Effect of temperature on fatigue life of asphalt mixture

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Abstract

Fatigue failure of asphalt or other bound layers is one of the most fundamental flexible pavement deteriorations and results from induced strain from repetitive traffic movements. Extensive study has been undertaken by many researchers to estimate the fatigue life of pavement for Mechanistic-Empirical design procedure. However many practitioners report that the fatigue transfer function currently prescribed in the Austroads method does not fit with observed performance. Hence developing an appropriate model for asphalt behaviour is of great importance. For this reason in depth testing has been performed at Curtin University Geotechnical Lab using the 4 Point Bending Beam Test to compare the fatigue life of samples of a control asphalt mix at a range of temperatures and frequencies. This paper outlines the effect of temperature on fatigue performance of pavement. A methodology to develop a shift factor to convert the laboratory results to better replicate the field condition is proposed.

Keywords: *Fatigue, 4 Point Bending Beam, Temperature, Shift Factor*

Introduction

The two fundamental types of deterioration in asphalt pavements are fatigue cracking evidenced as crocodile cracking and shear failure evidenced as rutting, also known as permanent deformation. Fatigue cracking is one of the pavement failure modes that have been investigated by many researchers. One of the most well-known tests to investigate laboratory fatigue performance is the four point bending beam apparatus. Generally there are two types of the test modes for four point bending beam tests, constant stress and constant strain. Twelve tests have been performed at Curtin University Geotechnical Laboratory using the EN standard tester provided by IPC Global. Generally tests continued for 2 million cycles or the number of cycles to 40 percent of initial flexural stiffness, noting that the fatigue life of beams is determined as the number of cycles to achieve 50 percent of the initial stiffness.

Background

The allowable number of repetitions to reach the fatigue life of a material can be related to either level of strain or stress and the sample flexural modulus. The simplified equation generally adopted for allowable load repetition is of the form given in equation 1 and 2:

$$N_f = K_1\left(\frac{1}{\varepsilon_t}\right)^{K_2} \qquad (1)$$

$$N_f = K_1\left(\frac{1}{\sigma_t}\right)^{K_2} \qquad (2)$$

Where

N_f = Number of allowable repetition

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ε_t = Tensile strain at the bottom of asphalt layer

σ_t = Tensile stress at the bottom of asphalt layer

K_1 & K_2 are constants that can be derived from laboratory tests, but must be calibrated based on field observed data to replicate the field condition. The calibrated models are known as transfer functions. These constants vary according to material properties, laboratory conditions and temperature. The remaining life of an asphalt pavement is determined by the type and extent of cracking [1]. Historically several different transfer functions have been derived including that of the Asphalt Institute [2], Shell [3], and Finn [4] models. The Asphalt Institute and shell models are presented in equations 3 and 4:

$$\boldsymbol{N_f = 0.0796(\varepsilon_t)^{-3.291}(E_1)^{-0.854}} \quad \textbf{(3)}$$

$$\boldsymbol{N_f = 0.0685(\varepsilon_t)^{-5.671}(E_1)^{-2.363}} \quad \textbf{(4)}$$

Where

N_f = Number of allowable repetition

ε_t = Tensile strain at the bottom of asphalt layer

E_1= Initial flexural modulus of asphalt (Psi)

In recent times there has been a transition towards the mechanistic design of flexible pavements. However in reality with current knowledge, the design of flexible pavements is not purely mechanistic, it is a Mechanistic-Empirical (ME) design as factors are applied to shift the laboratory derived theoretical models to fit with observed field performance.

Transfer functions including shift factors have been developed to convert the calculated stress or strain to the fatigue life of pavement in the field [5]. There are many reasons why the results from laboratory varies when comparing to the field. The most important reasons are as follows [6]:

- Continuous high frequency laboratory tests do not replicate rest periods between consecutive load pulses associated with the property of the bituminous binder to self-heal microcracks
- Temperature gradient and variations in field while temperature is constant in laboratory fatigue tests

Another factor that should be considered in the reliability of testing at very high strain levels, as the strains applied in the field are generally well below test strains, requiring the assumption that equations developed are applicable when extrapolated beyond the test range.

Objectives of current research

In Australia, the Austroads transfer function, based on the Shell model, is derived at a temperature of 25°C and 400 microstrains at constant strain and haversine loading. The aim of the research reported in this paper was to compare the fatigue life of pavement at a range of different temperatures and strain levels. This preliminary work will be continued to test beams by applying variable rest periods, variations in frequencies and variable temperatures to better replicate the field conditions.

