

Fatigue Characteristics of Stone Matrix Asphalt Mixes in Warm Climate

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Abstract: Tropical countries like India with predominantly warm climates, face problems of excessive rutting in flexible pavements with bituminous wearing courses. In order to provide rut resistant wearing courses, Stone Matrix Asphalt (SMA) mixes, which are basically gap graded mix, characterized by high coarse aggregates, high asphalt contents and polymer or fiber additives as stabilizers, have been suggested. High concentration of coarse aggregate maximizes stone-to-contact and interlocking in the mix which provides strength, and the rich mortar binder provides durability. The stabilizing additives composed of cellulose fibers, mineral fibers, or polymers are added to SMA mixtures to prevent draindown from the mix. In comparison to dense graded mixtures SMA has higher proportion of coarse aggregate, lower proportion of middle size aggregate and higher proportion of mineral filler. The present study presents the details of a laboratory study of stone mastic asphalt mixes, with emphasis on engineering characteristics under repeated load conditions. In this study, conventional binders namely locally used penetration grade bitumen 80/100 and 60/70, with locally available aggregates and cement as filler have been used. A non-conventional natural fiber, namely coconut fiber to the extent of 0.3% by weight, have been added to the mix to act as a stabiliser. It is observed that the natural fibres improve the engineering properties of the SMA mixes considerably.

Keywords Stone matrix asphalt, Coconut fibre, Resilient Modulus, Fatigue Life

1. Introduction

Bituminous wearing courses are conventionally used all over the world in construction and rehabilitation of flexible pavements. This basically consists of hot mix bituminous materials laid and compacted at suitable temperatures. These function well as long as the atmospheric temperature is moderate. Tropical countries like India have predominantly warm atmospheric temperatures during most part of the year. Even beyond the tropical regions also, many European and other nations face global warming

and thus, the resulting higher temperature, mainly in summer causes concern to paving engineers, in that they result in premature distresses in bituminous pavements in form of excessive rutting. To address this situation, one type of bituminous paving mix called Stone Matrix Asphalt (SMA) which basically consists of gap graded aggregates, has been suggested. SMA is a gap graded mixture containing about 70-80% coarse aggregate, 6-7% of binder, 8-12% of filler, and about 0.3-0.5% of fibre or modifier. The high amount of coarse aggregate in the mixture forms a skeleton-type structure providing a better stone-on-stone contact between the coarse aggregate particles, which offers high resistance to rutting. While the higher binder content makes the mix durable, the fibres or modifier hold the binder in the mixture at high temperature and prevent drainage during production, transportation and laying, as SMA being a gap graded mix has more air void content and thus has a greater tendency of draindown.

Brown and Mallick [4], Mogawer and Stuart [8], and Neubaur and Partl [9] have used unmodified binders for study of SMA mixes. Ibrahim Asi [2] reported the advantages of SMA mixes over dense graded mixes in terms of durability, resilience and rutting resistance. Xue et al. [12] used municipal solid waste incineration ash as partial replacement of fine aggregate and mineral filler in SMA mixes. Kumar et al. [7] reported the benefits of use of jute fibres and crumb rubber modified binders as stabilizers in SMA mixes. Chiu and Lu [5] found that the rut resistance and draindown effects of SMA mixes improved with asphalt modification by 20% ground tire rubber. Cellulose fibres have been successfully used by many investigators in SMA mixes to encompass the draindown problem. These fibres are costly and not readily available in India and many developing countries. Putman and Amirkhaniyan [10] have successfully tried to use waste fibres such as waste tire and carpet fibre in SMA mixes. As reported by Khalil et al. [1] coconut fibre contains certain amount of cellulose in it. Considering this, Suchismita [11] used commonly used binders such as 80/100 and 60/70 penetration grade bitumen and locally available coarse aggregates with 0.3% coconut fibres by weight to prepare and study the SMA mixes. An attempt has been made in this study to utilize a naturally and abundantly available low cost material such as locally available coconut fibre, in preparation of SMA mixes and study the fatigue properties of the SMA mixes.

