asphalt mix design was done on a control gradation of Bituminous Concrete (BC) mixture as per MORTH.

Table 1: Test Results of Bitumen (CRMB 60)

S.No.	Test Description	Results
1	Penetration at 25˚C, 0.1 mm, 100g, 5 s	30-50
2	Softening point, (R&B), ˚C, Min.	63.4
3	Flash Point, COC, °C, Mm.	220
4	Elastic recovery of half thread in ductilometerat 15°C, percent	60
5	Viscosity at 150˚C, Poise	5-9

Table 2 Results of Conventional Bitumen, CB(60/70)

S.No.	Test Description	Results
1	PG grading	64-22
2	Penetration at 25˚C, 0.1 mm, 100g, 5 s	56
3	Softening point ˚C, Min.	48.4
4	Elastic recovery at 15˚C, percent	20
5	Viscosity at 60˚C, Poise	3-5

Table 3 Test Results of Aggregates

S.No.	Test description	Results	Limits (As per MORTH)
1	Combined Flakiness & Elongation Index	26.52	≤ 30
2	Specific Gravity 20 mm 10 mm Stone Dust Lime	 2.756 2.654 2.526 2.800	2.5-3.00
3	Water Absorption	1.15%	≤ 2
4	Aggregate Impact Value	22.20 %	Max 24%
5	Stripping Value	5%	≤ 5

Marshall stability

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. Load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded.

Specimen preparation

Approximately 1200gm of aggregates and filler is heated to a temperature of 175−190˚C. Bitumen is heated to a temperature of 121−125˚C with the first trial percentage of bitumen (say 5.41 or 5.43% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of 154−160˚C. The mix is placed in a preheated mould and compacted by a rammer with 50 blows on either side at temperature of 138˚C to 149˚C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5±3 mm. Vary the bitumen content in the next trial by +0.02% and repeat the above procedure. Numbers of trials are predetermined

Table 4 Marshall Test Result of CRMB 60

Specific gravity 1.024				CRMB 60
Bitumen content	Stability	Voids in Min. aggregate (VMA)	Voids in fill with bitumen (VFB)	Flow value
5.41	1323.1	15.77	72.35	2.8
5.43	1383.7	15.68	73.02	3.1

Table 5 Marshall Test Result of CB (60/70)

Specific gravity 1.01				CB (60/70)
Bitumen content	Stability	Voids in Min. aggregate (VMA)	Voids in fill with bitumen (VFB)	Flow value
5.41	753.21	8.14	59.84	2.74
5.43	867.76	6.27	62.43	2.91

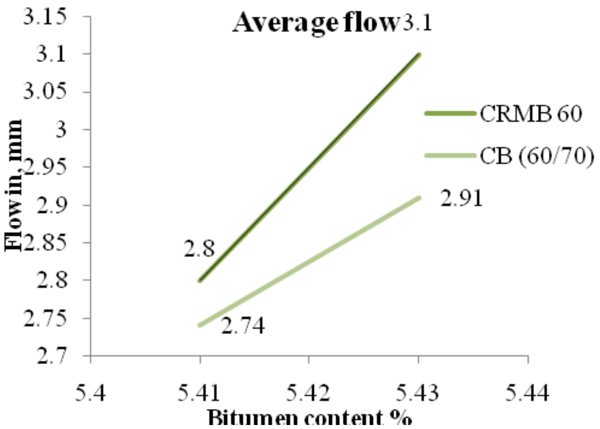

Fig 1 variation of flow with bitumen content

Figure 1 shows the graphical representation of flow for variation in percentage of bitumen content for Marshall Stability test. It can be seen that with the increase in bitumen percentage, flow value also increases. In this figure two types of bitumen content of same percentage are compared with respect to flow. CRMB 60 shows more flow as compared to CB (60/70), this is because the viscosity factor is more in CRMB 60.

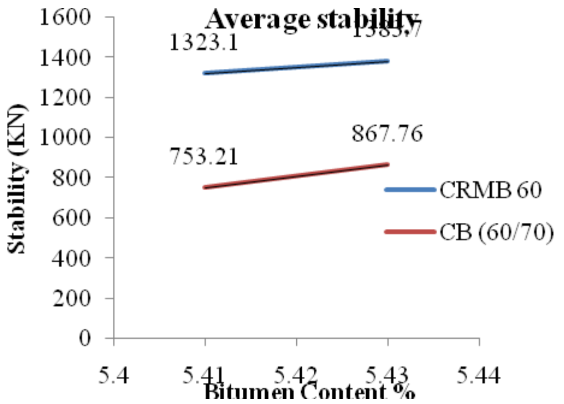

Fig 2 variation of stability with bitumen content

Figure 2 shows the variation of Marshall Stability with the bitumen content where it is seen that as usual the stability value increase with the bitumen increase. On comparing the stability of both the bitumen, CRMB 60 achieves the most frequent place for the construction purposes.