Also some effort will be placed on comparing the field data with the empirical results, and data from real time pavement strain and temperature data from test sites established by Curtin University in Gt Eastern Highway to develop an appropriate transfer function or shift factor.

Sample preparation

The asphalt used in this research is AC-14 75 with 4.7 percent binder content. The binder type is classified as Class 320 bitumen based on Australian standards. The mix is provided by BGC Asphalt at Hazelmere Western Australia. A Cooper roller slab compactor (Figure 1) has been used to compact the prepared mix into slabs at the target air void content (Figure 2).

After the cooling down process, but within 48 hours, the slabs were cut into the beams (Figure 3) used for fatigue testing (Figure 4). Dimensions, air void content, temperature of mix during the compaction, and testing conditions are shown in Table 1.

Table 1. Physical characteristics of beams and testing condition

Beam Number	Dimensions (mm)	Air void Content (%)	Compaction Temperature (˚C)	strain level (με)	Frequency (Hz)	Testing Temperature (˚C)
1	400×63×50	5.6	142	100	10	4
2	400×63×50	5.1	142	200	10	4
3	400×63×50	5.2	142	300	10	4
4	400×63×50	5.2	142	400	10	4
5	400×63×50	6	143	100	10	20
6	400×63×50	5.9	143	200	10	20
7	400×63×50	5.9	143	300	10	20
8	400×63×50	5.5	142	400	10	20
9	400×63×50	5.5	142	100	10	40
10	400×63×50	4.7	142	200	10	40
11	400×63×50	5.5	143	300	10	40
12	400×63×50	5.6	143	400	10	40

Figure 1. Cooper roller slab compactor

Figure 2. Compacted Slab

Figure 3. Cutting procedure and sample storage

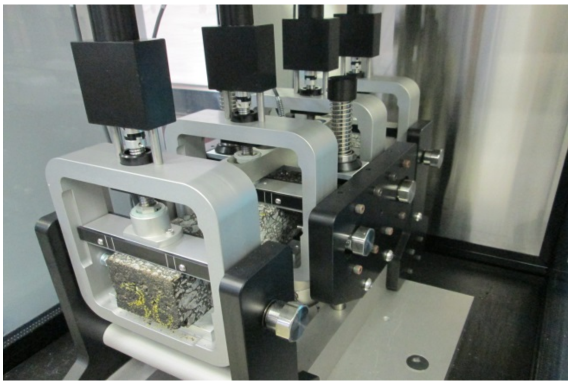

Figure 4. EN standard tester provided by IPC Global Australia

Results

Laboratory results for different levels of tensile strain and temperature compared. These tests conducted in four levels of micro strain 100, 200, 300 and 400 also in three different temperatures 4 ˚C, 20˚C and 40˚C. The test were terminated when the stiffness reached 40 percent of initial stiffness or two million cycles of the load application, except for beam number one which was terminated at 3,362,530 cycles, beam number ten terminated at 1,693,900 cycles due to time constraints and beam number eleven that was terminated at 2,499,700 cycles. Table 2 shows the results of the beam fatigue tests.

Table 2. Test results summary for 12 beams

Beam Number	Strain Level (με)	Temperature (˚C)	Cycle count	Initial Stiffness (MPa)	Final Stiffness (MPa)
1	100	4	3362530	15629	16345
2	200	4	2000000	15827	9244
3	300	4	279450	13778	6889
4	400	4	63940	14827	7414
5	100	20	2000000	6800	5922
6	200	20	2000000	6740	4844
7	300	20	775510	6713	3357
8	400	20	142980	6025	3013
9	100	40	2000000	1291	970
10	200	40	1693900	1183	637
11	300	40	2499700	998	499
12	400	40	1425300	968	484