2. Experimental programs

2.1. Materials used

2.1.1. Aggregates

For preparation of SMA mixes, aggregates as per National Council for Highway Research Program (NCHRP) given in Table 1 were used. Coarse aggregates up to 4.75 mm IS sieve size, consisted of stone chips collected from a local source. The basic physical properties of the aggregates as per relevant Indian Standards are summarized in Table 2. Fine aggregates, consisting of stone crusher dusts were collected from a local crusher with fractions passing 4.75 mm and retained on 0.075 mm IS sieve. Its specific gravity was found to be 2.65. The filler consisted of Portland slag cement (Grade 43) collected from local market passing through 0.075 mm IS sieve. Its specific gravity was found to be 3.15.

Table 1. Adopted aggregate gradation

Property	Grading
Nominal Size of Aggregate (NSA)	19 mm
Sieve size, mm	Percent Passing
25	100
19	99
12.5	61
9.5	40
4.75	22
2.36	19
1.18	18
0.6	16
0.3	14
0.075	9

Table 2. Physical properties of coarse aggregates

Property	Test Result
Aggregate Impact Value (%)	14
Aggregate Crushing Value (%)	12
Los Angeles Abrasion Value (%)	18
Flakiness Index (%)	17.24
Elongation Index (%)	12.38
Water Absorption (%)	0.09
Specific Gravity	2.64

2.1.2. Binders

Conventional penetration grade bitumen 80/100 and 60/70, procured locally was used in preparation of mix samples. The results of tests performed as per Indian/ASTM standards for important physical properties of these binders are summarized in Table 3.

Table 3. Physical properties of binders

Binder	Property	Test Result
80/100 Bit.	Penetration at 25°C, 100g, 5 sec, 0.1 mm	92
	Softening Point (R&B), °C	44.5
	Viscosity (Brookfield) at 160°C, cP	145
60/70 Bit.	Penetration at 25°C, 100g, 5 sec, 0.1 mm	68
	Softening Point (R&B), °C	48.5
	Viscosity (Brookfield) at 160°C, cP	200

2.1.3. Fibres

The peelings of ripe coconut were collected locally, dried and neat fibers taken out manually. The lengths of such fibers were normally in the range of 75 to 200 mm and diameter varied from 0.2 to 0.6 mm. The tensile strength of these fibers was tested in a materials testing machine, Tinius Olsen, UK, Model HIOKS. The test was done in tensile mode with 10 KN load cell and the cross head speed was maintained at 0.2 mm/min. The average tensile strength of the fiber thus obtained was found to be 70.58 N/mm². The coconut fibers were cleaned and cut in to small pieces of 2.5-7.5 mm in length to ensure proper mixing with the aggregates and binder during the process of mixing.

2.2. Preparation of mixes

As reported by Ibrahim Asi [2], Marshall samples were prepared for study of fatigue characteristics. In the similar line, the fatigue characteristics were studied on the Marshall samples. The required quantity of coarse aggregates, fine aggregates and cement according to the adopted gradation were taken on a pan on a hot plate. Coconut fibres after being cut to small pieces approximately 3-5 mm long, (0.3%) by weight were added directly to the aggregate sample and thoroughly mixed before adding required quantity of binder (4.2% by weight).

2.3. Tests on mixes

2.3.1. Static indirect tensile test

In this test, a compressive load is applied on a cylindrical specimen (Marshall Sample) along a vertical diametrical plane through two curved loading strips 13 mm (1/2") wide, 13 mm deep and 75 mm long having inside diameter same as that of a Marshall sample (102 mm). The static indirect tensile strength of a given specimen was determined using the procedure outlined in ASTM D 6931 [3] at temperatures 25 °C, 30 °C and 35 °C that has been considered for repeated load test. A loading rate of 51 mm/minute was adopted. The load was applied and the failure load was noted from the dial gauge of the proving ring. This test helps to decide the amount of repeated load to be applied during the fatigue testing.

