



## Observation of reversible moisture damage in asphalt mixtures



Alex K. Apeagyei\*, James R.A. Grenfell, Gordon D. Airey

Nottingham Transportation Engineering Centre, Department of Civil Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

### HIGHLIGHTS

- Durability of asphalt mixtures conditioned in water at 60 °C was investigated.
- Durability was evaluated using indirect tensile tests at 20 °C.
- Moisture conditioned asphalt mixtures lost up to 80% of the initial stiffness.
- Upon drying the mixtures fully recovered both their stiffness and tensile.
- The results suggest moisture damage in the mixtures tested is reversible.

### ARTICLE INFO

#### Article history:

Received 5 November 2013  
Received in revised form 6 February 2014  
Accepted 13 February 2014  
Available online 22 March 2014

#### Keywords:

Asphalt mixtures  
Moisture damage  
Moisture diffusion  
Durability  
Indirect tensile  
Strength  
X-ray CT  
Reversible damage  
Adhesive failure  
Cohesive failure

### ABSTRACT

Durability of asphalt mixtures conditioned in hot water was investigated using stiffness measurements. Stiffness generally decreased with conditioning time. The effect of moisture on stiffness was found to be reversible as moisture conditioned-asphalt mixtures that had lost up to 80% of their initial stiffness fully recovered upon subsequent drying. Estimates of mastic film thickness and length of diffusion paths obtained from image analysis of X-ray CT scans of the asphalt mixtures suggest moisture diffusion was mainly restricted to the bulk mastic. The results suggest cohesive rather than adhesive failure dominated the durability of asphalt mixtures under the long-term moisture exposure used in this study.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/3.0/>).

### 1. Introduction

There is little doubt about the detrimental effects that the presence of moisture has on the extent and severity of most pavement distresses around the world [1]. In the UK alone, billions of pounds are spent annually to repair the damage to pavement caused in part by the effect of moisture on asphalt mixtures [2]. A major challenge is the lack of fundamental understanding of the mechanism by which the presence of moisture in an asphalt mixture leads to damage. As a result many empirical tests have been developed in the past to predict moisture sensitivity of asphalt mixtures [3]. Recent attempts aimed at characterizing moisture-induced

damage in asphalt–aggregate mixtures in a more fundamental way have focused on applying physical adsorption theories [4]. The approach involves surface free energy measurements of the individual constituents of asphalt mixtures (aggregate and bitumen) by applying vapor sorption techniques and using the results to calculate thermodynamic work of adhesion and debonding in the presence of moisture, of various aggregate–asphalt mixtures. The physical adsorption approach represents a vast improvement over the existing empirical moisture sensitivity tests because it applies fundamental concepts of adhesion that is based on the molecular interaction between an adhesive and a substrate. Because the approach is based on fundamental material properties, the physical adsorption theory of moisture-induced damage is applicable to all mixture types unlike some current empirical tests that are both material and test method dependent.

The basic concepts behind physical adsorption theory suggest that (1) the adhesive and the substrate are in intimate contact

\* Corresponding author. Tel.: +44 1158468424.

E-mail addresses: [alex.apeagyei@nottingham.ac.uk](mailto:alex.apeagyei@nottingham.ac.uk) (A.K. Apeagyei), [james.grenfell@nottingham.ac.uk](mailto:james.grenfell@nottingham.ac.uk) (J.R.A. Grenfell), [gordon.airey@nottingham.ac.uk](mailto:gordon.airey@nottingham.ac.uk) (G.D. Airey).

and van der Waals forces operate between them, (2) van der Waals forces consist of two components – polar and dispersion, and (3) thermodynamic work of adhesion, calculated by using the two-component van der Waals forces, can be used to assess the stability of the bond between an adhesive and a substrate [5]. Adhesive-substrate bonds with positive thermodynamic work of adhesion are considered stable while bonds with negative work of adhesion are considered unstable. Energy parameters based on thermodynamic work of adhesion for characterizing moisture sensitivity have been developed for asphalt mixtures [4].

One important limitation of the physical adsorption theory-based moisture damage evaluation technique is that even though the technique can predict the stability of an adhesive-substrate bond under both wet and dry conditions, it is unable to account for the moisture damage that is reversible upon specimen drying. This type of damage has been observed in asphalt mixtures in previous studies, even though the phenomenon has neither been reported widely nor fully explained. For instance, evidence of moisture-induced stiffness degradation in wet specimens being fully recovered upon specimen drying was reported by Schmidt and Graf [6]. The authors reported that resilient modulus of moisture-deteriorated specimens returned to their original value on drying and attributed the occurrence of the phenomenon to the observed disparity between lab test data and field performance. The lack of correlation between field performance and some laboratory moisture sensitivity tests could be due to the fact that existing test methods and pavement design analyses techniques do not account fully for the reversibility of the moisture-induced stiffness degradation phenomenon directly. The chemical bonding theory could be used to address reversible stiffness degradation in moisture-damaged mixtures. The formation of covalent, ionic, or hydrogen bonds across an adhesive-substrate interface is the basis for the chemical bonding theory of adhesion [5]. The interfacial force due to ionic pairs is given by Eq. (1) [7], where  $q_1$  and  $q_2$  are the ionic charges,  $\epsilon_0$  the permittivity of a vacuum,  $\epsilon_r$  the relative permittivity of the medium, and  $r$  the inter-ionic distance.

