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Behaviour of asphalt concrete mixtures under tri-axial compression

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HIGHLIGHTS

- The triaxial tests were done under representative realistic stress conditions in the field.
- Porous asphalt strongly shows properties of frictional granular material at high temperature.
- The critical failure envelope of DAC highly depends on the strain rate.

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ABSTRACT

The mechanical behaviour of asphalt concrete is highly dependent on traffic loadings and environment conditions. Its compressive strength is sensitive to strain rate, temperature, as well as confining pressure. The influence of the confining pressure becomes more significant during the summer season due to the decrease of the viscosity of the bituminous binder which makes that the asphalt material tends to react more like an unbound granular material. This paper presents the results of an investigation into the effect of strain rate, temperature and confinement as determined on two different asphalt mixtures being dense and porous asphalt concrete. The results showed that the compressive strength and stiffness increased with a decreasing temperature, an increasing loading rate, and increasing confinement. The failure strength results of DAC in the $I_1 - \sqrt{J_2}$ space show a nonlinear failure envelope while the results of PAC show properties similar to frictional granular material. The investigation has shown that the critical failure envelope of DAC highly depends on the strain rate which is hardly the case for PAC.

1. Introduction

In order to be able to better predict the performance of pavements Mechanistic-Empirical Pavement Design systems (MEPDS) have been developed during the last decades. These systems require information about basic mechanical characteristics of the pavement materials as input parameters [1]. The mechanical behaviour of asphalt concrete is highly dependent on the magnitude of the traffic loadings, the rate at which they are applied and environmental conditions [2]. In order to be able to realistically correlate laboratory measurements to the behaviour of asphalt concrete in the field, it is important to conduct laboratory tests under stress, loading rate and temperature conditions similar to those in the field [3]. Although many efforts have been made to evaluate the material properties of asphalt concrete based on uniaxial compressive and tensile tests, there is still a strong need to conduct simple performance tests on asphalt concrete under more realistic multi-axial stress conditions which are similar to those in the field [4].

As mentioned earlier, the stress–strain behaviour of asphalt concrete mixtures under monotonic triaxial compressive conditions is sensitive to strain rate, temperature as well as confining pressure. The confining pressure becomes a critical factor to the mechanical performance especially at elevated temperatures, which occur in wearing courses during the summer season. The dramatic decrease in viscosity of the bituminous mortar at elevated temperatures results in a dangerous situation if the mixture is not “supported” by sufficient confinement. In this paper the stress conditions and loading rate at mid-depth of the asphalt wearing course were determined by means of layered elastic theory assuming a 50 kN wheel load and temperatures of 40 °C and 50 °C. Based on the calculation the impacts of temperature, loading rate and confinement on the compressive response of asphalt concrete were evaluated by means of tri-axial testing. Special attention was given to the evaluation of the dependency of strain rate on critical failure strength envelope in the $I_1 - \sqrt{J_2}$ space. It was found that the critical failure strength envelope of DAC greatly

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depends on loading rate which is much lesser than the case for PAC.

2. Materials and test design

In order to evaluate the stress–strain behaviour of asphalt concrete at elevated temperatures, two representative asphalt concrete wearing course mixtures were tested. One was dense asphalt concrete (DAC) in which the aggregate particles are continuously graded to form an interlocking structure. The other one was porous asphalt concrete (PAC) which is very commonly used on highways in the Netherlands to reduce traffic noise and splash and spray during wet weather conditions. It was decided to copy the mixtures that were extensively tested earlier by Muraya [5]. He used monotonic tension and unconfined compression tests in his research into the permanent deformation behaviour of asphalt mixtures. In this paper a triaxial compression testing program for DAC and PAC was designed at a variety of combinations of loading rates and temperatures. In this way a more complete database on the failure characteristics of these mixtures at elevated temperatures can be established. Prior to the introduction of mixture design and test setup, the method used to determine the test conditions is firstly described hereafter.

2.1. Determination of test conditions

In order to obtain realistic test conditions, the stress conditions in two heavy duty asphalt pavements were analysed. The analysed pavement structures were tested in the Rail and Road Research Laboratory research project on permanent deformation. In this project the Delft University's accelerated pavement testing (APT) device called LINTRACK was used. The pavements for which the stress analyses were made are shown in Table 1. The analyses were done for a 50 kN wheel load with a circular contact area, with a radius of 123 mm, moving at a speed of 20 km/h at temperatures of 40 °C and 50 °C (estimated average temperatures in the wearing courses).

The fact that asphalt mixtures exhibit a stress dependent behaviour at elevated temperatures was clearly shown by an extensive research program which was reported in [6].An example of the results reported there is given in Fig. 1.

The stress dependency can be written as follows:

Table 1
Layers of DAC and PAC sections.

