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Use of imaging technique and direct tensile test to evaluate moisture damage properties of warm mix asphalt using response surface method

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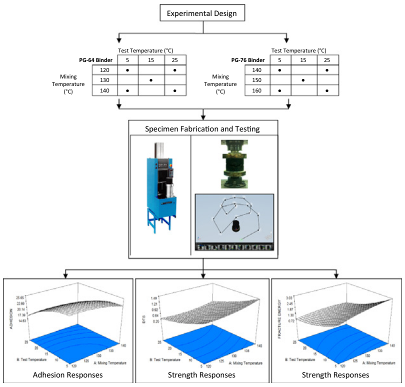
HIGHLIGHTS

- 3-D imaging technique gives precise quantification of the adhesion failure of WMA.
- At higher mixing temperature, lower adhesion failure and higher DTS were obtained.
- Lower adhesion failure and DTS were observed at higher test temperatures.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents a 3-D imaging technique to quantify the adhesion failure due to moisture on the fractured surfaces of WMA mixtures that were tested for direct tensile strength (DTS). An experimental matrix was developed based on the central composite design for two factors: mixing temperatures of WMA and test temperatures (5 °C, 15 °C and 25 °C) of specimens. Specimens were subjected to 1 Freeze-Thaw (F-T) cycle prior to testing. Adhesion failure and strength behavior of the specimens were analyzed using the Response Surface Method. The effects of mixing and test temperatures on the percent adhesion failure, DTS and fracture energy of WMA were found to be significant. Adhesion failures of WMA prepared with polymer modified binder were lower than mixtures prepared with unmodified binder. At higher mixing temperature, lower percent adhesion failure was observed, while at lower mixing temperature, lower DTS was obtained. Lower adhesion failure and DTS were observed at higher test temperatures.

1. Introduction

Moisture has always been the main concern affecting the use and performance of asphalt pavements [1]. It is considered as one of the main factors influencing the functionality of HMA [2]. WMA being produced at lower temperature than HMA is more susceptible to adhesion failure at the binder-aggregate interface. This is caused by the presence of trapped moisture due to inadequate drying of the aggregates [3]. Infiltration of moisture into asphalt mixtures results in two failure modes, namely adhesion and cohesion failures. Adhesion failure is due to binder films stripping away

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from the aggregate surfaces, while cohesion failure is caused by failure within the binder or mastic [4]. Most of the current measurement methods to evaluate the percentage of binder stripping are based upon visual inspections using the naked eye. These measurements are inaccurate as they are very subjective in nature, varies with different observers and highly dependent on the skill and experience of the inspectors. Human vision is relatively poor at distinguishing between the perceived brightness and color features. Gray scale digital imagery is capable of producing hundreds of levels of gray and color digital imaging permits the quantitative differentiation of millions of different colors. This range of image perception which is unachievable by the human naked eye can be very helpful for quantitative image analysis [5]. In this paper, the percentage of adhesion failure of WMA was analyzed using an advanced imaging technique on the fractured surfaces of samples that failed after subjected to direct tension.

To date, there are already several image analysis softwares available in the market for use in various engineering applications. Hamzah et al. (2014) used the Environment for Visualizing Images (ENVI) software to quantify the amount of adhesion failures of compacted samples in two dimensions (2-D) [6]. Loss of adhesion and cohesion were computed for various mixtures at different levels of mixing temperatures and moisture conditionings. Table 1 shows some of the studies carried out by other researchers using 2-D image analysis. However, it has been observed that the surface of the fractured sample is not always parallel to the plane of the captured image. This may induce a certain degree of inaccuracy when quantifying the amount of binder stripping from the aggregate surface. Fractured surface that is not parallel to the image taken may lead to an underestimation of the percent adhesion failure. To mitigate this, a 3-D image analysis was used for evaluation of moisture susceptibility of asphalt mixtures. The inclusion of 3-D imaging technique in this paper will contribute to the body of knowledge in the field of fracture studies. The use of 3-D imaging technique will serve as a stepping stone for other researchers to further improve and employ more precise quantification of surface failures. With the utilization of three dimension technologies, a variety of problems and challenges of the past can now be readily solved.