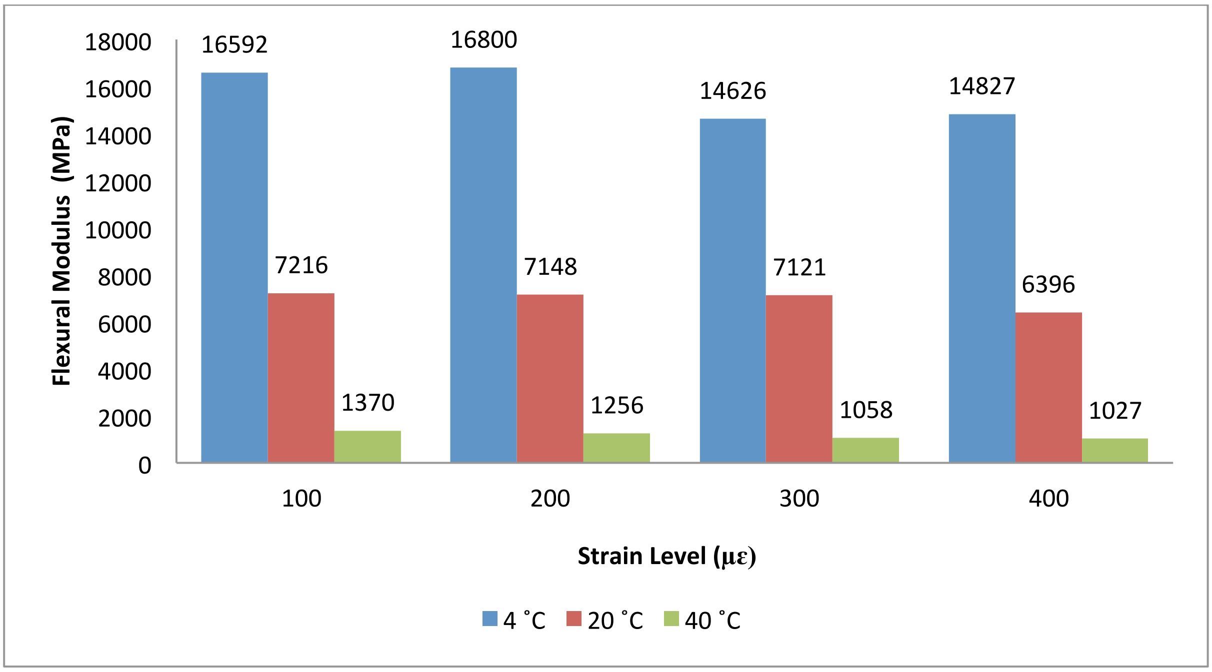

Figure 5. Initial flexural modulus for different temperatures and strain levels

As can be seen from figure 5 the initial flexural modulus is significantly affected by temperature at all strain levels, being inversly proprtionsl to temperature, but the effect of strain at any temperature is minor. Fatigue life of terminated tests at 300 and 400 microstrains in the laboratory compared with Asphalt Institute and Shell models which are illustrated in figure 6 and figure 7.

