Construction and Building Materials 78 (2015) 8–17

Contents lists available at ScienceDirect

Construction and Building Materials

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

Behavior of asphalt mastic films under laboratory controlled humidity conditions

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HIGHLIGHTS

- Normal strength and direct shear strength of asphalt mastic films were measured after vapor conditioning.
- Normal strength of mastic films decrease with increase in vapor absorption.
- Direct shear strength of mastic films increase with increase in vapor absorption.
- Mastic films consist of binder and fines lose viscosity after vapor absorption.

ARTICLE INFO

Article history:
Received 5 May 2014
Received in revised form 21 December 2014
Accepted 28 December 2014
Available online 13 January 2015

Keywords:
Asphalts
Brittle failures
Ductility
Humidity
Mastic
Pull-off

ABSTRACT

Normal and shear pull-off strength of asphalt mastic films are measured at three relative humidity (RH%) conditions. Mastic films of size 5 mm^2 with thickness ranges from 0.193 to 0.210 mm were prepared in between two aggregate slices. Laboratory RH conditioning was applied by aqueous solution of potassium acetate (25% RH), potassium carbonate (49% RH), and sodium chloride (71% RH) in enclosed desiccators. After humidity conditioning, one aggregate slice was attached to the base of a testing frame, and pull-off force was applied on the other aggregate slice. Load–displacement curves indicate that mastic films show ductile behavior at 71% RH conditioning and brittle behavior at 49% and 25% RH conditioning while normal pull-off strength is measured. Average yield and ultimate strength for 71% RH is the lowest compared to those at 49% and 25% RH. The ductile nature of mastic films at high RH% influences the shear pull-off strength by showing higher shear pull-off strength. Average shear strength of mastic films increases with an increase in relative humidity.

1. Introduction

The mixture of fines (mineral size smaller than 0.075 mm) and asphalt binder is known as asphalt mastic or mastic materials [1–3]. The mixture of asphalt binder with fine aggregates (aggregate size ranges from smaller than 4.75 mm to larger than 0.075 mm) is known as matrix materials [4]. Two damage mechanisms named as adhesive and cohesive damage in mastic materials have been recognized by researchers [5,6]. Adhesive damage is the separation between aggregate or mastic materials and cohesive damage is the strength degradation within the mastic or matrix materials. It has also been noticed that the interface between the aggregate and mastic is the weakest region and more prone to initiate damage [7,8]. Damage accumulates and causes cracking and other distress in the mastic and/or Asphalt Concrete (AC). It has been observed that both adhesive and cohesive damage increases due to moisture or humidity [9–11]. This study determines mastic strength under different laboratory controlled humidity conditions.

Fig. 1 represents a schematic diagram of mastic damage and failure of AC. Fig. 1a shows a mastic film binding two hypothetical circular shape aggregates. Under vertical tire pressure and traction force, the aggregates tend to pull-off from each other horizontally and vertically, as shown in Fig. 1b. As pull-off force increases, damage occurs inside the mastic film and/or at the mastic–aggregate interface. Fig. 1c shows damage initiates within the mastic film and propagated through the mastic–aggregate interfaces. This study focuses on whether such mastic damage is affected by the presence of water vapor.

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http://dx.doi.org/10.1016/j.conbuildmat.2014.12.107
0950-0618/

Currently, a considerable amount of research is going on to define mechanical properties such as dynamic shear modulus, fracture strength, and cohesive strength of mastic materials to understand damage in AC [1–3,12,13]. Mastic–aggregate interface strength was determined using ASTM D4541 [14] known as pull-off strength of coating using portable adhesion tester, well known as Pneumatic Adhesion Tension Testing Instrument (PATTI) test [8,15]. In the PATTI test, the substrate is aggregate and the mastic materials are placed on the aggregate, a pull-off force is applied to the mastic materials. The pull-off strength required to separate mastic film from the aggregate surface is recorded and the failure surface is qualitatively analyzed. If more than 50% of the aggregate surface is exposed, then the failure is adhesive, otherwise the failure is cohesive. The limitation of the PATTI test is the pull-off stud is not an aggregate; it is made of steel or ceramic plate attached to a steel head. As a result, when the mastic film separates from the substrate aggregate, the other side of the film is attached with stud materials. In addition, the PATTI test is unable to measure shear pull-off strength. Moreover, PATTI test has been used by the researchers to evaluate pull-off force of aggregate and Warm Mix Asphalt (WMA) and aggregate retention in chip-seal maintenance work on old and aged AC pavement [16–18]. Therefore, even though there are some limitations, PATTI test is a popular test to gain an understanding about the fundamental properties such as adhesion and cohesion of AC materials. This study is done to overcome the PATTI test limitations and determine the mastic film strength.