Figure 1 shows a static indirect tensile test in progress. The tensile strength of the specimen was calculated by using the following formula.

$$S_t = \frac{2000 \times P}{\pi \times t \times D} \quad (1)$$

where

S_t = Indirect Tensile Strength, kPa
 P = Maximum Load, N
 t = Specimen height before testing, mm
 D = Specimen Diameter, mm

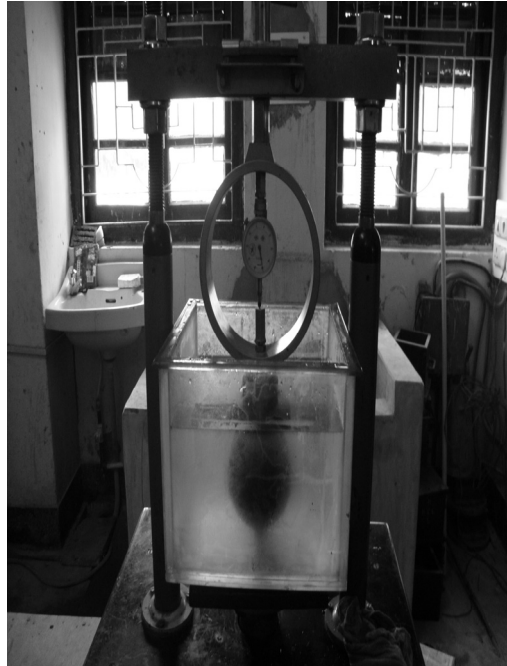


Figure 1. Static indirect tensile test in progress

2.3.2. Repeated load indirect tensile test

This test is similar to the static indirect tensile test except that instead of static load a repeated load is applied with a suitable frequency, having appropriate loading time and rest period. Both horizontal and vertical deformations are accurately measured. The resilient modulus of elasticity, resilient Poisson's ratio, tensile stress, tensile strain etc. is computed by using the following equations as reported by Kennedy [6]. The repeated load indirect tensile test was conducted in a set up designed and fabricated in the Highway Engineering Laboratory of N.I.T., Rourkela. The close view of the sample under test is shown in Figure 2. This test has been conducted on samples at three predominant temperatures in India, i.e. 25 °C, 30 °C and 35 °C, though other extremes are also possible.

- Resilient Poisson's ratio, $\mu_R = \frac{3.59 \times H_R}{V_R} - 0.27$ (2)

- Resilient Modulus of Elasticity, MPa, $M_R = \frac{P(0.27 + \mu_R)}{H_R \times h}$ (3)

- Tensile Stress, MPa, $\sigma_t = \frac{P_{fail}}{h} \times D_1$ (4) Stress Difference, MPa, $\Delta\sigma = 4\sigma_t$ (5)

where, H_R = Horizontal deformation, mm

V_R = Vertical Deformation, mm

P = Repeated Load, N

h = Height of specimen, mm

$D_1 = 0.0061$ (a constant)

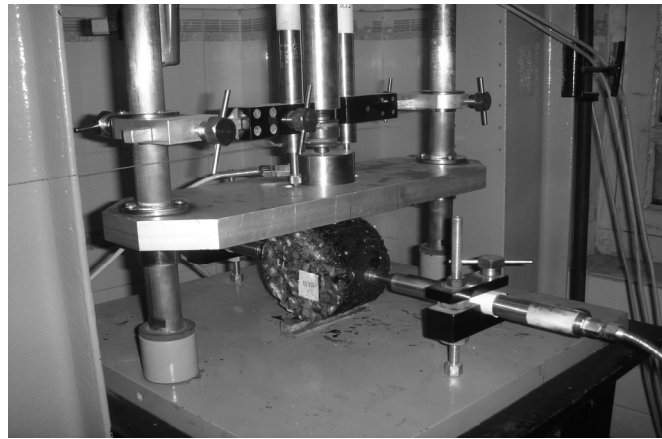


Figure 2. Repeated load indirect tensile test setup

Fatigue life is the number of load applications to cause failure at a particular stress level for a mix at a particular temperature. The failure to define fatigue life is defined as that which causes a permanent horizontal deformation of 5mm which can be noted directly from the output of the computer software.