The currently available mechanical tests for the evaluation of moisture susceptibility use either compressive stress or tensile stress indirectly as induced by the compressive load. The most commonly used moisture susceptibility test is the indirect tensile test. The indirect tensile strength ratio from unconditioned and moisture-conditioned specimens is used as an indicator of the moisture susceptibility of the mixture tested. Although this method uses the tensile strength of the material, it is important to recognize that the compressive load is used indirectly to cause the tensile stress. The quantification of adhesion failure via this method might not be representative of the actual adhesive strength of the mixture. This justifies the need for direct tensile test which applies tensile stresses directly to evaluate the adhesive property of the mixture. Another type of mechanical test commonly used by agencies for moisture susceptibility evaluation implicates use of the Hamburg wheel tracker. The wheel tracking test uses the compressive load on specimens immersed in water at an elevated temperature to induce moisture damage in asphalt concrete specimens. Tables 2 and 3 present the currently available moisture-conditioning procedures and mechanical tests that have been used to evaluate moisture susceptibility. Tensile stress is the state of stress that is most appropriate to test the adhesive properties at the interface of two materials. The most representative test method that measures the tensile properties of a material is the direct tensile test. For example, NCHRP Project 9-26A suggests the use of cyclic direct tension tests for evaluation of moisture susceptibility of cored and cut specimens [15]. In this study, moisture susceptibility of WMA containing a surfactant-based warm additive was investigated using direct tensile stresses at different test temperatures.

As shown in Table 4, most of the moisture damage analyses are conducted at 25 °C. Recently, some researchers used lower test temperatures for evaluation of moisture damage. This is strongly motivated by the higher brittleness of these mixtures at low temperatures, causing it to more easily disintegrate when loaded until failure [22]. Hence, this low temperature condition will ensure that the asphalt mixtures attain close to elastic properties [23]. For instance, Hamzah et al. (2014) carried out their experiments at 15 °C [6]. The European standard [24] specified test temperatures ranging from 5 °C to 25 °C. It was found that the percentage of adhesion failures when tested at 15 °C was relatively low when compared to those tested at 25 °C. There seems to exist a gap in knowledge on the effects of different test temperatures on the

Table 1
Previous studies carried out using 2-D imaging technique.

No.	Test parameters	Test responses	Software	References
1	• Mixing temperature	• Adhesion failure • Cohesion failure • Direct Tensile Strength (DTS)	ENVI	[6]
2	• Compaction methods • Compaction pressures and temperatures • Maximum aggregate size • Aggregate type • Design ESALs	• Number of aggregate contact points • Aggregate orientation spectrum • Aggregate segregation	N/S[1]	[7]
3	• Aggregate gradation	• Percentage air voids on surface section of asphalt mixtures	N/S	[8]
4	• Test temperatureStress level	• Changes in air voids content and shape properties • Crack formation and propagation	N/S	[9]
5	• Methods of determining the aggregate size distribution	• Aggregate size distribution in asphalt samples	N/S	[10]
6	• Methods of determining the aggregate size distribution	• Aggregate gradation in asphalt mixture	N/S	[11]
7	• Aggregate type • Anti-stripping additive	• Tensile Strength Ratio (TSR) • $\|E^*\|$ Stiffness Ratio (ESR) • Retained Marshall Stability (RMS) • Adhesion failure	Image Toll	[12]
8	• Production temperature • Mixing time	• Degree of blending of reclaimed asphalt concretes	N/S	[13]
9	• Mixing temperature	• Linear viscoelastic characteristics • Viscoelastic damage characteristics • Adhesion failure	Adobe Photoshop	[14]

[1] Not stated.