In addition, binder strength in between two aggregates are determined using modified Dynamic Shear Rheometer (DSR) test [19]. Torsional shear strength of binder or mastic materials can be measured by DSR. Very few studies have been conducted to understand the normal and torsional shear pull-off strength of mastic using mastic in between two aggregates [20,21]. They performed fatigue normal pull-off tests using Dynamic Mechanical Analyzer (DMA), torsional fatigue shear tests using DSR and oblique fatigue shear tests using hydraulic machine. Furthermore, the test results were incorporated in the two dimensional and three dimensional Finite Element Method (FEM) model to understand the complex stress strain scenario of idealized aggregate coated with mastic materials under moving load [22,23]. In other study, the fracture tests that have been done to simulate cohesive zone fracture modeling using Finite Element Method (FEM), have mastic materials in between polystyrene sheets [12]. In their study, the fracture strength of mastic materials is measured by applying normal pull-off forces from two ends of polystyrene sheet.

AC pavements, exposed to traffic, experience repeated load from moving tire pressure. Overtime AC shows damage that progress to failure, fracture, and permanent deformation due to its visco-elastic–plastic materials behavior. The irrecoverable viscous stain causes damage and progressive failure in pavements. Moisture or water vapor accelerates this damage by decreasing adhesive action between asphalt binder and aggregates [24]. Flexural strength of asphalt concrete can be determined by applying four-point bending using beam fatigue apparatus. Repeated vertical loads were applied on an AC beam sample with specified dimension. Degradation of flexural stiffness due to fatigue load can be determined from the test. Recently, fatigue tests on AC beams have been performed considering 15% RH and 40% RH [25]. Both RH and freeze–thaw conditioning of AC beam samples have been done using environmental chamber. Four freeze–thaw cycles were applied in addition with the RH conditioning. It has been observed that fatigue life of the selected AC samples was decreased by 37.5% due to 40% RH conditioning at 20 freeze–thaw cycles. Fatigue test at the interface of aggregates in AC is not common. Though, fatigue tests at the interface of two materials are done for fiber reinforced composite materials [26]. Very few studies have been done to measure normal and direct shear strength of mastic materials. For this reason, static pull-off tests were performed in this study to measure the normal and direct shear strength of mastic materials in between two aggregates; direct shear strength and shear strength are used interchangeably in the following sections unless otherwise mentioned. However, Finite Element Method (FEM) model can be developed and simulation can be performed for mastic–aggregate interface damage due to fatigue load. In addition, vapor induced damage in composite and concrete structure is also an important and challenging research area that have been studying for many years [27,28].

Moisture causes damage in AC; in the following sections moisture and water are used interchangeably. Moisture gets into AC by diffusion of water. Physical–chemical–mechanical actions occur while moisture gets into AC. Physical action consists of diffusion of moisture; chemical action consists of chemical affinity between aggregate and binder in the presence of moisture; and mechanical action consists of friction between aggregate surfaces with mastic materials in the presence of moisture. In addition to moisture, water vapor can diffuse in AC. Water vapor could come from beneath the pavement due to the capillary rise of water and suction gradient of vapor from the base or subgrade to the top of pavement [13]. Moisture diffusion occurs when the pavement is wet but vapor diffusion occurs from the atmosphere even the pave-

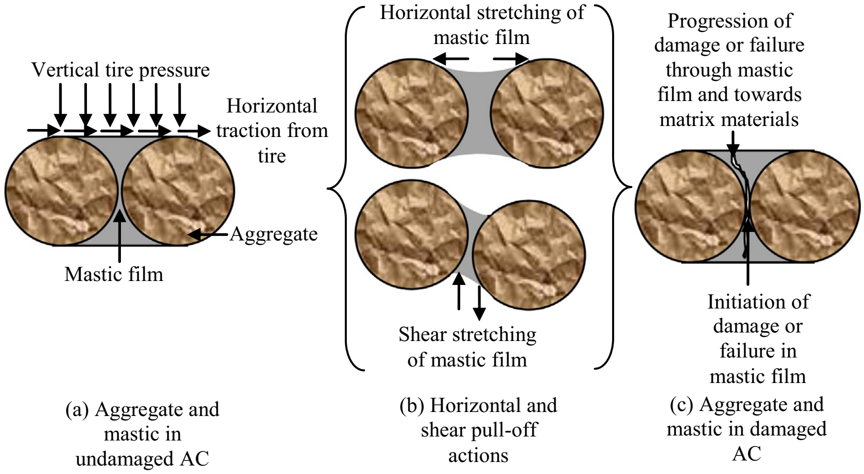

Fig. 1. Schematically aggregate and mastic film in undamaged and damaged AC.