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Investigation on the effect of aging temperature and experimental conditions on the rheological properties of asphalt binder

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Vorwort des Herausgebers

Straßenbauasphalt ist ein verdichtetes Haufwerk aus Mineralstoffen und dem Bindemittel Bitumen. Diese Stoffe variieren in Zusammensetzung, Eigenschaften und Gebrauchsverhalten erheblich, abhängig von den Ausgangs-, Produktions- und Beanspruchungsbedingungen. Insbesondere die Auswahl des Bitumens in Abhängigkeit von seinen rheologischen Eigenschaften ist daher für die Mischgutzusammensetzung von Asphalt von essentiellem Interesse. Zur Prüfung der Bitumeneigenschaften ist eine Reihe von rheologischen Prüfverfahren bekannt. Allerdings sind einige prüftechnische Fragen noch nicht abschließend beantwortet, beispielsweise zur bestmöglichen experimentellen Ansprache des rheologischen Materialverhaltens von Bitumen im Tieftemperaturbereich, oder zum Einfluss der Prüfbedingungen und der Alterung auf die Prüfergebnisse.

Die in diesem Heft der ISBS Schriftenreihe zusammengestellten fünf Fachbeiträge sind solchen, noch offenen Fragen gewidmet. Mittels Reihenuntersuchungen im Dynamischen Scherrheometer (DSR) und im Biegebalkenrheometer (BBR) werden systematisch die sich überlagernden Einflüsse aus den gewählten Prüfbedingungen und aus der Probenkonditionierung infolge Kurzzeitalterung und Verhärtung auf die Prüfergebnisse analysiert. Der Fachbeitrag „An Alternative Experimental Method for Measuring the Low Temperature Rheological Properties of Asphalt Binder by Using 4mm Parallel Plates on Dynamic Shear Rheometer“ beschreibt ein am ISBS entwickeltes Verfahren zur Prüfung von Bitumen im DSR im Tieftemperaturbereich (System Platte-Platte, 4 mm Messgeometrie, 3 mm Spalt). Eine Form aus Silikon wird erprobt, die ein ausreichend präzises und gut wiederholbares Trimmen der Probe ermöglicht. Anhand von umfangreichen Auswertungen (inkl. Modellierung mittels 2S2P1D Modell) wird die Güte des neuen Verfahrens für eine Auswahl an Bitumenproben demonstriert. Der Beitrag „Investigation on the Low Temperature Properties of Asphalt Binder - Glass Transition Temperature and Normal Shift Factor“ ist der Auswertung von DSR-Messdaten im Tieftemperaturbereich gewidmet, wobei eine neue Vorgehensweise vorgeschlagen wird, um Messdaten unterhalb der Glasübergangstemperatur zu korrigieren. Im Beitrag „Rheological Modeling of Asphalt Binder under Different Short and Long-term Aging Temperatures“ wird festgestellt, dass eine Temperaturreduktion bei der Mischgutproduktion eine reduzierte Kurzzeitalterung des Bitumens und damit Vorteile gegenüber dem Heißmischprozess bewirkt. Schließlich sind die Beiträge „Investigation on the combined effect of aging temperatures and cooling medium on rheological properties of asphalt binder based on DSR and BBR“ und „Investigation on the Effect of Physical Hardening and Aging Temperature on Low-Temperature Rheological Properties of Asphalt Binder“ der Analyse der sich überlagernden Einflüsse aus den gewählten Prüfbedingungen und aus der Probenkonditionierung infolge Kurzzeitalterung und Verhärtung auf die Prüfergebnisse aus DSR und BBR gewidmet.

Alle fünf Fachbeiträge entstanden ab 2015 am ISBS unter der Federführung von Di Wang in Kooperationen mit unterschiedlichen Mitautoren und Mitautorinnen. Sie wurden im

Jahr 2019 in unterschiedlichen Fachjournalen im Peer-Review-Verfahren publiziert. Im Herbst 2019 reichte Di Wang diese Beiträge in Form einer kumulativen Dissertation an der Technischen Universität Braunschweig ein, und mit der Disputation am 14. Oktober 2019 in Braunschweig schloss er sein Promotionsverfahren erfolgreich ab.

Ich freue mich sehr, seit 2015 bis heute mit Di Wang eng zusammenarbeiten zu dürfen. Beruflich wie privat wünsche ich ihm weiterhin viel Erfolg!