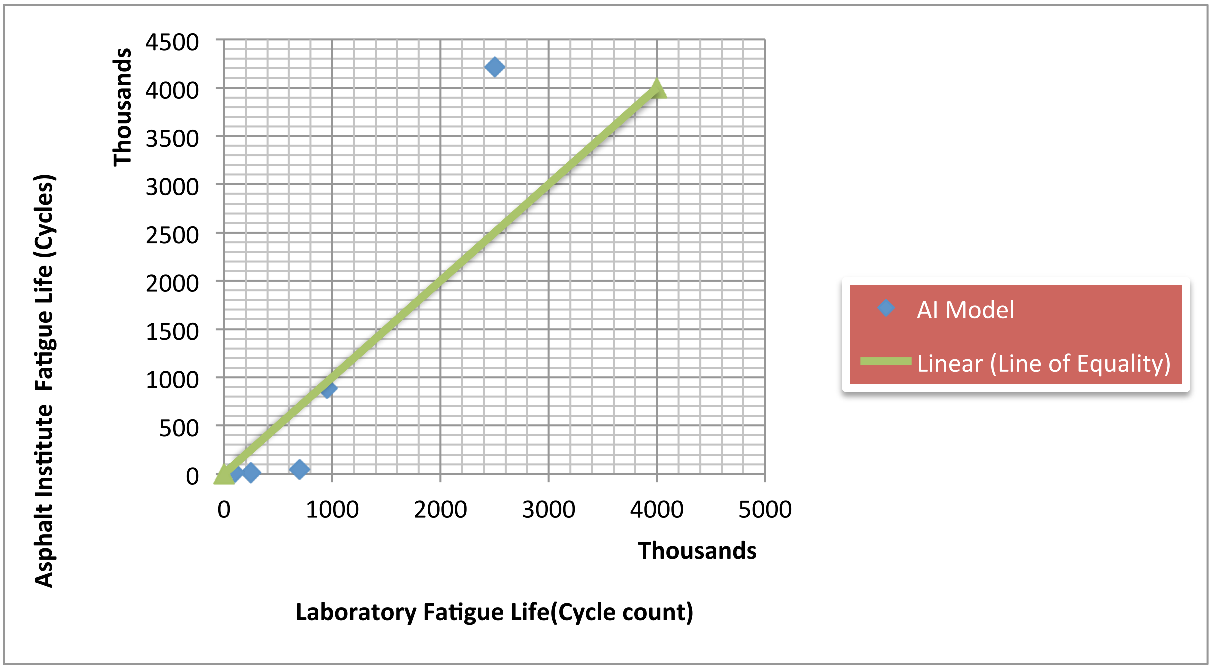

Figure 6. Laboratory cycle count versus AI model predicted fatigue life

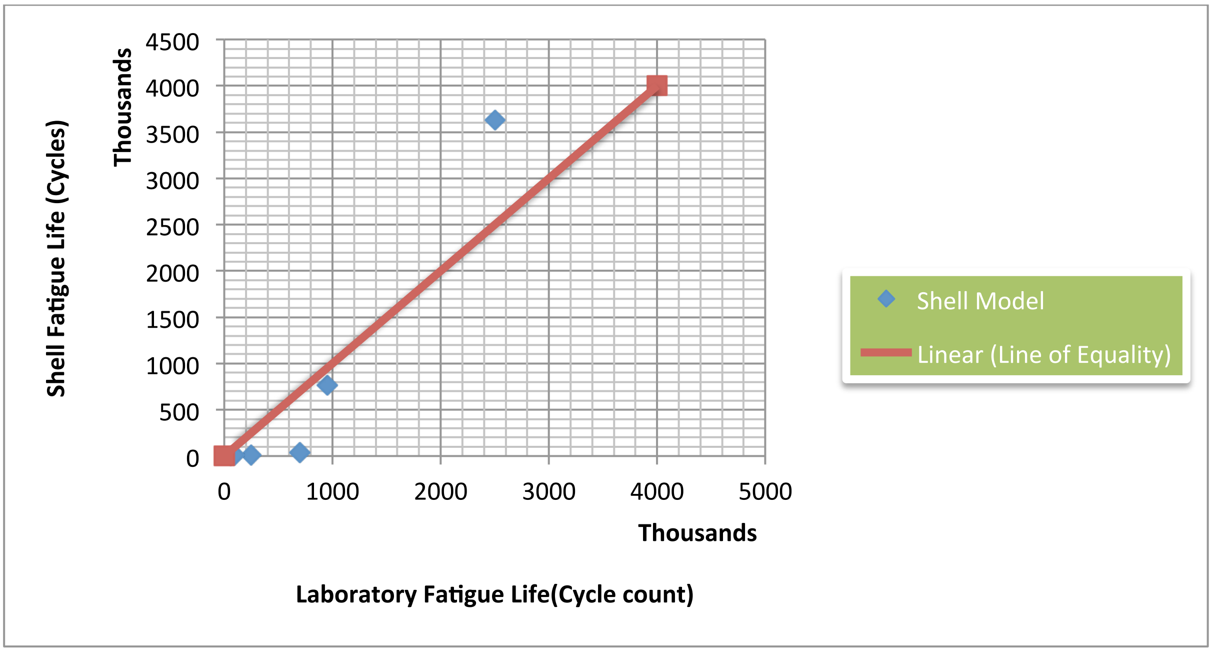

Figure 7. Laboratory cycle count versus Shell model predicted fatigue life

Summary and Conclusion

Referring to the table 3 it is apparent that the fatigue life of beams increased when temperature increased at high levels of strain (300με and 400με), where at the lowest level of strain, temperature has less effect on fatigue life. Comparing terminated results of the laboratory with Asphalt Institute and Shell models shows that at 4˚C and 20˚C both models underestimate the fatigue life while the results for 40˚C are similar to the laboratory measurements. Results outlines that there is a need to consider temperature as an important parameter in fatigue models rather than the method in traditional models where it is included in the flexural modulus of the asphalt mix.

References

[1] Huang H (2005). Pavement analysis and design. Prentice Hall.

[2] Thickness Design Manual. Research Report 82-2. Asphalt Institute, Lexington, Ky., 1982.

[3] Shell pavement design manual, asphalt pavements and overlays for road traffic,
Shell International Petroleum Company Limited, 1978, London

[4] Finn, F. N., Saraf, C., Kulkarni, R., Nair, K., Smith, W., and Abudllah, A. "The Use of Distress Prediction Subsystems in the Design of Pavement Structures." Fourth International Conference on the Structural Design of Asphalt Pavements, 1977, University of Michigan, 33-38.

[5] Sanjeev Adhikari, Shihui Shen, and Zhanping You. "Evaluation of Fatigue Models of Hot Mix Asphalt through Laboratory Testing." Transportation Research Record: Journal of the

Transportation Research Board, No. 2127, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 36–42.

[6] Angel Mateos, Javier P. Ayuso, and Belen Cadavid Jáuregui. "Shift Factors for Asphalt Fatigue from Full-Scale Testing." 2011 Annual Meeting of the Transportation Research Board.