Construction and Building Materials 75 (2015) 220–226

Contents lists available at ScienceDirect

Construction and Building Materials

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

Feasibility of ultrasonic measurements for characterizing rheological properties of asphalt binders

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HIGHLIGHTS

- This feasibility was examined for the first time.
- Promising results were obtained by this study.
- Ultrasonic pulse velocity of the asphalt binder decreases with temperature increase.
- Aged samples showed higher velocity than the original samples.
- Modified asphalt binders showed lower velocity compared to un-modified ones.

ARTICLE INFO

Article history:
Received 28 June 2014
Received in revised form 1 October 2014
Accepted 12 November 2014

Keywords:
Asphalt binder
Ultrasonic method
Temperature effects
Performance grade

ABSTRACT

Ultrasonic measurement (UM) may provide an inexpensive alternative to sophisticated tests currently used to characterize rheological properties of asphalt binders. This research investigates the feasibility of application of high frequency immersion UM to characterize performance grade (PG) asphalt binders. Nine different PG asphalt binders were selected for this investigation. Short term aged, long term aged and un-aged samples were prepared for ultrasonic measurements. For each binder, velocity (*V*) and integrated response (*IR*) of the ultrasonic wave were measured at five temperatures. Mechanical test to obtain rheological properties were also performed on the same asphalt binder grades. Variation of ultrasonic measured parameters with temperature was studied. Correlations between the ultrasonic measurements and rheological properties were explored. Results indicated that ultrasonic velocity of the asphalt binders decreases with increase in their temperature. Modified asphalt binders showed lower velocity compared to un-modified ones.

1. Introduction

Asphalt binders have been used for many years in Hot Mix Asphalt (HMA) as part of empirical or mechanistic mix designs. Asphalt binders are categorized into "grades" based on their rheological properties. Performance grade (PG) is the most commonly used system because its specifications is based on the high and low pavement temperatures expected at roadway's geographic location [1]. The grade verification of asphalt binders, however, requires the extensive use of laboratory testing. These tests are time consuming, and they require expensive equipment as well as skillful technicians. The laboratory tests related to an asphalt binder are based on physical properties, such as elastic shear modulus and stiffness that show how it will perform as a constituent in HMA. Three major tests for PG asphalt binders, based on the Strategic Highway Research Program (SHRP), are the Dynamic Shear Rheometer (DSR) test, the Bending Beam Rheometer (BBR) test, and the Direct Tension Tester (DTT) [2].

There is a need for a rapid, simple and non-destructive test to verify asphalt binder grades. Ultrasonic measurement may provide a viable alternative. Parameters like sound velocity, attenuation, and frequency content from ultrasonic measurements could be correlated to elastic moduli, viscosity, density, and porosity size and distribution of construction materials [3]. The use of non-contact ultrasound to characterize asphalt binder was explored by Krishnan [4] in order to find correlations between physical properties (viscosity and penetration) of asphalt binder with ultrasound measurements [4]. This research was unable to prove the correlation conclusively, but some trends were noticed. Use of ultrasound to characterize asphaltic concrete has also been studied [5–8]. It was found that ultrasonic measured parameters

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http://dx.doi.org/10.1016/j.conbuildmat.2014.11.018
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could be related to asphalt concrete properties such as bulk specific gravity and performance value of Asphalt Pavement Analyzer (APA) rut test [9]. The coupling of ultrasonic testing with laboratory-based performance testing of HMA would provide a vital link to rapid quality control testing and quality assurance verification.

By using ultrasonic device instead of mechanical test equipment, savings in time and money is possible. The objective of this study was to find the best ultrasonic technique to eventually be used as a substitute for mechanical tests. The ultrasonic measurements were performed on an array of PG asphalt binders with known grades. These measurements were done at a range of temperatures higher that room temperature. Mechanical tests were also performed on the same asphalt binders to find the rheological properties and verify their grades.

2. Basic principles of ultrasound

Ultrasonic testing (UT) uses high frequency sound energy to conduct examinations and make measurements. It can be used for, but not limited to, flaw detection/evaluation, dimensional measurements, and material characterization. A typical UT system consists of a pulser–receiver, transducer(s), and a display unit. A pulser–receiver is an electronic device that can produce high voltage electrical pulse, which causes the transducer to generate a high frequency ultrasonic energy. The sound energy is transmitted through the material in the form of waves [10].

