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Fatigue Modelling for Stone Mastic Asphalt (SMA)

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ABSTRACT

Fatigue cracking is one of the major distresses found in many asphalt pavements. The premature cracking of the pavements results in the increased annual cost of resurfacing, maintenance and rehabilitation. Generally, any asphalt mix is tested in the laboratory and predictions are made using the performance curves and local conditions. However, in Malaysia there are not any pavement prediction models developed yet that can be used to predict the asphalt mix's fatigue life performance under the local environmental conditions. This paper looks into the fatigue characteristics of SMA by using local materials and environmental conditions. For the purpose of evaluation SMA14 (SMA with 14mm aggegate as nominal) with 5 different gradations within the JKR's ACW14 gradation envelope were used. The repeated load indirect tensile tests at three different temperatures (30°C, 40°C, 50°C) and five different dynamic loadings (500N, 750N, 1000N, 1250N, 1500N) were carried out under stress controlled mode using the MATTA Machine. The fatigue performance test results plotted on a logarithmic scale of fatigue strain and load repetitions showed a good agreement with the historic trend of the fatigue data. The logarithmic relationship between fatigue loading and strain was evaluated and found to be linear at certain reliability regardless of the testing condition and mix parameter. This indicates that the fatigue model for SMA is a function of asphalt volume, resilient modulus and the fatigue strain values.

Keywords: Fatigue modelling, stone mastic asphalt

INTRODUCTION

The surveys of asphalt pavement performance conducted in the United States and United Kingdom indicated that fatigue cracking was generally the most important type of distress (Rogers *et al.* 1963; Finn *et al.* 1972). The same problem also happened in Malaysia, based on the investigations into the distresses on Malaysian roads. The studies also showed that one of the primary modes of pavement distress was fatigue cracking in bituminous surfacing, especially on heavily trafficked roads (Bullman *et al.* 1977; Ministry of Works 1987). This shows that the conventional mixes around the world including Malaysia, are inadequate in minimizing fatigue cracking in road pavements.

The Pavement Engineering Unit of Universiti Putra Malaysia had been working on the formulation of the Stone Mastic Asphalt (SMA) mix design modified to suit the local environment and traffic loading (Ratnasamy *et al.* 1995; Ratnasamy *et al.* 1996). Since then, the Unit had come to the point where SMA was used in the analysis to predict fatigue cracking. It was because SMA had shown good performance including longer fatigue life in Europe, the United States and Australia (Wonson 1996), it is necessary to predict the fatigue life of SMA in order to be effective in evaluating and controlling the fatigue cracking of SMA Pavements.

SPECIMEN PREPARATION

Materials

The materials for the preparation of the SMA samples were selected based on the standard set by the European countries. However, the Malaysian JKR specifications were widely used in confirming the properties of the binders and aggregates. Since SMA is a gap graded mix, cellulose fibers were used to ensure its durability in tropical climates. In this study granite stones and Petronas rubberized asphalt were used.

Mixtures

At the beginning of this study, SMA14 (SMA with 14 mm aggregate as nominal) with five different gradations within the JKR's ACW14 gradation envelope were used. Several adjustments were in the gradations to ensure high percentage of coarse aggregates. The five different aggregate gradations (G1, G2, G3, G4 and G5) and a typical SMA gradations are presented in Fig. 1. The SMA formulation was done by using the modified Marshall method and the Asphalt Institutes MS-2 specifications.

