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Influence of cooling medium on low temperature strength of asphalt binders

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HIGHLIGHTS

- Strength and histogram tests were performed on asphalt binders at low temperature.
- Bending Beam Rheometer (BBR) and Direct Tension Tester (DTT) were used for testing.
- Ethanol, potassium acetate solution and air were used as cooling media.
- Ethanol diffuses in asphalt binder specimens while potassium acetate does not.
- Size effect analysis demonstrates that BBR and DTT strength are equivalent.

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ABSTRACT

The effect of three different cooling media, ethanol, potassium acetate (PA) and air, on the strength of asphalt binder at low temperature is investigated with a modified Bending Beam Rheometer (BBR) and the Direct Tension Tester (DTT). Similar strength values are obtained in air and PA and significantly lower values are obtained in ethanol. The use of fluorescing markers demonstrates that ethanol diffuses in the asphalt binder, while diffusion does not occur when PA is used. Using size effect theory, BBR strengths in PA and in air are found to be equivalent to DTT strength in PA.

1. Introduction

Low temperature cracking of asphalt pavements is a major distress in cold regions. This phenomenon manifests as a set of almost parallel surface-initiated transverse cracks of various lengths and widths. Water penetration, freeze-thaw cycles, and traffic loads can cause additional distresses in the pavement base and subbase dramatically affecting the service life. Therefore, the selection of asphalt binders with better low temperature properties is critical in preventing early cracking of asphalt pavements.

The current Superpave specifications address low temperature cracking through the use of strength and creep tests. During the Strategic Highway Research Program (SHRP), two laboratory instruments were developed to investigate the low temperature behavior of asphalt binders: the Bending Beam Rheometer (BBR) [3] and the Direct Tension Tester (DTT) [4]. These two devices are used to obtain the performance grade (PG) of asphalt binders [1]. The BBR is used to perform low-temperature creep tests on beams of asphalt binders conditioned at the desired temperature for 1 h in ethanol (C_2H_6O). The DTT is used to perform low-temperature uniaxial tension tests at a constant strain rate of 3% on dog-bone shaped specimens of asphalt binder conditioned at the desired temperature for 1 h in potassium acetate (CH_3CO_2K).

The DTT device is relatively expensive and requires very careful sample preparation. In addition, manufacturer support has declined in recent years. A strong effect of cooling media was observed on the DTT material strength in a study conducted by Dongré and D'Angelo [17]. This is currently the only available research on this topic, and a more in-depth analysis on cooling

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medium effects is very much needed. It becomes, therefore, important to develop an alternative strength test method that can be easily performed and implemented, possibly relying on the current testing devices commonly available in the majority of asphalt pavement laboratories.

2. Objective and research approach

In this paper, an alternative testing method to obtain the tensile strength of asphalt binder using a modified BBR device (TE-BBR Pro) is presented. Two factors that significantly affect strength are investigated: the cooling medium used to store and test the binder specimens, and the specimen size. In the first part of the paper, three different cooling media, ethanol, potassium acetate and air, are investigated using a Cannon TE-BBR Pro instrument, and an investigation to determine if the cooling fluids diffuse in the binder sample is performed. In the second part, BBR strength values are compared with DTT strength values using statistical tools and size effect analysis, to understand if the two methods produce comparable results.

3. Materials and experimental procedure

Two asphalt binders were used in this study: a plain PG58-28 binder, and an Elvaloy modified PG58-34 binder. Prior to testing, both binders were long term aged according to the Pressurized Aging Vessel (PAV) [2] method.

All DTT and BBR tests were performed at one temperature equal to the binder PG lower limit + 4 °C. Direct tension (DT) testing was performed according to the current standard [4] using a Bohlin DTT instrument. All three-point bend strength tests were performed on a Cannon TE-BBR Pro device (Fig. 1). This testing machine differs from the conventional BBR apparatus: it is equipped with a proportional valve air bearing system that allows the application of more complex loading patterns, and can apply and accurately measure loads as high as 44 N. The previous system could only perform creep tests and the maximum load was 4.5 N. The new machine is therefore capable of imposing ramp loading at different rates, up to the failure of the specimen. All DT testing was performed under strain control, and all BBR strength testing was performed under load control.