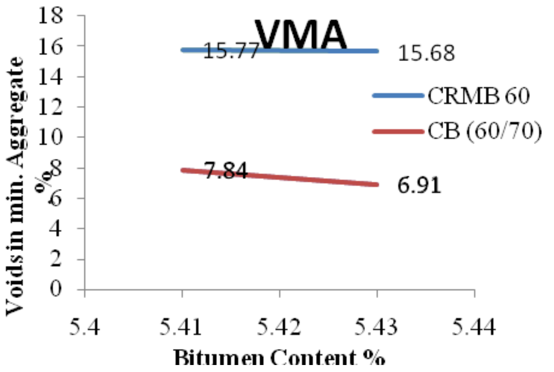

Fig 3 variation of voids in Min. Aggregate with bitumen content

Figure 3 shows the variation of voids in Min. aggregate with bitumen content in Marshall Stability test. As the bitumen content increases voids are minimized in aggregates. More voids are found in the specimen of the sample of CRMB 60 as compared to CB (60/70).

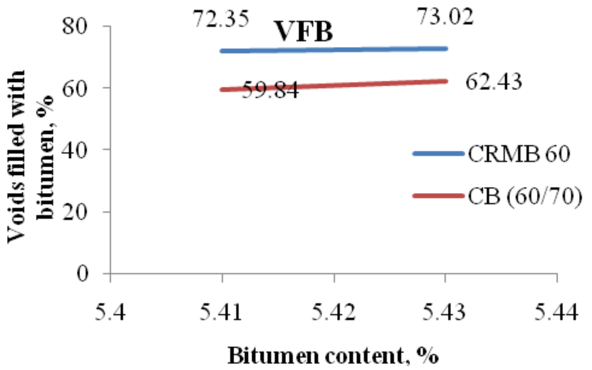

Fig 4 variation of VFB with bitumen content

From the figure 4 clearly shows the variation of voids filled with bitumen with bitumen content. By increasing the bitumen the more voids are filled but the difference is that Crumb Rubber Modified

Bitumen (CRMB 60) fills more voids as compared to the CB (60/70).

Flexural Fatigue Test

Procedure

Fatigue testing cores were taken from each slab and the direction of coring was horizontal so that the direction of the axial stress was parallel to the surface, simulating horizontal stresses occurring in a pavement.

Obtain a test beam by sawing at least 6 mm from both sides of a compacted hot mix bituminous specimen. The final dimensions should be 380 mm length by 50 mm height by 63 mm width. Measure the height and width of each beam to the nearest 0.01 mm at three points along the middle 100 mm of the beam and determine the average for each dimension. Condition the beams at the test temperature 20°C for two hours. Select an initial strain (10–500 micro strain), loading frequency (5–10 Hz), and interval at which the results should be recorded and enter them into the control components of the test program. Apply 50 load cycles and determine the beam stiffness at the 50th cycle. This will be recorded as the initial stiffness of the beam. Select a strain level that will provide an estimated 100000 load cycles before the initial stiffness is reduced to 50 percent or less. For the estimation of mixture stiffness the tensile strain corresponding to fatigue lives of 10^4 and 10^5 cycles were calculated from the equation

1) Parameters Measured

The beam fatigue test provides a measure of the fatigue life and fatigue energy of Hot Mix bituminous pavements.

1. Maximum tensile stress
2. Maximum tensile strain
3. Flexural stiffness
4. Phase angle
5. Dissipated energy per cycle

Maximum tensile stress

$$\sigma t = \frac{3ap}{bh^2}$$

σt = Tensile Stress
a = space between inside clamps
P = load applied (N)
b = average beam width (m)
h = average beam height (m)

Maximum tensile strain

The capacity of a material or structure to withstand loads tending to elongate, as opposed to compressive strength, which withstands loads tending to reduce size.

$$\varepsilon t = \frac{12\delta h}{3L^2 - 4a^2}$$

εt = maximum tensile strain
δ = applied load
h = average beam height
L = beam length between outside clamps
a = space between inside clamps

Flexural Stiffness

The stress in a material just before it yields in a flexure test. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three point flexural test technique.

$$S=\frac{\sigma t}{\varepsilon t}$$

S stiffness (Pa)
σt = maximum tensile stress (Pa)
εt = maximum tensile strain (m/m)

Phase Angle

A phase difference expressed as an angle, 360 degrees (2π radians) corresponding to one complete cycle.

$$\Phi t=360\ f\ s$$

Φt = phase angle (degrees)
f = load frequency (Hz)
s = time lag between maximum load and deflection(S)