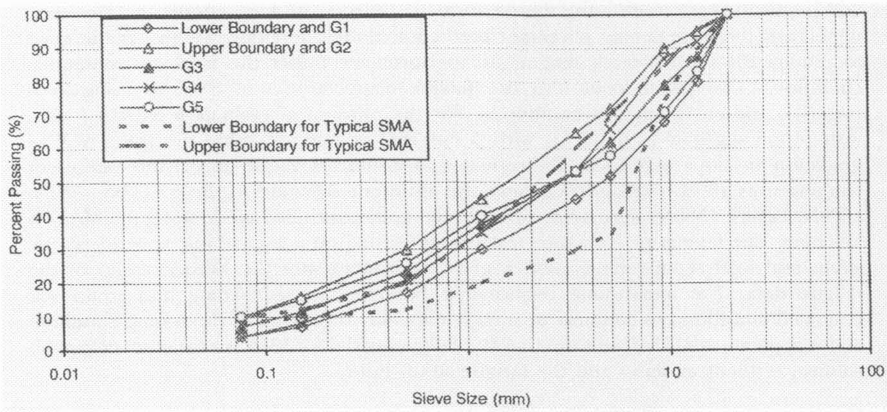

Fig. 1. Five aggregate gradations for SMA14 mix and typical SMA

Test Apparatus

The Repeated Load Indirect tensile Test was used for investigating the fatigue performance of SMA mix. This method has been chosen due to its convenience for routine measurements. The sophisticated and user-friendly universal testing machine called Material Testing Apparatus (MATTA) from Australia has been used to carry out the fatigue tests. The pneumatic and electronic control and data acquisition equipment is conveniently housed in a compact stainless steel trolley, and an environmental chamber that provides accurate control of temperature (2°C – 60°C) for bituminous mixture testing.

Fatigue Performance Test Procedure

The timing of the dynamic loads is selected in such a way as to simulate the actual load pulses on the pavement by the moving vehicles on the roads. Pavement temperatures can reach 60°C during real hot weather. As such a range of temperatures were selected for the fatigue tests. The tests were ran under the following conditions:

- Loading time was set at 0.1s while rest time set to 0.4s.
- Three different temperatures (30°C, 40°C and 50°C) were selected.
- Five different dynamic loads (500 N, 750 N, 1000 N, 1250 N and 1500 N) were selected.

Fig. 2 shows a general outline of fatigue performance test procedure for SMA14. The data from the fatigue tests and voids analysis were used to develop the SMA14's fatigue model.

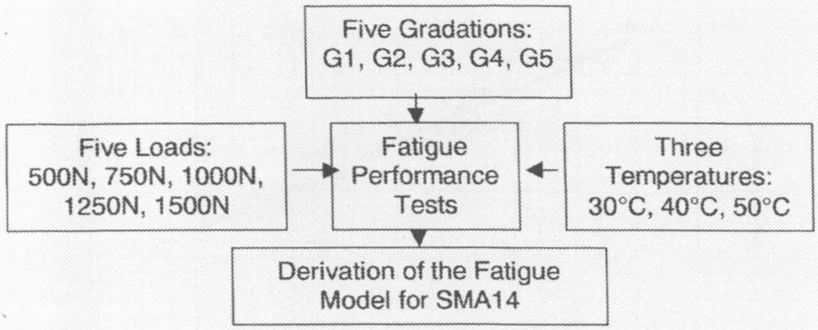

Fig. 2. General outline of fatigue performance test procedure

VARIABLES USED IN THE MODELLING

The fatigue performance of any asphalt mixes are a function several variables. In this study, the following parameter were used extensively.

Percentage of volume of asphalt
Percentage of volume of voids in the mix
Percentage of voids in mineral aggregates
Strain values of the mix

RESULTS AND DISCUSSION

The fatigue life is defined as the total number of load repetitions that cause a fracture of the specimen. The strain levels were measured at 200th load cycles.

When all the fatigue performance data of SMA14 mixes were plotted on an initial strain-fatigue life logarithmic basis, the fatigue life of SMA14 can be represented by only one fatigue life equation. Fig. 3 presents the relationship between initial strain and fatigue life. The relationship between fatigue life and initial strain for SMA14 displayed a definite trend or pattern in material behavior. This is quite similar to studies under taken previously in the 60's and 70's (Saal and Pell 1960; Epps *et al.* 1972; Pell and Cooper 1974; Brown *et al.* 1974).

