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Mechanisms in Healing of Bitumen and the Impact of Normal Force

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Abstract Damage in pavements is known to reduce over time when the material is left to rest, this phenomenon is known as healing. It has been shown that healing is an important influence factor in pavement performance. However, an accepted method to assess the healing capability of a pavement is currently not available. Healing of cracks is assumed to be the sum of two processes, cracked surfaces coming into contact (wetting) and strength gain of surfaces in contact (intrinsic healing). The paper describes influencing parameters of these two processes. The healing potential of bitumen is assessed using a novel test method. In this method two pieces of bitumen are brought together and left to heal under controlled conditions. After healing the amount of healing is assessed by testing the specimens using a direct tensile test. From the results it can be seen that normal force has a significant impact on the observed healing, indicating that the process of two surfaces coming into contact (wetting) has a significant impact on healing behavior of the bitumen.

Keywords Healing test, Bitumen, Intrinsic healing, Wetting

1 Introduction

Asphalt concrete has the advantageous ability to heal. Measurements on asphalt concrete show a regain of strength and stiffness after rest periods. The phenomenon is called healing and was first described by (Bazin and Saunier 1967) and it is studied ever since. Almost all research shows that the level of healing increases with longer resting periods, higher healing temperatures (Bonnaure et al. 1982, Qui 2012). However, the mechanisms behind healing of asphalt are not fully understood, consequently many observed trends in healing behavior remain unexplained (Bhasin et al. 2008, Qui 2012). Fundamental understanding of the healing mechanism can be used to optimize the healing properties of asphalt to increase the performance of pavements.

This paper will continue by presenting a popular model for healing of asphalt, which separates observed healing in different processes. The model describes healing as the combination of surfaces coming into contact and the ability of surfaces in contact to transfer loads. Also influencing parameters for both processes will be described. Next, a novel test method is presented that aims to quantify the different healing processes. The paper presents some results obtained with this novel test method. After this implications of the test results are discussed in light of the presented model.

2 Healing Model

2.1 Conceptual Healing Model

In order to understand the mechanisms driving the healing process, researchers in asphalt have adopted the healing model used in polymers (Wool and O' Conner 1981, Bhasin et al. 2008). This model describes healing of cracks as the combined effect of two processes, which are schematically shown in Figure 1. Firstly, surfaces can only transfer loads if they are in contact. The process of two surfaces coming into close contact is referred to as *wetting*. Secondly, the ability of surfaces in contact to transfer loads changes over time. There is an initial ability to transfer loads from the moment of first contact based on adhesion (or cohesion as the two sides of the crack are of the same material). Subsequently, the load bearing capacity of the interface in contact, increases over time as molecules diffuse across the interface. This diffusion leads to full homogenization of the interfaces if time is infinite. This second process describing how load bearing capacity of the interfaces increases over time is named *intrinsic healing*.

Following the definition that intrinsic healing originates from molecular motion at the crack interface, is can be concluded that the level of intrinsic healing should not be affected by normal force (Wool and O’ Conner 1981).

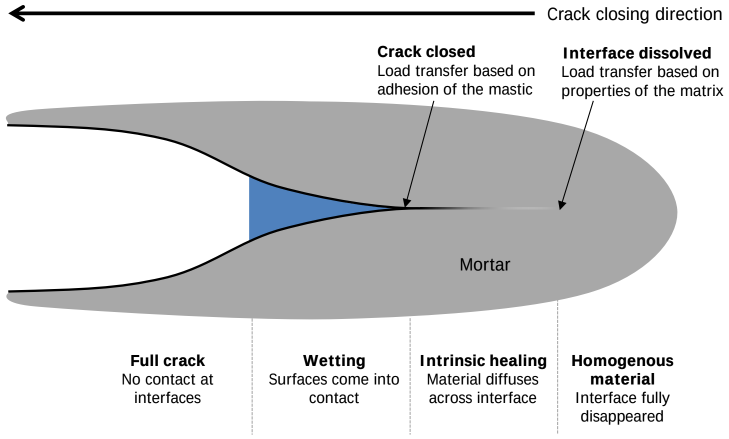

Fig. 1 Schematic representation of the closing of a crack

Figure 1 represents the healing of a single crack, however on a macroscopic level a multitude of surfaces are in different stages of wetting and each interface is in its own stage of intrinsic healing. Consequently the observed healing on a macroscopic level is the convolution of the wetted area and the load transfer ability over time.

Influencing factors of wetting are; the external load that brings the surfaces together; the geometry (roughness of the surface); the viscoelastic properties of the material and the adhesion of the material (Schapery 1989).

2.2 *Mathematical Healing Model*

The conceptual model described in the previous paragraph has a mathematical representation (1), also formulated by (Wool and O' Conner 1981). In order to address the regain of strength it uses a convolution integral to sum up the macroscopic healing based on all the separate areas that are healing.

$$R = \int_{\tau=-\infty}^{\tau=t} R_h(t-\tau)\frac{d\phi(\tau,X)}{d\tau}\,d\tau \tag{1}$$

In equation 1 R is the ratio of the healed performance compared to the original performance, it ranges from 0 to 1. The formula consists of a wetting function $\phi(\tau,X)$ and an intrinsic healing function R_h, τ is the running variable on the time axis.

The wetting function is expected to have a sigmoidal shape, based on the physical process which stands at its basis (Wool and O' Conner 1981). The intrinsic healing function is expected to have an initial level R_0 that originates from intermolecular forces, and a part related to diffusion over time which is expected to be a power function of time. A graphic overview of the mathematical model and the shape of the expected healing processes is presented in Figure 2.

