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Influence of post - processing methods for ranking of fatigue life of bituminous mixture

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Abstract

In this study, four point beam tests were conducted on bituminous mixture sample pertaining to Bituminous Concrete (BC) grade II as per MORTH specification. The samples were produced using unmodified binder and modified binders. Two types of modified binders, one with crumb rubber and other with polymer were used. A beam sample of size 450×150×160 mm was fabricated using PReSBOX shear compactor with 4% air voids. This sample was cut into samples of size 380×63×50 mm and tested in a four point beam bending equipment. Tests were performed in a controlled displacement mode using sinusoidal waveform with strain amplitude of 200, 400 and 600 microstrain and at a frequency of 10 Hz. The entire test was carried out at 0˚C. The load and displacement data as a function of time for every cycle was recorded at the time interval of 1/100th second. The stiffness modulus, normalized stiffness modulus, phase angle, energy dissipation and cumulative energy dissipation were calculated from the load-displacement data and fatigue life was calculated using all the aforementioned approaches. It was observed that considerable disparity existed between the results. The present investigations threw light on the difference in the fatigue life of the bituminous concrete mixture obtained using these different methods of analysis. Also, the ranking of different bituminous mixture for unmodified and modified binders based on the fatigue life was carried out.

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Keywords: Bituminous concrete, fatigue, stiffness modulus, normalised modulus, dissipated energy

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1. Introduction

Bituminous pavements are subjected to mainly two types of distresses and they are rutting and fatigue cracking. In the mechanistic-empirical pavement design method, distress transfer functions are used to quantify the expected performance of the pavements as far as these distresses are concerned (MEPDG, 2008). Laboratory investigations and field observations are required for establishing these distress functions. This investigation reports the ongoing laboratory investigations currently being carried out at IIT Madras towards quantifying the fatigue behaviour of unmodified and modified binder mixtures.

Fatigue distress in the bituminous mixtures occurs due to repeated loading. Fatigue distress is normally characterised in the laboratory through beam bending tests. These include two/three/four point beam bending techniques (Baburamani, 1999). The recent technique used is the four point bending test. In four-point bending test, beams of 380×63×50 mm size are clamped at two outer ends in such way that its vertical movement is restricted. The beam is subjected to repeated sinusoidal/haversine loading for a given amplitude and frequency at two inner points in the direction perpendicular to the longitudinal axis of the beam. Such experiments are conducted under controlled load or displacement condition and the fatigue life (number of load cycle) is defined for a preselected magnitude of stress or strain (SHRP A 404, 1994).

The stress and strain amplitude from the sinusoidal/haversine waveform and the phase lag between the stress and strain data are post-processed to define the fatigue life of the bituminous mixture. Different guidelines exist for fatigue damage quantification and the post-processing of fatigue test data based on these guidelines are different. Three different standards widely used include AASHTO T321-07, ASTM D7460-10 and EN 12697:24-2004. All these standards record the evolution of damage based on some predefined parameters. One such parameter is the stiffness modulus. Stiffness modulus within the realm of linearised elasticity as far as beam bending is concerned is defined as a ratio of maximum tensile stress to maximum tensile strain. As the fatigue damage accumulates due to repeated loading, the stiffness modulus of the bituminous mixtures reduces. The fatigue life of bituminous mixture as per AASHTO T321-07 is defined as the number of cycles corresponding to 50% of initial stiffness modulus. AASHTO T321-07 (2007) suggests the use of exponential relationship for parametric comparison of stiffness modulus data. Here, AASHTO considers the initial stiffness as the stiffness modulus corresponding to 50^{th} cycle. However, EN 12697:24-2004 standard considers the initial stiffness as the stiffness modulus corresponding to 100^{th} cycle. ASTM D7460-10 approach is based on Miner's equation. In this approach, the failure point is considered as the peak of normalized modulus versus cycles curve. These standards assume the bituminous concrete as a linearised elastic material and linearised elasticity is used to calculate the stiffness modulus, notwithstanding the fact that such analysis has limitations since bituminous concrete mixtures behave like viscoelastic material.

In addition to this, energy dissipation and cumulative energy dissipation are used to quantify the fatigue damage (Shen and Carpenter, 2005 and Pais et al., 2009). The damage due to loading in the bituminous mixture is assumed to occur due to relative amount of energy dissipation between consecutive loading cycles. The ratio of dissipated energy change (RDEC) is defined as the change in dissipated energy with the loading cycles. Figure 1 shows the schematic of RDEC as a function of loading cycles. In the first stage of the curve, RDEC decreases as a function of loading cycles. In stage two (plateau), RDEC value is constant over number of loading cycles indicating that as the loading cycle increases, the energy dissipated is constant. This plateau stage lasts till there is sudden increase in the RDEC. This signifies the onset of third stage in which the major amount of input energy is dissipated indicating the starting of fatigue failure (Shen and Carpenter, 2007). According to this approach, the fatigue life of bituminous concrete is related to plateau value (PV) energy parameter, which corresponds to the RDEC value at 50% of initial stiffness. Studies conducted by Shen and Carpenter (2007) demonstrated that the plateau value is uniquely related to the fatigue life of the bituminous mixtures irrespective of the testing conditions.

Fatigue of bituminous mixture is a complex process to unravel and the definitions are always rife with inconsistencies. Different guidelines exist for fatigue test and fatigue damage quantification. However, few unresolved issues exist related to post-processing of fatigue test data. It is not clear how the collected data should be analysed to arrive at an acceptable value. The issue gains prominence when a wide range of modified binders are used since the material property and damage accumulation are completely different for modified binders. It is also noted that the fatigue life depends on different test parameters including temperature. Kim et al. (2013) evaluated