Engineering Fracture Mechanics 179 (2017) 203–212

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

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

Evaluation of the fracture performance of different rubberised bitumens based on the essential work of fracture

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ARTICLE INFO

Article history:
Received 10 February 2017
Received in revised form 8 April 2017
Accepted 13 April 2017
Available online 3 May 2017

Keywords:
Fracture
Fatigue
Rubberized bitumen
CTOD
Recycled tyre rubber

ABSTRACT

The fracture performance of rubberised bitumen in addition to one pre-treated with a Warm Mix Additive (Sasobit®) was investigated using different test methods measuring different damage mechanisms. Two Recycled Tyre Rubber (RTR) modifiers together with two base binders were blended in the laboratory to produce various combinations of Recycled Tyre Rubber Modified Bitumens (RTR-MBs). The first RTR is a standard recycled polymer derived from discarded truck and passenger car tyres by ambient grinding. The second RTR consists of 100% recycled truck tyres derived by cryogenic grinding and pre-treated with special oil and WMA to allow further decrease of asphalt mixture production temperatures. A fracture mechanics testing approach was used for evaluating the binder fatigue resistance; consisting of the double-edge-notched tension (DENT) test. The critical tip opening displacement (CTOD) obtained from the DENT test was used for fracture characterization of the binders within the ductile failure region. The study applied the partitioning concept of the total energy of bituminous binders to have a more reliable parameter that could be independent of the stress state of the ligament. The results show that generally the addition of RTR improves the fracture properties of binders indicating better fatigue performance. Pre-treatment with Sasobit® makes the materials more brittle and hence more susceptible to fracture.

1. Introduction

It is well recognized that the cracking resistance of hot-mix asphalt (HMA) mixtures is significantly related to the properties of bituminous binders. Fatigue cracking usually starts and propagates within the binder or the mastic. Therefore, characterizing the fatigue resistance of binders and improving this property by the means of modification has been a topic of intensive studies for many years. Although, many studies have shown that crumb rubber modified asphalt mixtures have superior fatigue characteristics, only limited studies have considered characterizing the binders on their own. Another challenge is to find the most representative binder tests and parameters that can best describe the binder contribution to fatigue damage resistance.

Many studies have suggested that characterizing the binders at small strains within the linear viscoelastic region, as in the case of the SHRP fatigue parameter $G * \sin\delta$, does not necessarily reflect the true binder performance related to asphalt mixture or pavement performance [1–6]. It is believed that the main drawback of the SHRP fatigue parameter is that it neglects the damaging circumstances that would take place in the pavement during the fracture process [7,8]. These

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http://dx.doi.org/10.1016/j.engfracmech.2017.04.035

damaging conditions are normally accompanied with high strains level and yielding within the nonlinear viscoelastic range. Thus, the resistance properties of materials under these circumstances should be considered in order to develop fundamental and more related performance based characterizations. In response to this, researchers at Queen's University proposed the double-edge-notched tension (DENT) test which is based on the concept of essential work of fracture (EWF) of materials under ductile failure [8]. The binder ranking based on this method showed a strong correlation to the observed fatigue cracking performance under accelerated loading facility (ALF) conditions and exactly the same ranking as the push-pull asphalt mix fatigue test [1,9].

The DENT test was also used to study the effects of RAP sources on fracture performance of polymer modified binders (PMB) [10]. The results of this study showed that both the essential work of fracture and CTOD decreased with the addition of RAP indicating that the fracture resistance of PMB is reduced when mixed with RAP. In other study, the effect of adding different chemical modifiers to different bitumens was investigated by means of strain tolerance as measured by DENT test [11]. The results of DENT test showed significant differences for binders of comparable Superpave grades, and the addition of waxes exhibited a pronounced and negative effect on the strain tolerance [11].

In this study, the fracture characteristics of binders in the ductile state were studied by the means of EWF needed to generate new surfaces using the DENT test. This test allows the materials' resistance to fracturing on notched samples under high levels of strains, yielding and fracture processes to be evaluated.

2. Background

2.1. Essential work of fracture method

The EWF concept has been increasingly used to determine the fracture toughness in polymers. Yet, there are only few studies using this test on bituminous materials. Andriescu, Hesp [8] successfully applied this test on bituminous binders and found that no correlation exists between the fracture properties and SHRP fatigue parameter $G * \sin\delta$. This means that binders with desirable fatigue properties, according to $G * \sin\delta$, do not necessarily have good fracture properties and vice versa. Therefore, it is important to characterize the exact fracture behaviour of materials for proper material selection.

According to the EWF test when a notched ductile specimen (binder or bituminous mixture) is being loaded the total energy required for fracturing consists of two separated parts: an essential work (W_e) which takes place in the inner process zone of the progressing crack, and nonessential or plastic work (w_p) performed in the outer plastic zone [12], as shown in Fig. 1. The essential work (W_e) is the energy dissipated in the fracture region that is needed to create two new fracture surfaces. The EWF is considered a material constant property where it is more sensitive to materials integrity and modifications than the testing conditions [12]. The nonessential or plastic work is the energy dissipated in ductility, plasticity, and tearing. The essential work

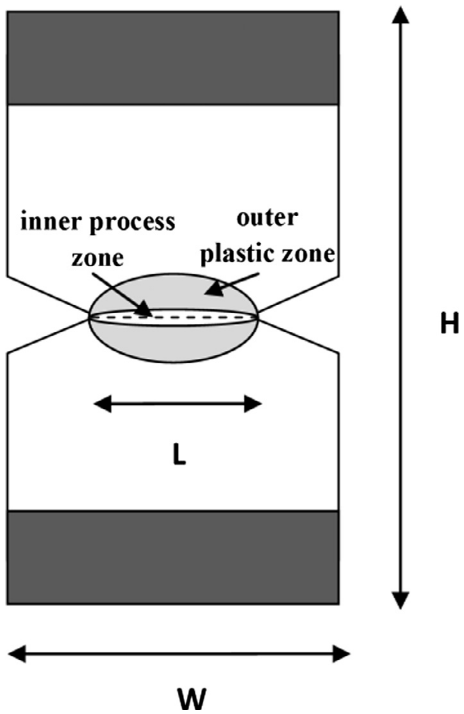

Fig. 1. Schematic representation of inner and outer zones for a typical DENT specimen.