Dissipated Energy per Cycle

$$D=\pi\ \sigma t\ \varepsilon t\ \mathrm{Sin}\ (\varphi t)$$

D = dissipated energy per cycle (J/m^3)
σt = maximum tensile stress (Pa)
εt = maximum tensile strain (m/m)
φt = phase angle (degrees)

The cumulative dissipated energy is then the sum of the dissipated energy for each load cycle

Table 6 Energy dissipation at various Load cycles

No. Of load cycles	Energy dissipated (MJ/m³)		
	250 Micro strain	400 Micro strain	750 Micro strain
675	0.090	0.053	0.024
1140	0.161	0.141	0.102
1860	0.298	0.243	0.207
2000	0.460	0.393	0.311
2365	0.890	0.636	0.521
3000	1.050	0.936	0.892
3500	2.020	1.833	1.525
4000	2.13	2.984	2.632
4500	2.16	3.537	3.014
6000	2.21	3.231	3.681
6200	2.05	3.168	3.719
6500	1.987	2.987	3.421
7000	1.943	2.635	3.027

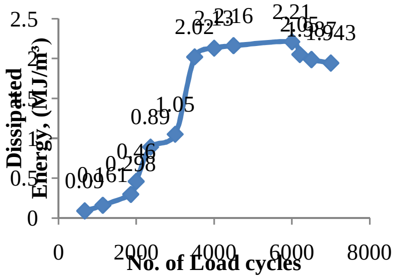

Fig 5 dissipated energy with the no. of load cycles at 250 micro strains

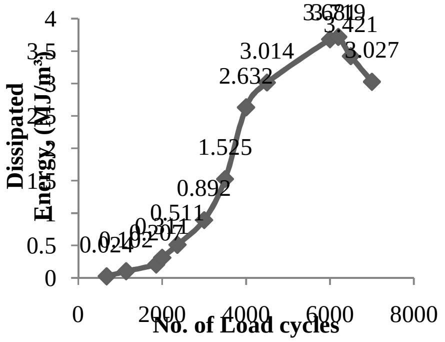

Fig 6 dissipated energy with the no. of load cycles at 400 micro strains

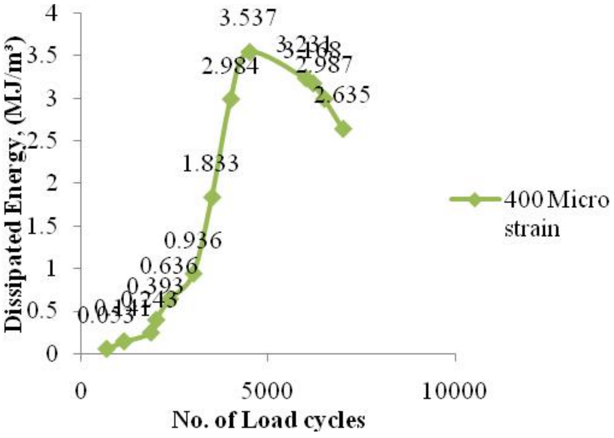

Fig 7 dissipated energy with the no. of load cycles at 750 micro strains

At the initial stages of loading, the trend of the relationship between load cycles and dissipated energy is a straight line, and the variation in the dissipated energy in minimum, then after 10 to 30 load cycles, non- linear behavior of the trend line could be detected. The point where the trend line leaves the linear slope corresponds to the point where the possible fatigue cracks are initiating in the binder. This point is referred as crack initiation point. Beyond this point, the variation in dissipated energy goes on increasing upto maximum possible point. After that point the curve again fall that means failure has occurred there.

CONCLUSION

In this present, work evaluation and development of the concept of dissipated energy to explain the fatigue process in bituminous pavement materials has been conducted. The CRMB 60 (Crumb Rubber Modified Bitumen) improves the viscoelastic behavior of the bitumen and changes its rheological properties.

- The penetration value of paving bitumen is affected more by temperature changes i.e. temperature susceptibility. Viscosity Grading (VG) i.e. degree of fluidity, higher the grade, stiffer the bitumen. At lower strain levels, mixes prepared with crumb rubber modified bitumen had higher fatigue life as compared to mixes prepared with conventional bitumen.

- The Marshall Stability Test results indicated higher stability for dense graded mixtures prepared with CRMB 60 bitumen than CB (60/70).
- The elastic recovery in conventional binder is much less than that of CRMB 60. So, the conventional binder does not recover its original shape when tension is released but CRMB 60 recovers to its original when load is withdrawn at a faster rate. This degree of elastic recovery was used as an indicator of permanent deformation in pavement materials.
- The Flexural Fatigue Test is routinely used to determine the fatigue life of bituminous materials. The flexural fatigue test result showed that the addition of CRMB increased the fatigue life of the bituminous mix; it could sustain higher number of load cycles in comparison to conventional bituminous mix

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