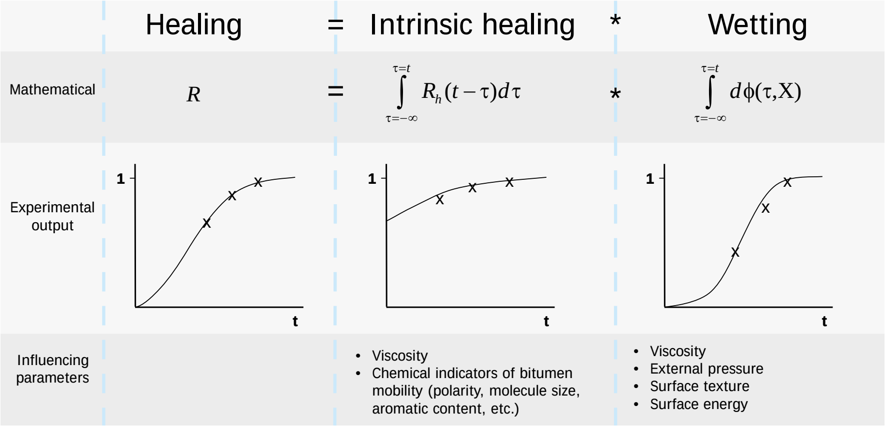

Fig. 2 Graphical overview of healing model

3 Direct Tensile Test to Asses Healing

To quantify the relative importance of the processes that play a role in healing, as described in the previous chapter, a novel test method has been developed to asses healing. The damage in asphalt concrete is assumed to be a (micro) discontinuity in the material. The design of the test method is aimed to investigate the most extreme version of a discontinuity; two separate pieces of bitumen. These two pieces of bitumen are brought together and after a period of healing, they are pulled apart again, testing the amount of tensile strength that has built up during the healing period. The global set-up of the test method is shown in Figure 3.

Special bitumen test samples are designed. A small piece of bitumen is cast inside a stainless steel ring, this ring enables handling and fixation during preparation and testing. The size and design of the ring and bitumen samples are shown in Figure 3 on the left. Two pieces of bitumen are brought together and left to heal for a specific amount of time while controlling temperature and the normal force perpendicular to the contact area. The contact area is controlled by a piece of silicon paper with a small hole of Ø5.5mm, which is placed in between the two bitumen samples. After healing, the specimens are tested in *direct tension* using a DSR equipped with a temperature chamber and a normal force load cell (Anton Paar, EC Twist 502).

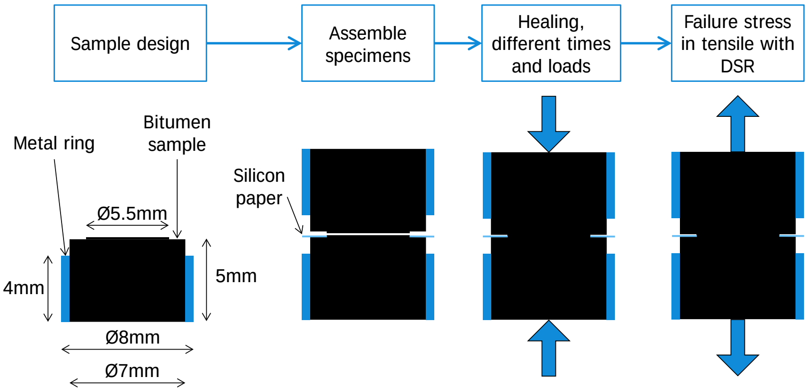

Fig. 3 Schematic impression of sample design, preparation and testing

4 Test Program and Results

Past research (Bazin and Saunier 1967) pointed towards normal force as an important factor for healing, this study aims to expand on this insight, by varying the normal force during healing to evaluate the impact on healing.

The samples are made of a relatively soft bitumen, pengrade 70/100, which is known to have good healing properties. Samples were left to heal for 1 hour, at a temperature of 13°C +/- 1°C. During healing five load levels were applied; 0.24 mN/mm^2, 0.65 mN/mm^2, 1.06 mN/mm^2, 4.36 mN/mm^2, 8.26 mN/mm^2. The smallest load level is the self-weight of the sample paced on top. The results are presented in Figure 4.

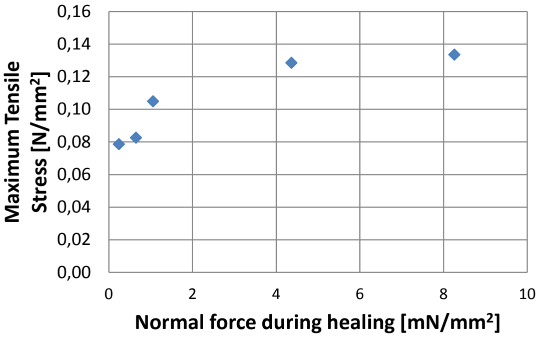

Fig. 4 Impact of normal force on the Maximum tensile stress

5 Discussion, Conclusion and Outlook

Figure 4 presents the maximum tensile stress after the healing period as an indicator for the amount of healing. From the graph it can be seen that up until a load level of 4.36 mN/mm^2 the amount of normal force has a significant impact on the amount of healing that is observed, increasing the observed healing up to 70%.

Following the definitions of intrinsic healing and wetting presented in the chapter 2 of this paper, wetting is influenced by the load level, while intrinsic healing is not, as the latter is governed by diffusion. The clear impact of the load level on the observed healing demonstrates the large influence of the wetting process in these short time frames.

If the presented result is extrapolated to asphalt, it is likely that the stress state during healing of asphalt is of significant importance for the observed healing.

The test method and program presented in this paper are the start of a larger investigation into healing of bitumen and mortaric, which aims to improve fundamental insight into healing behavior of asphalt. A large tests program is foreseen to explore the relative impact of wetting and healing. In this test program healing conditions such as temperature, time and load level will be varied, also different types of bitumen and mortar will be tested.

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