<table>
<tr><td>40 mm DAC 45/60[a]</td><td>50 mm PAC 70/100</td></tr>
<tr><td>60 mm OAC</td><td>60 mm STAC0</td></tr>
<tr><td colspan="2">80 mm STAC1</td></tr>
<tr><td colspan="2">90 mm STAC2</td></tr>
<tr><td colspan="2">250 mm AGRAC</td></tr>
<tr><td colspan="2">Compacted sand subbase</td></tr>
</table>

Note: OAC – open asphaltic concrete layer, STAC1–STAC2 – stone asphaltic concrete layer, AGRAC – asphalt granulate cement layer.

[a] Bitumen pen grading.

$$M_r = \begin{cases} k_1\left(\frac{\sigma_3+k_3}{\sigma_{3_0}}\right)^{k_2}, & \sigma_3 > -k_3 \\ 0, & \sigma_3 \leqslant -k_3 \end{cases} \tag{1}$$

where $M_r = 0$ if $\sigma_3 \leqslant -k_3$; σ_3 = confining pressure (kPa); σ_{3_0} = reference pressure = 1 kPa; k_1, k_2, k_3 = model parameters.

The computer program BISAR, developed by Shell [7], was used to calculate the stresses and strains at mid-depth (20 mm from surface for DAC, 25 mm for PAC) of the bituminous wearing course. Although this program assumes linear elasticity of all layers, stress dependent behaviour of the asphalt materials at elevated temperature could be simulated by dividing the structure in a large amount of sublayers and assigning a modulus to each of the sublayers based on the prevailing stress conditions [8]. In these calculations initial moduli were assumed as starting values and in iterative process calculations were repeated until the change in moduli was less than 5% [9,10].

In this study the profile of maximum principle stress was fitted by means of a haversine function from which the duration of a loading pulse was determined [11]. The strain rates were calculated from the change in strain in interval 1–3 of the principle strain profile and the assumed vehicle speed. Figs. 2 and 3 show the profiles of the principle stress and strain at mid-depth of the DAC layer at 40 °C.

Table 2 shows the representative strain rates at mid-depth of the DAC and PAC layers. It can be seen that the highest strain rate occurs near the edge of the load. This is also the location where the highest shear stresses will occur.

Permanent deformation in asphalt concrete is caused by a combination of densification, viscous flow of the bituminous binder and plastic deformation of the skeleton. In well-compacted asphalt layers, densification should not play a significant role [12]. In that case the high shear stress at the edge of the load accumulates permanent deformation due to viscous flow and plastic deformation in the pavement layer. In this study the representative confining pressures were selected at the edge of the load where the confining pressure sharply varies from around 100 kPa to 200 kPa.

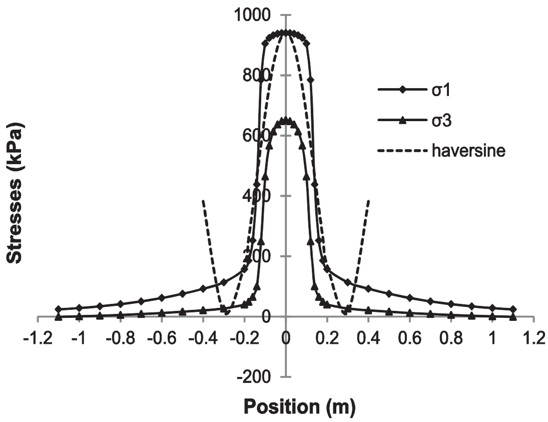

Fig. 2. Illustration of profile of principle stresses of DAC at 40 °C.

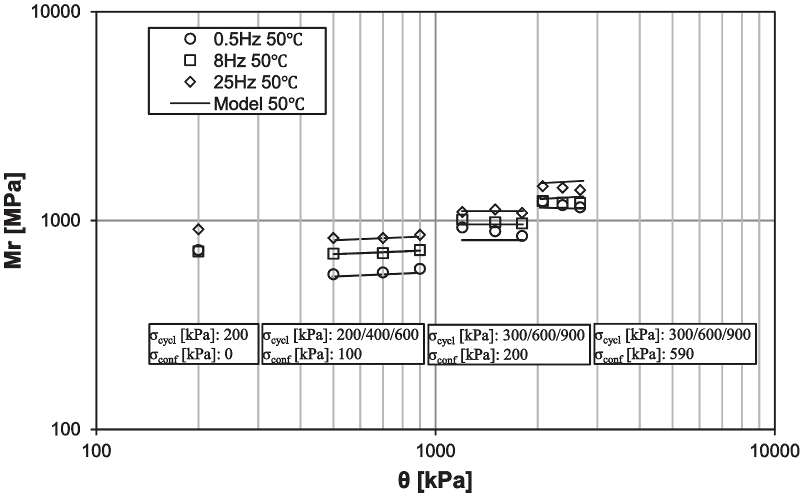

Fig. 1. The stress dependency of resilient modulus of DAC at 40 °C (after Antes, P.W., 2002).