Braunschweig, im August 2020

Michael P. Wistuba

Contents

1 Introduction

1.1 Context

Asphalt binder is an important component of bituminous material, its properties can significantly affect the performance of asphalt mixture and asphalt pavement (Olard, Di Benedetto, Eckmann and Vaniscote, 2004). Since asphalt binder is a kind of temperature-sensitive materials (Olard et al., 2004); hence, the performance and the properties of the asphalt mixture are highly dependent on its service temperature and the production temperatures.

The conventional Hot Mix Asphalt is produced at temperatures higher than 160 °C. Considering the environmental impact, Warm-Mix Asphalt (WMA) technology was first introduced to asphalt pavement construction for the purpose of reducing the emission of greenhouse gas in the 1990s (EAPA, 2017). Nowadays, WMA can achieve comparable performance with the conventional Hot-Mix Asphalt (HMA) with reduced production temperatures between 20 °C to 40 °C than HMA (Hurley and Prowell, 2006; EAPA, 2017). However, there is still ongoing scientific debate whether the lower production temperature can reduce the aging effect of the material and ultimately result in better durability of the pavement infrastructure. Several studies (EAPA, 2017) have already worked on the effect of aging temperature on the rheological properties of bituminous materials; however, most of the previous works focused on the asphalt mixture, only a few studies worked on the pure asphalt binders.

Currently, several devices and testing methods can be used to measure the pure asphalt binders' rheological properties, especially for the aging properties. Among them, Dynamic Shear Rheometer (DSR) (AASHTO T315, 2012) and Bending Beam Rheometer (BBR) (AASHTO T313, 2012) are two of the most commonly used machines. For the conventional DSR, a torque test is applied for the asphalt binder sample at high and intermediate temperatures. The corresponding rutting resistance properties and fatigue properties can be measured and evaluated. In the case of the conventional BBR device, the low temperature creep stiffness and relaxation properties are measured by a three-point bending test at low temperatures. Due to the drawback of BBR, such as a large amount of material requirement (Sui et al., 2010) and underestimates the low temperature properties for the modified binder (Nicholls, 2006). An alternative experimental method based on the DSR device was recently proposed. This method can reach temperatures as low as -40 °C and relies on smaller DSR plate geometry. Several studies (Sui et al., 2010; Lu, Uhlback and Soenen, 2017; Riccardi et al., 2017; Laukkanen, Soenen, Winter and Seppälä, 2018) have already successfully evaluated this method to measure the low temperature properties of asphalt binders.

1.2 Objective and research approach

The main objective of this study is to investigate the effect of aging temperature and experimental conditions on the rheological properties of asphalt binders. To accomplish this purpose, the following research approaches are adopted:

- Improve the current low temperature Dynamic Shear Rheometer (DSR) sample preparation and data pre-processing method.
- Address the effect of different short-term aging temperatures on the rheological properties of asphalt binder under different aging conditions in a wide range of temperatures based DSR and Bending Beam Rheometer (BBR).
- Evaluate the possibility of using DSR to replace BBR test at low temperatures, and the effect of experimental conditions on the rheological properties of asphalt binder at low temperatures.
- Investigate the correlation between DSR and BBR results when the experimental conditions are carefully controlled

1.3 Organization and innovation

This thesis consists of five main chapters. The first chapter is devoted to providing a general overview of research work and motivation. The second chapter firstly outlines the conventional specification evaluation and experimental methods of asphalt binders, follows with the literature review on the effect of aging temperatures and experimental conditions. The third chapter includes five high level peer-reviewed international journals papers in the area of civil engineering and material science. The first publication describes a new sample preparation when DSR testing is performed at low temperatures while the second one focuses on the pre-analysis of raw data obtained by DSR. The third research effort addresses the effect of aging temperature on the rheological property of asphalt binder. The last two papers evaluate the combined effect of aging temperatures and experimental conditions, such as cooling medium and conditioning time, on the low temperature rheological properties of asphalt binder. The fourth chapter contains the summary and conclusions of this dissertation while providing recommendations for future research. The fifth chapter lists the author's scientific publications during the Ph.D. period. The corresponding innovative respects of the present dissertation can be summarized as follows:

- Develop an alternative sample preparation solution with the purpose of reducing the effect of instrument compliance for the low temperature DSR testing;
- Implement a data pre-processing method based on the free volume theory for the modulus results measurements obtained by DSR below the glass transition temperature T_g, while introducing a modulus shift factor b_T;
- Evaluate the effect of reduced short-term aging temperature on the rheological properties of asphalt binder under different aging conditions;
- Address the combined effect of aging temperature and experimental conditions, such as cooling medium and physical hardening (steric hardening), on the low temperature rheological properties of asphalt binders; and assess the possibility of using DSR to replace BBR at low temperatures.