3. Analysis and discussions

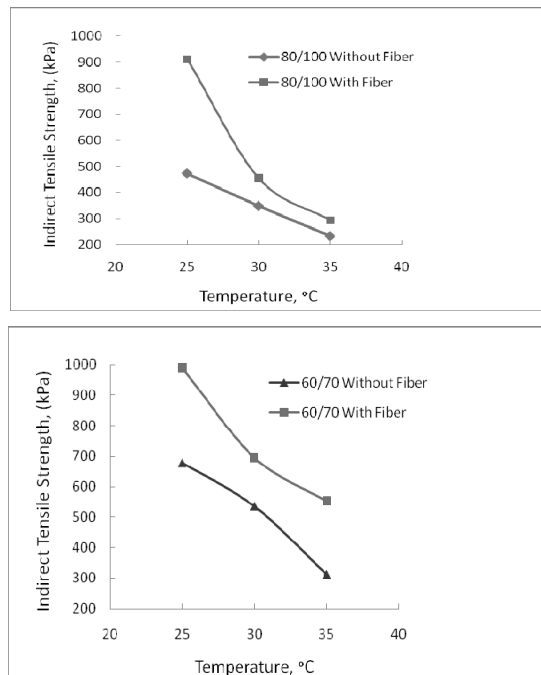


Figure 3. Variation of indirect tensile strength

3.1. Static indirect tensile test

Figure 3 shows the variations of indirect tensile strength with temperature for mixes with 80/100 and 60/70 bitumen, with and without fibre. It is seen that the fibre addition results higher tensile strength. It is also observed that for a particular binder, the tensile strength decreases with increase in temperature. At all temperatures, the mixes with 60/70 bitumen result higher indirect tensile strength than 80/100 bitumen.

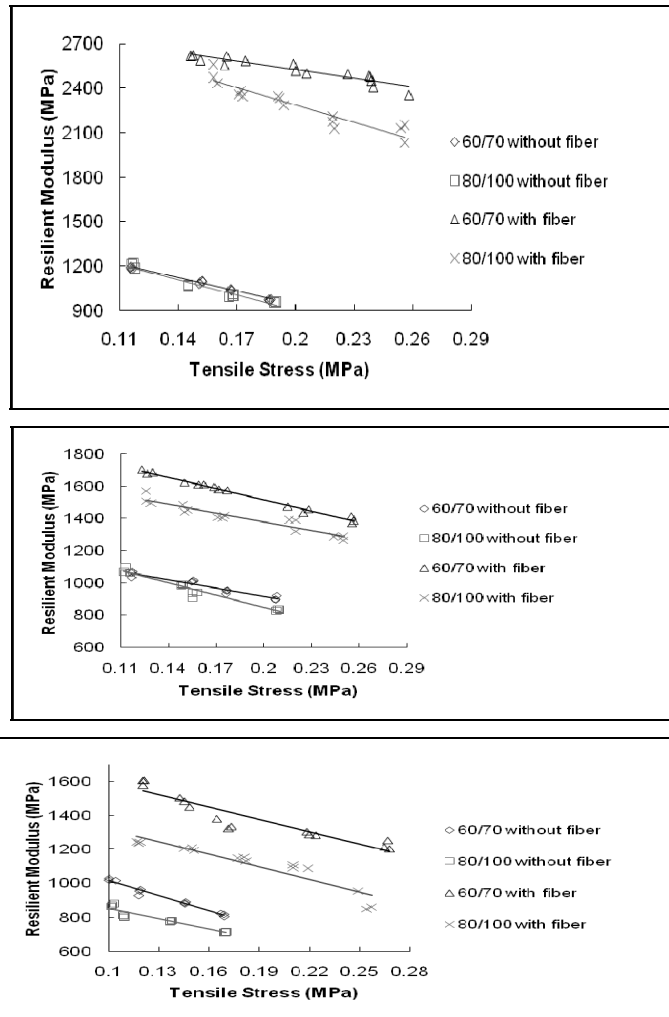


Figure 4. Variation of resilient modulus with tensile stress for different mixes at 25 °C, 30 °C and 35 °C

3.2. Repeated load indirect tensile test

The parameters studied in this test are the resilient Poisson’s ratio (μ_R), resilient modulus of elasticity (M_R) and fatigue life (N_f) at varying stress levels and at three most

prevailing temperatures, namely 25 °C, 30 °C and 35 °C. Figure 4 shows the variations of resilient modulus of elasticity with tensile stress for different mixes at three different testing temperatures. It is observed that, fibres result in increase in M_R value at a particular temperature, and a particular stress level mixes with 60/70 bitumen have more M_R value than that with 80/100 bitumen.

