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Modelling and characterising the fatigue behaviour of asphaltic concrete mixtures

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HIGHLIGHTS

- Characterised AC mixtures using ITFT in a stress-controlled mode.
- Investigated the differential effect of binders and gradations on fatigue behaviour.
- Developed statistical models to express fatigue life.
- 40/50 bitumen provided as much as four times longer fatigue life than 60/70 bitumen.

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ABSTRACT

This paper investigates the fatigue behaviour of asphaltic concrete mixtures subjected to Indirect Tensile Fatigue Test (ITFT) under a stress-controlled mode. The conventional stress/strain based approach is used to determine the number of cycles to failure and initial strain value under specified repeated load levels. The fatigue test results indicate that the MS-2 mix (containing 60% and 40% of coarser and finer particles, respectively) prepared with the 40/50 penetration grade binder accumulates less initial strain, and has a relatively better resistance to fatigue than the other tested mixtures. Furthermore, this fatigue behaviour is modelled using a power, intrinsically linear, and non-linear functional specifications. Among these, a non-linear model formulation is found to be the best suited, expressing the number of cycles to fatigue failure as a function of the initial strain, the viscosity, the optimum bitumen content, and the resilient modulus. The fatigue model captures high variability in the data ($R^2 = 0.86$) with a reasonable prediction error (of 15%) as compared to other models. The findings of this study can serve as the basis for selection of asphaltic concrete mixtures based upon the fatigue life criterion; the models proposed in this study can be used as a precursor to determining the fatigue behaviour without performing laborious laboratory testing.

1. Introduction

A flexible pavement primarily consists of binder and aggregate, and strength of such pavements largely depends on both the ingredients. However, when a flexible pavement is exposed to moving traffic, various distresses manifest on the surface of the flexible pavement such as rutting, fatigue cracking, and etc. [1]. These distresses eventually lead to a premature failure of flexible pavements, resulting in a reduced service life, high maintenance, and rehabilitation cost [2]. Fatigue in AC mixtures is defined as the phenomenon causing cracking (consisting of a crack initiation and propagation phase) due to the tensile strains generated in pavements when subjected to load repetition, temperature variation, and inadequate construction practices collectively [3]. In general, characterisation of fatigue is carried out using two approaches: the traditional/conventional method using the strain (or stress)-based models [4], and the dissipated energy method that is defined as a damage indicator of a material [5].

In general, the fatigue behaviour of an AC mix can be expressed as a relationship between the number of cycles to failure and initial strain [6], however, the literature review reveals disagreement in the definition of fatigue especially in strain-controlled mode. Some researchers claim that 50% loss in modulus or stiffness value from

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an initial value should be termed as a fatigue life [7,8], while others use phase angle as a parameter to determine the fatigue life in fatigue testing [9]. Reese [9] argued that the fatigue failure point could be related to maximum phase angle because the curve of phase angle against time indicates a drastic decline in phase angle when AC mixtures could not attain further distress. In addition, many researchers used 50% loss in pseudo stiffness as a failure criterion [10,11] since pseudo stiffness can closely predict the damage accumulation occurred due to repeated fatigue loading, which did not induce damage because linear viscoelastic time-dependency is eliminated.

Strain and stress controlled modes are respectively used to simulate conditions in thinner and thicker pavements. The tensile strains are accumulated at the bottom of an AC layer in the first mode, while in the latter, the cracking appears on the top of an AC layer due to the localised stresses developed because of the tyre-pavement interaction [12]. The review of the past studies suggests that for a given mix under same conditions, stress and strain mode yields different results [13]. Moreover, Monismith and Salam [14] concluded that strain and stress controlled modes of loading are respectively characteristics of asphalt layers less and greater than 50 mm.

The difference in these testing modes is explained by Brown [15] using the failure mechanism. The failure is observed at two stages: the first when cracks are manifested at distinct points due to high stresses followed by crack propagation through a mix until the complete failure occurs. The crack propagation in stress controlled mode is very rapid since it mainly depends on the intensity of stress at the tip of cracks. On the other hand, the crack propagation in strain-controlled mode is relatively slower

Table 1
Evaluation of Fatigue life in the Literature.