$$F = \frac{q_1 q_2}{4\pi\epsilon_0\epsilon_r r^2} \quad (1)$$

Water at ambient temperatures has a very high relative permittivity of 80. The corresponding relative permittivity of bituminous materials, however, are quite low with reported values in the range of 2.6–2.8 for bitumen, 4.0–4.6 for newly constructed dry asphalt pavements, and 6–8 for wet or moisture damaged pavements [8–11]. Since an approximately linear relationship exists between the relative permittivities of mixtures of water and organic solvents and mixture composition [7,12,13], the high  $\epsilon_r$  of water means even small amounts of absorbed water in the adhesive can cause large increases in  $\epsilon_r$  and a reduction in  $F$ . For asphalt mixtures, assuming an increase in relative permeability from 4.3 for a new asphalt mixture to 7.0 for old/moisture damaged mixtures, a reduction in  $F$  of about 63% is possible. The reduction in  $F$  due to moisture absorption by an adhesive is reversible; hence complete removal of water (say by drying) from an adhesive joint can restore  $F$  to the original value. Thus the major difference between the adsorption theory and the chemical bond theory of adhesion is that the latter permits partial recovery of damage in a wet adhesive bond when the bond is dried while the former determines whether an adhesive bond is stable or not stable (zero strength) in the presence of water. The insight gained from the work presented in the current paper is intended to help to develop a framework for describing the mechanism responsible for the reversibility of moisture-induced stiffness degradation in asphalt mixtures and suggest a unified adhesion–cohesion theory to characterize moisture sensitivity of asphalt mixtures.

This paper presents indirect tensile testing results for dense-graded asphalt mixtures that contain limestone aggregates and two different mineral fillers (granite and limestone) and that had been compacted to three different air void levels and subjected to water immersion testing at 60 °C for up to 70 days. The mechanical test data were compared with the thermodynamic work of adhesion of the asphalt mixture components. Moisture diffusion analysis and computerized tomography techniques were used to estimate moisture transport in the asphalt mixtures in order to determine the possibility of moisture reaching the aggregate–mastic interface. Adhesion theory, based on chemical (covalent bonds or ionic pairs) were used to explain the apparent recovery of stiffness degradation in previously moisture-damaged specimens. Analysis of the results lead to the development of a novel framework for describing moisture-induced damage in asphalt mixtures in terms of both adhesive and cohesive failure.

## 2. Materials and methods

### 2.1. Mixture composition, design and conditioning

The asphalt mixtures used were 10 mm nominal maximum size dense bitumen macadam (DBM) mixtures that had been compacted to three different air void levels using a gyratory compactor. The selection of the constituent aggregate, mineral filler, and bitumen were based on experience from previous studies that found mixtures fabricated from these materials exhibit different moisture sensitivity depending on aggregate and or mineral filler type [14,15]. For each aggregate, mineral filler, and air void level, four replicate 100 mm diameter by 60 mm thick specimens were fabricated for moisture conditioning and mechanical testing. Overall, 48 asphalt (100 mm by 60 mm) specimens were fabricated for moisture conditioning and mechanical testing (indirect tensile stiffness and tensile strength). Of these, 24 specimens were tested in the dry condition without moisture conditioning to determine their tensile strength while the rest were conditioned by immersion in a water bath at 60 °C for up to 70 days. The moisture-conditioned specimens were removed at regular intervals for testing and then returned to the water bath for additional conditioning. Additional details of the asphalt mixtures used, including the constituent material properties, key mixture design features, and moisture conditioning, are listed in Table 1. Fig. 1 shows a photograph of the moisture conditioning test set-up used for asphalt mixture immersion test.

### 2.2. Physico-chemical properties of aggregates and bitumen

Physico-chemical properties of the aggregate and bitumen used were determined by using vapor sorption techniques and contact angle measurements, respectively. Detailed experimental procedures used, including selection of probe liquids and procedures for estimating surface free energy components of the aggregate and bitumen, are provided elsewhere [16,17]. The data were used to calculate the thermodynamic work of adhesion and debonding of the aggregate–bitumen mixtures. Summary of the physico-chemical properties of the bitumen and the aggregate including the thermodynamic work of adhesion are listed in Table 2.

As expected the thermodynamic work of adhesion between the aggregate and bitumen in the dry state was positive suggesting a stable bond. However, the negative nature of the work of debonding suggests the bond between aggregate and bitumen in the presence of water is unstable, which is in agreement with expectation based on common experience. It is important to note in Table 2 that the work adhesion between the aggregate and the bitumen is higher than the cohesion within the bitumen. This would suggest that in the absence of water, the dominant failure mode in asphalt mixtures should be cohesive. This observation will be used to develop the moisture damage mechanism framework introduced in this paper.

### 2.3. Indirect tensile stiffness testing of mixtures

Indirect tensile stiffness tests were performed in accordance with EN 12697-26 [18] on the 100 mm diameter by 60 mm thick specimens at various moisture conditioning times starting from the dry condition until the end of a 70 day period. Specifically specimens were removed from the water bath and tested on the following days: 8, 15, 30, 55, and 70. In each instance, except for specimens conditioned for 70 days in water, the same mixtures were returned to the bath for additional specimen conditioning. After the 70 day testing, the specimens were stored at room temperature (20 °C and 55% relative humidity) for another 47 days to dry and were then tested. The latter testing enabled a determination to be made as to whether moisture-induced stiffness degradation in asphalt mixtures was reversible. All the stiffness testing was conducted at 20 °C. The applied load was selected to ensure that the mixture deformation stayed in the linear viscoelastic range in order not to damage the specimens as the same specimens were tested and then put back in the water bath for additional conditioning.

Download English Version:

<https://daneshyari.com/en/article/6723399>

Download Persian Version:

<https://daneshyari.com/article/6723399>

[Daneshyari.com](https://daneshyari.com)