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New phenomenological approach for modeling fatigue life of asphalt mixes

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HIGHLIGHTS

- Fatigue life of different asphalt mixes have been evaluated.
- Plastomeric modified binder show high strain susceptibility.
- A new hypothesis has been proposed to model the fatigue response.
- The new model is found to give excellent fit with the measured response.

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ABSTRACT

In this study three different aggregate gradation as per Ministry of Road Transport and Highways (MoRT&H), India, were evaluated for fatigue life determination using four point beam bending (4PBB) test. Sinusoidal loading with 10 Hz frequency was applied in controlled strain mode at 20 °C. All the mixes were compacted to an air void content of 4 ± 0.2%. Tests like retained Marshall stability and Indirect Tensile Strength (ITS) were also carried out to judge the mix performance. A new phenomenological model has been proposed for determination of the fatigue life of asphalt mixes. Experimental studies show that elastomeric modified bitumen display the highest fatigue life with least susceptibility to change in strain amplitude. Plastomeric modified mixes are found to be highly vulnerable to strain giving poor results at higher strain levels. The fatigue life of Stone Mastic Asphalt (SMA) is almost five times higher than the dense graded mixes. The new proposed model gives excellent fit with the experimental results and is statistically more reliable than the traditional modeling techniques.

1. Background

Fatigue is one of the three (rutting, fatigue cracking and low temperature cracking) major distresses in flexible pavements which results in degradation of the pavement materials and finally the pavement structure [1]. The materials in pavement are subjected to short time load amplitudes upon passage of a vehicle. Higher amplitudes or higher number of load repetitions of this repeated loading results in reduction of material stiffness and its subsequent accumulation with time may lead to complete failure [2].

Simulating the fatigue behavior of hot mix asphalt (HMA) has been done using different test methods over the past 40 years, with varying success [3–10]. Tangella et al. [11] listed the general categories of different test methodologies which included: simple flexure, supported flexure, diametral test, triaxial test, direct axial test, fracture test, and wheel tracking test. Flexure test such as four point beam bending has the advantage of providing a constant bending moment and zero shear over the length of the specimen. Considering the deflection due to shear to be very small, uniform bending moment is produced in the central third of the specimen which simplifies the overall analysis [10].

In laboratory fatigue testing can be done using two different modes: constant strain (controlled–strain) mode and constant stress (controlled–stress) mode. However, complex loading conditions are present in the field, and are usually combined modes of loading [12]. A plethora of studies [11–13] have suggested that controlled strain mode of testing simulates conditions pertaining to thin pavements with HMA less than 50 mm (2 in.), because the strain in thin asphalt pavement layer is mainly governed by the underneath layers and is merely affected by the reduction in stiffness of the asphalt mix. On the other hand, controlled-stress testing might be more appropriate for thicker pavements of more than 152 mm (6 in.) where the main load – carrying component

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Table 1
Properties and processing variables of binders used in the study.

Properties/processing variables	VG 10	VG 30	PMB (S)	PMB (E)
Penetration, dmm	75	62	56	49
Softening point, °C	47	49	60	65
Penetration index	−1.01	−0.95	1.31	1.92
Dynamic viscosity @ 60 °C, Pa s	258	375	2120	6120
Polymer storage stability [16], ΔSoft. Point, °C	–	–	1.5	1.3
High temperature PG Grade	PG 58-XX	PG 64-XX	PG 70-XX	PG 76-XX
True grade, intermediate temperature, °C	25.3	20.1	15.7	12.2
Mixing temperature, °C	–	–	180	190
Blending time, minutes	–	–	60	30
Shear rate, rpm	–	–	1500	600

is the top layer. For intermediate thicknesses, a combination of constant strain and constant stress exists. It has been found that constant stress mode gives shorter fatigue life as compared to constant strain testing condition [13]. In this study, constant strain mode has been adopted assuming that the thickness of the wearing course is not high.

Prediction of fatigue cracking is usually based on Miners concept of cumulative damage [14]. The allowable number of load repetitions is related to the tensile strain at the bottom of the asphalt pavement layer. The damage is calculated by the ratio of the predicted number of load repetitions to the allowable number of those repetitions. The overall history of the development of fatigue models can be subdivided into five main categories/approaches as follows [12]:

- The phenomenological approach
- The continuum damage mechanics approach
- The fracture mechanics approach
- The energy and dissipated energy approach.