The sound frequency range is wide from sub-sonic to high frequency. In general Ultrasonic Non Destructive Testing (UNDT) utilizes the range of frequencies from approximately 20 kHz to over 100 MHz, with most work being performed between 500 kHz and 20 MHz. Both longitudinal and shear, as well as surface wave modes of vibration are commonly used. Many material analysis applications benefit from using the highest frequency that the test piece can support due to better resolution of the measurement [11].

2.1. Ultrasonic transducers

Mechanical vibrations for measurement, analysis, or test purposes are generated by electromechanical transducers, i.e., elements having the ability to transform electrical into mechanical energy, and vice versa. Contact, no-contact and immersion are three main types of transducers.

Immersion transducers do not contact the test material. These transducers are designed to operate in a liquid (usually water) environment and all connections are watertight. Immersion transducers propagate the sound energy into the water and, in turn, into the component being inspected (Fig. 1) [12].

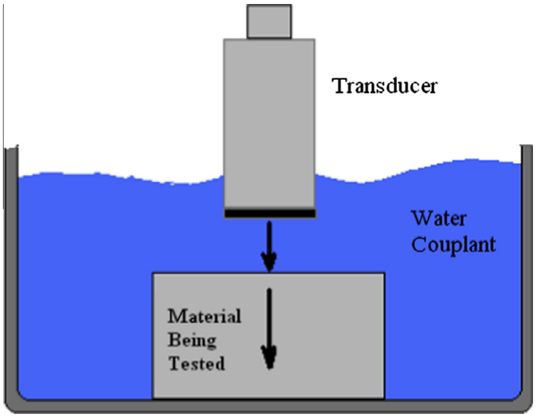

Fig. 1. Immersion ultrasonic method.

2.2. Measurement techniques

Pulse/receive and pulse/echo are two major configurations for ultrasound testing and measurement. In pulse/receive method one transducer emits the ultrasonic wave and another transducer receives the wave passed through the testing material. In pulse/echo method, the transducer which emits the ultrasonic wave receives the reflected wave from the near and far surface of the testing materials (Fig. 2). Pulse/receive and pulse/echo methods with contact and immersion transducers were examined in this research in four different configurations. The preliminary showed pulse/echo method in an immersed configuration with an immersion transducer as the best method that could distinguish between two different asphalt binder grades [13]. Therefore, it was selected for the main ultrasonic measurements.

2.3. Measured parameters

The progression rate of a wave is the wave-speed also termed phase velocity. The wave-speed does depend on the material type and, with exception of isotropic materials, also on the direction of the wave propagation.

Ultrasonic waves are reflected at boundaries where there is a difference in acoustic impedances (Z) of the materials on each side of the boundary. The acoustic impedance of a material is defined as the product of density (ρ) and acoustic velocity (V) of that material. The difference in Z is commonly referred to as the “impedance mismatch”. The greater the impedance mismatch, the greater the percentage of energy that will be reflected at the interface or boundary between one medium and another.

The value produced is known as the reflection coefficient (R), shown in Eq. (1). Since the amount of reflected energy plus the transmitted energy must equal the total amount of incident energy, the transmission coefficient (T) is calculated by simply subtracting the reflection coefficient from one.

$$R = \left[\frac{Z_{II} - Z_I}{Z_{II} + Z_I}\right]^2 \tag{1}$$

$$T = 1 - R = 1 - \left[\frac{Z_{II} - Z_I}{Z_{II} + Z_I}\right]^2 = \frac{4Z_I Z_{II}}{(Z_I + Z_{II})^2} \tag{2}$$

where Z_I and Z_{II} are the acoustic impedances of material I and II.

The reflection and transmission coefficients are often expressed in decibels (dB) to allow for large changes in signal strength to be more easily compared.

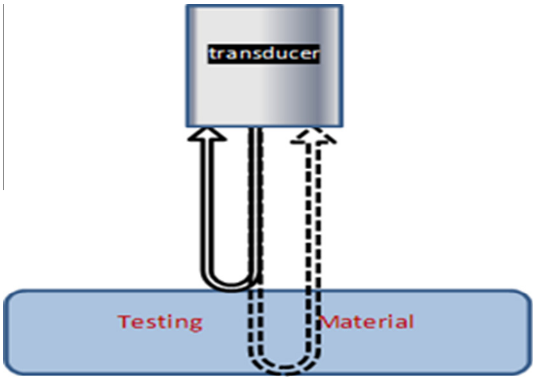

Fig. 2. Pulse/echo ultrasound.