Study	Explanatory variables	Model functional form
Lytton et al. [21]	Bitumen content, stiffness, air voids, aggregate type, gradation and angularity	Linear
Harvey and Tsai [22]	Initial stiffness and mix volumetric	Intrinsically linear
Kim et al. [10]	Stress level	Power
Lee and Kim [23]	Pseudo stiffness	Linear
Rodrigues [24]	Traffic speed and the shape of the stress pulse	Quadratic
Hartman [25]	Type of compaction	Linear
Kim et al. [13]	Strain rates and damage growth	Linear
Kim et al. [26]	Initial pseudo-stiffness, damage parameter to fatigue failure, material parameter	Exponential
Zhou et al. [27]	Initial stiffness	Power
Yeo et al. [28]	Tensile strain	Power
Xiao et al. [29]	Initial flexural strain, VFA, AV, initial dissipated energy, initial mix stiffness	Artificial neural network
Al-Rub et al. [30]	Fundamental material properties	Finite element model
Salama and Chatti [31]	Axle load and truck configuration	Power
Al-Khateeb and Ghuzlan [32]	Temperature, stress, and loading frequency	Exponential
Ali et al. [20]	Dynamic modulus and phase angle	No model was developed
Mannan et al. [33]	Strain	Power
Underwood [19]	Strain amplitude	Power

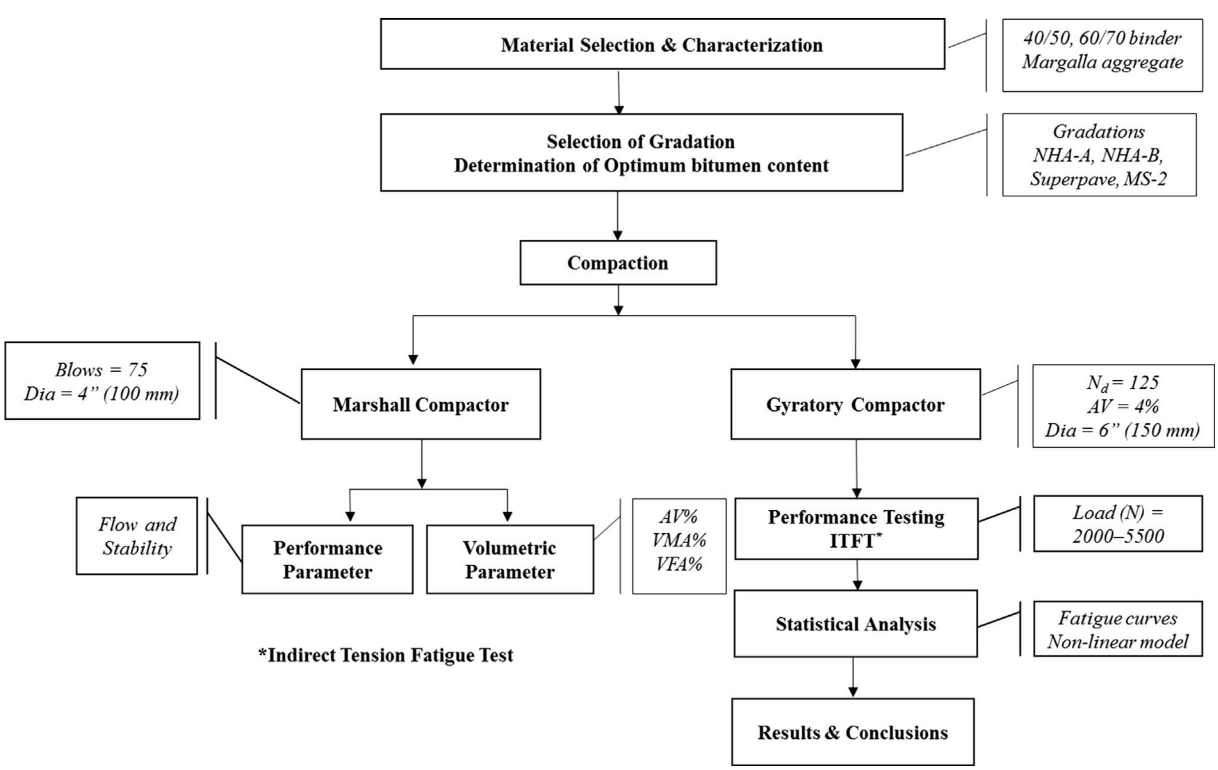

Fig. 1. Research Methodology.