ABSTRACT

Fatigue cracking is one of the significant distress modes commonly observed in bituminous pavements. Considering this, pavement researchers have undertaken several initiatives to understand and improve the fatigue performance of bituminous binders and mixtures. These initiatives have led to the development and usage of new or modified binders and mixtures, test methods for evaluating concepts and performance prediction models. Despite these efforts, the characterization and analysis of fatigue damage to bituminous materials remain a concern due to the visco-elastic nature of bituminous materials and exposure to variable wheel loads and climatic conditions during the pavement's service life. Most of the developed models used data obtained from laboratory tests by applying constant cyclic loading while the applied load is variable in the field.

In light of the aforementioned, the broad objective of the current study is to characterize the fatigue damage of different bituminous binders and mixtures based on the cumulative fatigue damage (CFD) approach and model their behavior when these are subjected to constant and variable amplitude loading. Five binders (viscosity grade 30, viscosity grade 40, polymer modified binder, crumb rubber modified binder, Sasobit modified binder) and four aggregate gradations (bituminous concrete grade II, dense bituminous concrete grade II, stone matrix asphalt, gap gradation) were considered to accomplish the goal. Binders were evaluated based on their chemical, physicochemical, and rheological properties. Thin Layer Chromatography - Flame Ionization Detection (TLC-FID) and Fourier Transform Infrared (FTIR) spectroscopy tests were conducted to characterize the chemical properties of binders. Further, a contact angle analyzer was used to calculate surface free energy (SFE), which measures the physicochemical properties of binders. The rheological and fatigue characteristics of binders were assessed by employing a Dynamic Shear Rheometer (DSR) to perform a temperature-frequency sweep test, Multiple Stress Creep and Recovery (MSCR) test, Linear Amplitude Sweep (LAS) test, and time sweep test (constant and variable amplitude loading).

A fair-to-good correlation was observed between the binders' all rheological, chemical, and physicochemical properties. Among all binders, PMB showed superior performance in fatigue, followed by CRMB, SMB, VG30, and VG40.

Good correlations were observed between chemical parameters (from the SARA and FTIR tests) and fatigue parameters of binders. Further, a good correlation between physicochemical

parameters (from the SFE test) and fatigue parameters confirms that fatigue life would increase with increased cohesive and adhesive SFE. The variable amplitude sweep test results revealed that binders followed a nonlinear trend and did not follow the traditional Miner's rule. The cumulative fatigue damage prediction model was developed from the test results on the binder, and this model matches more closely with experimental data than Miner's rule.

Similar to the modeling of binders, the present study proposes to develop a model for bituminous mixtures. To accomplish this, bituminous mixtures were prepared using selected aggregate gradations and binders, and the Marshall mix design was adopted to arrive at optimum binder content. Samples of mixtures were evaluated for indirect tensile strength (ITS), resilient modulus (M_r), and indirect tensile fatigue test (ITFT) by adopting standard test procedures. The cracking tolerance index (CT_{Index}) derived from the ITS test and the time lag parameter derived from the M_r test exhibited good to excellent correlations with the fatigue lives of the binders. Viscosity, asphaltene content, and elastic recovery of binders showed good correlations with CT_{Index}, indicating higher cracking tolerance of stiffer yet elastic binders. The observed sensitivity of CT_{Index} to bituminous mixture parameters and correlations of CT_{Index} with fatigue resistance showed that CT_{Index} is an effective parameter for evaluating the fatigue characteristics of bituminous mixtures. This study shows that with an increase in time lag value, the viscous nature of the mixture increases, resulting in poor fatigue life.

Furthermore, results from the ITFT showed that factors such as aggregate gradation, bitumen type, bitumen content, mixture type, test temperature, and stress level considered in this study have a statistically significant effect on the fatigue performance of bituminous mixtures. The correlation between binder and mixture fatigue life shows their possible interchangeability to assess the cracking potential. The ITFT was also conducted under variable amplitude loading. The experimental results highlighted the nonlinear nature of the mixture under variable amplitude loading and the dependency of the damage sum on the material used and load order. Thus, Miner's linear damage rule was inapplicable in predicting the CFD of bituminous mixtures. A non-linear model was proposed based on load and material properties to predict the progression of fatigue damage in bituminous mixtures subjected to variable amplitude loading. The influence of the loading sequence and the material properties were considered for model prediction. The proposed predictive model can be utilized to anticipate damage under variable amplitude or compound loading.

Keywords*: Fatigue cracking, Cumulative fatigue damage, Miner's rule, Constant and variable amplitude loading, Non-linear model.*