Construction and Building Materials 172 (2018) 396–405

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Refining the indirect tensile (IDT) N_{flex} Factor test to evaluate cracking resistance of asphalt mixtures for mix design and quality assurance

Fan Yin [a,*], Josue Garita [b], Adam Taylor [a], Randy West [a]

[a] National Center for Asphalt Technology, Auburn, AL 36830, USA
[b] Instituto Tecnológico de Costa Rica, Cartago, Costa Rica

HIGHLIGHTS

- Temperature and specimen air void affected the Poisson's ratio and N_{flex} Factor results.
- A good correlation was found between the IDT secant modulus and Poisson's ratio.
- N_{flex} Factor was sensitive to changes in asphalt binder content and grade.
- N_{flex} Factor is a reliable cracking parameter for mix design and quality assurance.

ARTICLE INFO

Article history:
Received 20 December 2017
Received in revised form 16 March 2018
Accepted 27 March 2018

Keywords:
N_{flex} Factor
Poisson's ratio
Cracking resistance
Mix design
Quality assurance

ABSTRACT

A procedure has recently been developed using the IDT strength test to evaluate the cracking resistance of asphalt mixtures. This procedure includes the determination of toughness and brittleness slope, which are then combined to calculate a cracking resistance parameter termed N_{flex} Factor. Although a reasonable correlation was found between IDT N_{flex} Factor with the FHWA ALF fatigue cracking data, the determination of N_{flex} Factor has several limitations. This study was undertaken to refine the IDT N_{flex} Factor test for evaluating the cracking resistance of asphalt mixtures for mix design and quality assurance. In the first phase, the test was performed using a closed-loop, servo-hydraulic control system with on-specimen instrumentation. Test results showed that test temperature had a significant effect on both Poisson's ratio and IDT N_{flex} Factor results, while the effect of loading rate was insignificant. It was also found that assuming a constant Poisson's ratio was likely to bias the accurate determination of IDT N_{flex} Factor; instead, a practical correlation was established between Poisson's ratio and secant stiffness determined from the load-displacement data. In the second phase, the sensitivity of IDT N_{flex} Factor to various mix design parameters was evaluated using a simplified test frame. In general, the N_{flex} Factor was found sensitive to changes in asphalt binder content, asphalt binder grade, as well as inclusion of recycled asphalt materials. Thus, the IDT N_{flex} Factor shows the potential for being used as a reliable cracking parameter for mix design and quality assurance.

1. Introduction

Although the Superpave mix design has been widely used by the asphalt paving industry, its sufficiency to ensure desirable pavement performance has been questioned in recent years. For example, asphalt mixtures with high percentages of recycled materials, such as reclaimed asphalt pavements (RAP) and recycled asphalt shingles (RAS), can be designed to satisfy the volumetric requirements, but these mixtures are more prone to cracking and raveling due to increased stiffness and embrittlement [11,7,17,13,19]. In addition, a number of additives such as polymer modifiers, polyphosphoric acids, and recycled engine oil bottoms have been incorporated in asphalt binders in some regions of the United States to help meet the Superpave performance grade (PG) specifications [5,15,16,10]. Whether or not these additives improve or diminish the performance of asphalt mixtures is not evident with the volumetric-based Superpave mix design method.

Currently, there is strong interest in the asphalt paving industry to develop and implement mixture performance tests that provide a good indicator of mixture resistance to the key forms of pavement distresses. Considering that an increasing number of projects have experienced premature cracking failures over the past decade, the most urgent need is to identify a suitable cracking test

* Corresponding author at: 277 Technology Parkway, Auburn, AL 36830, USA.
E-mail address: f-yin@auburn.edu (F. Yin).

https://doi.org/10.1016/j.conbuildmat.2018.03.251
0950-0618/

for use in mix design and quality assurance. There are over a dozen different cracking tests available in AASHTO, ASTM, and state DOT standards, or as draft procedures by different researchers [20]. Some of these tests are intended to discriminate asphalt mixtures with different cracking potentials based on index parameters, while others are better suited for use in modeling pavement responses and may ultimately provide a means for predicting cracking over time. Despite substantial efforts in the past, most of these tests are not ready for implementation into routine practice due to tedious test procedures, complex data analysis, high test variability, or insensitivity to mix design parameters.

One of the simplest asphalt mixture tests is the indirect tensile (IDT) strength test. The test was originally developed in Japan [2] and Brazil [6] for determining the strength of concrete, but it is currently specified by many highway agencies for evaluating the susceptibility of asphalt mixtures to moisture damage per AASHTO T 283. Although the IDT strength by itself is not a good indicator of mixture cracking potential, evaluation of the load and displacement data from the test can provide additional parameters that may be used to evaluate mixture resistance to load-related cracking.