The linear relationship between fatigue life and initial strain can be improved by adding other variables into the model. This has been done by using three regression methods: forward, stepwise, and backward elimination procedures. The regression methods were conducted to determine which variables made a significant contribution to explain fatigue life. Variables of interest in the development of the fatigue model are: fatigue life (N_f), percentage volume of asphalt (V_A), percentage volume of air voids (V_V), percentage of volume voids in mineral aggregate (VMA), percentage of voids filled with asphalt (VFA), resilient modulus (MR), and initial strain (STRN).

Two different fatigue model equations were developed. The equations are as follows:

The fatigue model (with the Mallows $C_P = 83.6$, $R^2 = 0.847$, and adjusted $R^2 = 0.845$) is:

$$\mathbf{LN = - 0.337 + 3.568\ LA + 0.828\ LR - 1.129\ LSN}$$

While the fatigue model (with the Mallows $C_P = 5.55$, $R^2 = 0.932$ and adjusted $R^2 = 0.927$) derived from backward elimination procedure is:

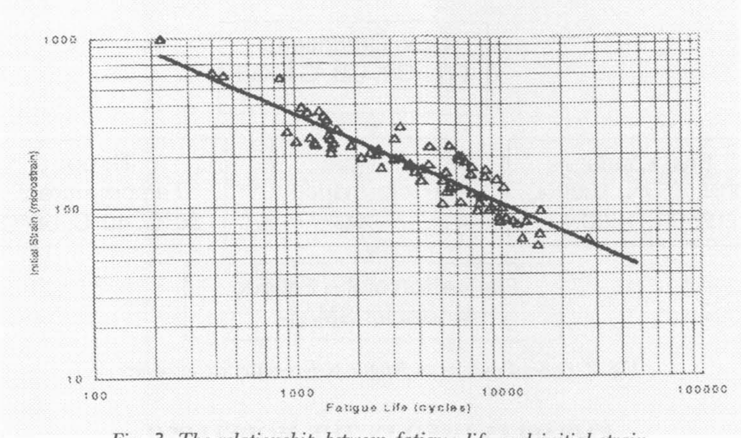

Fig. 3. The relationship between fatigue life and initial strain

$$LN = -655.459 - 334.736\ LA - 12.454\ LV + 358.946\ LVM + 319.614\ LVF - 1.39\ LSN$$

where:

LN = log(Fatigue life, N_f in unit of cycle)
LA = log(Percentage volume of asphalt, V_A)
LV = log(Percentage volume of voids, V_V)
LVM = log (Percentage of volume voids in mineral aggregate, VMA)
LVF = log(Percentage of voids filled with asphalt VFA),
LR = log(Resilient modulus, MR in unit of MPa)
LSN = log(Strain, STRN in unit of 10^{-6})

Theoretically, the second model seems to be the best fatigue model in the regression analysis because of the bigger R^2 and adjusted R^2 compared to the first model. Whereas, the Mallows CP in the second model is smaller than first model.

However, the pairwise correlation r of –0.84 between LA and LV, 0.90 between LA and LVF, 0.97 between LA and LVM, –0.99 between LV and LVF, and –0.94 between LVM and LVF. The pairwise correlation of the pair of predictors (LR, LSN) is –0.92. It is more effective to include only one of four volume variables LA, LV, LVF and LVM in the fatigue model. The first fatigue model only contains the LA predictor among LA, LV, LVM, LVF predictors. For this reason, the first fatigue model has been selected.

CONCLUSIONS

There is a linear relationship between initial strain and fatigue life when data plotted on a logarithmic scale. The linear relationship shows good agreement with the historic trend of the fatigue data.

The fatigue life can be related to the asphalt volume, the resilient modulus, and the initial strain by the equation:

$$LN = -0.337 + 3.568\ LA + 0.828\ LR - 1.129\ LSN$$

Where the LN is the log of fatigue life in the number of load applications, LA is the log of asphalt volume in percentage, LR is the log of resilient modulus in MPa, and LSN is the log of initial strain in unit of 10^{-6}.

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