The BBR nominal strength (maximum stress at peak load) σ_N^{BBR} and corresponding strain ε_N^{BBR} at the bottom of the BBR beam (Fig. 2a) can be obtained from Eqs. (1) and (2):

$$\sigma_N^{BBR} = \frac{3P_N L}{2bh^2} \tag{1}$$

$$\varepsilon_N^{BBR} = \frac{6\delta_N h}{L^2} \tag{2}$$

where σ_N^{BBR} nominal strength (MPa), ε_N^{BBR} strain at failure, P_N maximum measured load (N), L span length (101.6 mm), b width of the beam (12.5 mm), h thickness of the beam (6.25 mm) and δ_N deflection (mm) of the beam corresponding to maximum load P_N.

For DTT (Fig. 2b), failure stress σ_N^{DTT} and failure strain ε_N^{DTT} can be calculated according to Eqs. (3) and (4).

$$\sigma_N^{DTT} = \frac{P_N}{A} \tag{3}$$

$$\varepsilon_N^{DTT} = \frac{\Delta_N}{L_e} \tag{4}$$

where σ_N^{DTT} nominal strength (MPa), P_N failure load (N), A original area of the cross section (mm^2), and $A = b \times b$, b cross section side (b = 6 mm), ε_N^{DTT} failure strain, Δ_N elongation at failure (mm), and L_e effective gage length (33.8 mm).

4. BBR strength investigation

In the first part of the experimental campaign, three different cooling media were used to investigate the influence of BBR cooling fluid on the failure stress: ethanol (E), potassium acetate (PA) and air (A). Although ethylene glycol can be also used as cooling medium for BBR testing, due to anti-freezing properties, it was not investigated in this study, since it presents a chemical composition ($C_2H_6O_2$) which is comparable to that of ethanol (C_2H_6O).

In order to improve the efficiency of the BBR cooling system when air is used, a small fan was introduced into the device chamber; a temperature offset of +1.5 °C was imposed as correction through an external thermometer in order to obtain the desired temperature (see Fig. 1). A conditioning time of 1 h was imposed

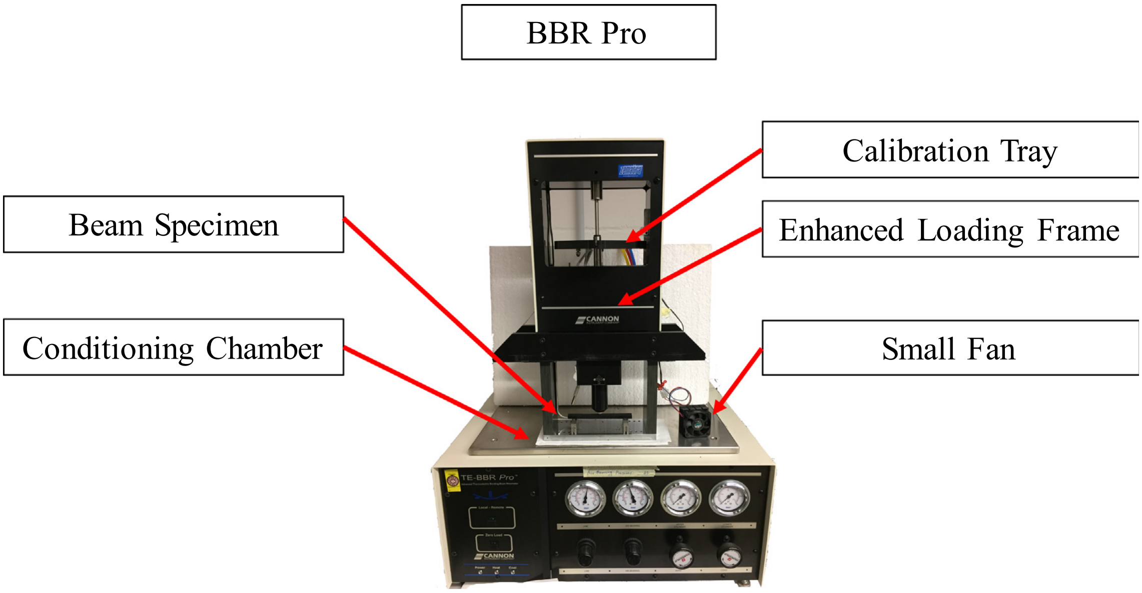

Fig. 1. Cannon TE-BBR Pro strength device.