This study focusses on analyzing the phenomenological approach. Traditionally the failure in this approach is defined to be reduction in 50% of the initial stiffness of the material. The fatigue life is quantified by N_f, which is the number of load repetition to failure. For a controlled strain mode, N_f can be modeled in one of the following ways [5]:

- Fatigue models relating N_f with strain.
- Fatigue models relating N_f with strain and stiffness.
- Fatigue models relating N_f with strain, stiffness and volumetric parameters.

Though the simplest approach, this method has been criticized mainly due to the inability in providing an accurate mechanism of damage accumulation in the mixture under repetitive load. This study emphasizes on analyzing the previously developed models and providing a more fundamental way which could be applied directly to the complex loading scenarios that are actually common to in-service pavements.

2. Materials and methods

2.1. Bitumen

Two conventional and two polymer modified binders were used in this study. Among the conventional binders, VG10 and VG 30 were used. VG stands for viscosity grade. Modification of VG 10 was done using Styrene Butadiene Styrene (SBS) and Ethylene Vinyl Acetate (EVA) at various percent level. In a previous study done by the authors [15], it was established that for EVA the interlocked phase of the polymer with the base binder is acquired using 5% polymer. Similarly, for SBS, this optimum modifier content was found to be 3%. Higher percentages produced binders which were vulnerable to phase separation. Furthermore, lower percentages did not fully enhance the properties of the base binder, which resulted in an uneconomical blend. So for comparison only 3% SBS and 5% EVA is considered in the study. Table 1 presents the various properties obtained for these binders. In this paper the polymer modified bitumen will be represented as PMB (E) and PMB (S) indicating modification with EVA and SBS.

2.2. Aggregate

The aggregates used in this study were acquired from a local quarry. Table 2 presents the conventional properties and the required specifications of the aggregates. These specifications are in accordance to Ministry of Road Transport and Highways (MoRT&H), India [17].

2.3. Gradation adopted

Three gradations were adopted in the study, which included bituminous concrete (BC), dense bituminous macadam (DBM) and stone mastic asphalt (SMA). The sieve size distribution for the respective mixes are shown in Fig. 1. Each type of mix was prepared with all the four binders. Owing to the gap gradation for SMA, the binders are susceptible to flow out of the mix at high handling temperatures (about 163 °C). This phenomena is known as draindown which should not be more than 0.3% as per specification outlined in IRC SP-79 2008 [18]. Drain down test was carried out using Schellenberg method [18] for all the binders and it was found (as can be seen in Table 3) that only the modified binders (PMB (S) and PMB (E)) satisfied the maximum draindown criteria. So, VG 10 and VG 30 were not used for preparing SMA samples.

2.4. Mix design

All the asphalt mixes in the study were prepared using Marshall mix design procedure. Optimum binder content (OBC) was determines as per the procedure recommended by National Asphalt Pavement Association (NAPA). According to the method, the binder content corresponding to 4% air void is determined first

Table 2
Conventional properties of aggregates.

Parameter	Specification (MORT&H)	Result
Water absorption	Max. 2%	0.6%
Specific gravity	Coarse aggregate	2.704
	Fine aggregate	2.717
	Filler	2.720
Aggregate impact value	Max. 18%	12.83%
Los Angeles abrasion value	Max. 25%	14.68%
Combine flakiness and elongation index	Max. 30%	21.47%

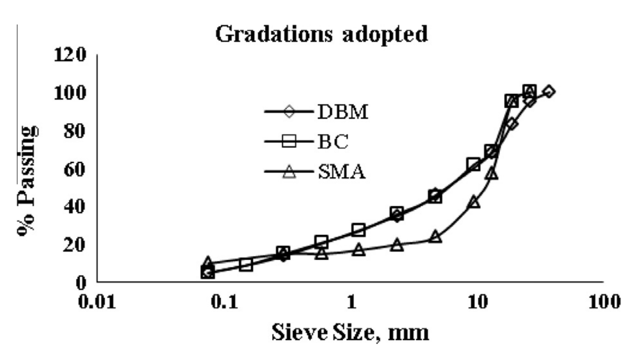

Fig. 1. Aggregate gradation adopted in the study.