A procedure has recently been developed using the IDT strength test on specimens prepared for regular volumetric tests such as those used in the Superpave mix design and quality assurance testing [18]. The procedure includes the determination of toughness and brittleness slope based on the stress-estimated strain data, which are then used to calculate a cracking resistance parameter termed N_{flex} Factor. The determination of N_{flex} Factor was inspired by a similar method used in the Illinois Flexibility Index (I-FIT) test developed at the University of Illinois [3]. As expressed in Eqs. (1)–(4) and schematically illustrated in Fig. 1, N_{flex} Factor is defined as the specimen toughness divided by the slope of the post-peak stress-estimated strain curve at the inflection point (hereinafter referred to as brittleness slope). Since the test typically does not require on-specimen instrumentation, the IDT horizontal strain has to be estimated by multiplying the vertical displacement by an assumed Poisson's ratio of 0.35 and dividing by the specimen diameter. A preliminary study found that the N_{flex} Factor had a good correlation with the fatigue cracking data from test sections at Federal Highway Administration (FHWA) accelerated loading facility [18]. In general, a higher N_{flex} Factor is desired for asphalt mixtures to provide good cracking resistance.

$$\sigma = \frac{2000P}{\pi t D} \tag{1}$$

where
σ: IDT stress, kPa;
P: vertical load, kN;
t: specimen thickness, mm;
D: specimen diameter, mm.

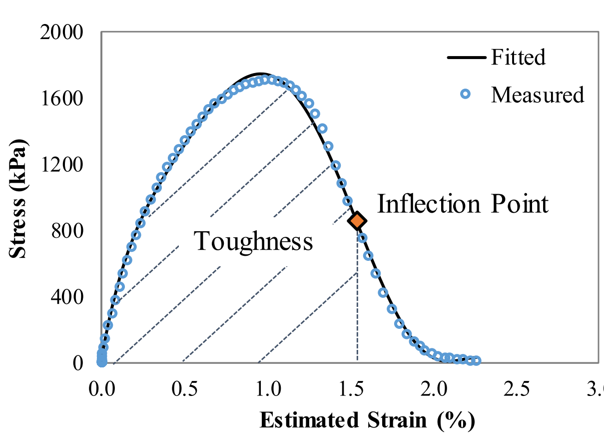

Fig. 1. Determination of IDT N_{flex} Factor.

$$\bar{\varepsilon} = \frac{\Delta}{D}\mu \tag{2}$$

where
$\bar{\varepsilon}$: estimated horizontal strain,%;
μ: Poisson's ratio, assumed to be 0.35 at 25 °C;
Δ: vertical displacement, mm.

$$T_{\inf} = \int_0^{\bar{\varepsilon}i_{nf}} \sigma(d\bar{\varepsilon}) \tag{3}$$

where
T_{inf}: toughness up to the inflection point on the post peak stress-strain curve, kPa;
$\bar{\varepsilon}_{\inf}$: estimated horizontal strain at the inflection point on the post peak stress-strain curve, %.

$$N_{flex}\ Factor = \frac{T_{\inf}}{|s|} \tag{4}$$

where
|s|: slope of the post peak stress-estimated strain curve at the inflection point, kPa.

Although the IDT N_{flex} Factor has shown preliminary promise, it has a few limitations from being implemented for routine use in mix design and quality assurance testing. For example, a constant Poisson's ratio of 0.35 is currently used to estimate the IDT horizontal strain. However, previous research recognized that Poisson's ratio of asphalt mixtures is a fundamental material property; mixtures with different components and production parameters are likely to have different Poisson's ratio values [9,12]. In the current Mechanistic-Empirical Pavement Design Guide (MEPDG), Poisson's ratio is characterized using the modulus (E_{ac}) data for the user-defined input level, as expressed in Eq. (5) [9]; asphalt mixtures with a higher E_{ac} are expected to have a lower Poisson's ratio than those with a lower $\underline{Eac}$. Thus, using a constant Poisson's ratio of 0.35 is likely to bias the accurate determination of IDT N_{flex} Factor. In addition, the sensitivity of N_{flex} Factor to mix design parameters has not been yet investigated. Ruggedness and inter-laboratory evaluations are also needed for N_{flex} Factor prior to being considered for routine use.

$$\mu_{ac} = 0.15 + \frac{0.35}{1 + e^{(a+bE_{ac})}} \tag{5}$$

where
μ_{ac}: Poisson's ratio of asphalt mixture at a specific temperature;
E_{ac}: Modulus of asphalt mixture at a specific temperature;
a and *b*: model coefficients.

2. Objective

The overall objective of this study was to refine the IDT N_{flex} Factor test for evaluating the cracking resistance of asphalt mixtures for mix design and quality assurance. To achieve the objective, the experimental plan was designed into two phases; the first phase was to investigate the effects of test temperature and loading rate on the Poisson's ratio of asphalt mixtures measured in the IDT N_{flex} Factor test. In addition, the sensitivity of IDT toughness, brittleness slope, and N_{flex} Factor to these two variables was evaluated. The second phase was focused on the sensitivity analysis of N_{flex} Factor to two mix design parameters of asphalt binder content and asphalt binder grade.