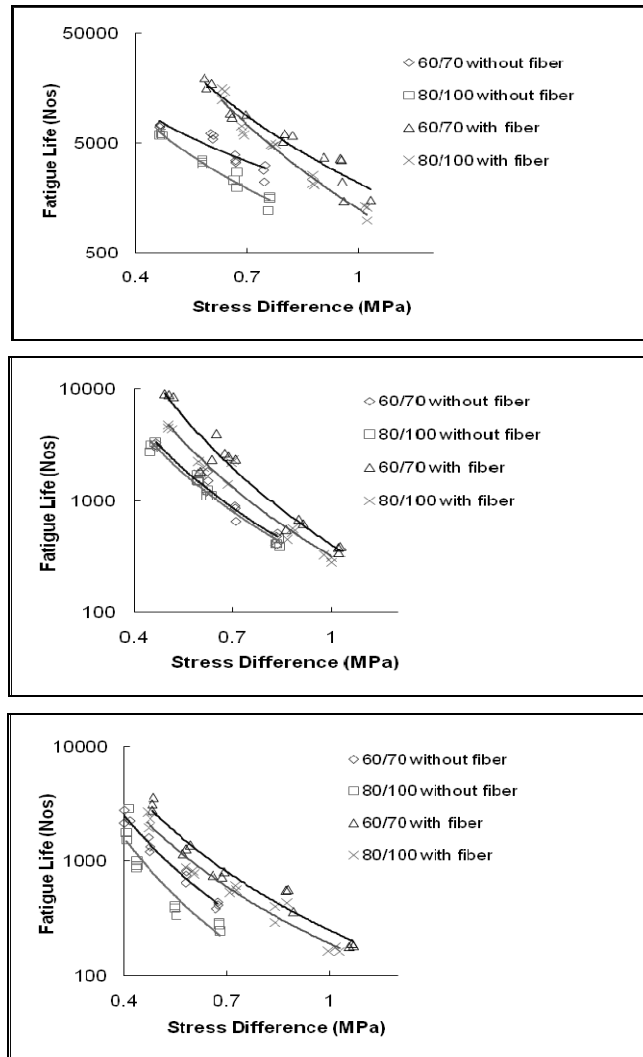


Figure 5. Variation of fatigue life with stress difference for different mixes at 25 °C, 30 °C and 35 °C

3.3. Relationship between fatigue life (N_f) and stress difference ($\Delta\sigma$)

The variation of fatigue life with stress difference for SMA mixes with the two types of binder at three different temperatures are shown in Figure 5. It is observed that addition

of fibre to the mix improves its fatigue life. At a particular test temperature and for a particular stress difference value, the mixes with 60/70 binder have the longest fatigue life value as compared mixes with 80/100 binder.

4. Conclusions

Stone Matrix Asphalt (SMA) mixes, which are basically gap graded mix, characterized by high coarse aggregates, high asphalt contents and polymer or fiber additives as stabilizers, have been suggested. Coconut fibres have been used in this study as a stabilizing additive in place of conventional cellulose fibres in SMA mixes and the paving mixes have been evaluated in terms of the static and resilient properties. Marshall samples were used in this investigation.

Addition of fibres results in higher tensile strength for a given bitumen sample at a given temperature. The resilient modulus value does not change significantly with applied tensile stress. It has been observed that a mere 0.3% incorporation of binder results in considerable increase of the resilient moduli and fatigue life of the mixes at all tested temperatures, which is an added advantage to the paving industry, particularly in the context of prevailing warm temperatures in tropical countries and even beyond to produce durable paving mixes, particularly when dense graded aggregates are not easily available.

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