Asphalt Concrete Rutting Response: A matter of dimensions?

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Summary

In this paper experiences and questions related to the use of the conventional triaxial compression test to assess the rutting resistance of asphalt concrete (AC) are presented. As such, it summarizes past experiences and presents a new, elaborate project intended to address several remaining questions by a combined experimental and analytical/numerical approach.

Introduction

The response of asphalt concrete (AC) depends on many variables. Such as the state of stress to which the material is subjected, the temperature and strain rate. All in all, the material behavior is rather complex which makes it hard to model pavement response accurately. However, there is a worldwide movement to allot more responsibility to contractors via design & build and design, build & maintenance contracts. In order to provide a useful and workable framework of specifications, the requirements need to be functional or performance based rather than empirical and recipe based as is now most of the time the case.

Current specifications are based empirical relations between lab results and field behavior. For example, the requirements for the Marshall stability and flow (i.e. indications of the strength and resistance to permanent deformation) are not based on a direct relation between what is tested and a failure mechanism in a pavement, but rather on the experience that mixtures of a given type with Marshall properties in a particular range usually perform reasonably well in a pavement. Due to the lack of a direct or functional relation between what is tested in the laboratory and what happens in a pavement, a similar criterion for an innovative asphalt mixture can be derived only after years of application in the field.

Even when materials prove to function well in test sections, they often do not fit within the existing criteria, which hinders their application. An example is the performance of asphalt mixtures with modified binders in the Marshall test. These materials often do not reach their peak in this test, rendering the parameters obtained unusable [1]. An example is Figure 1. On the left the results of a mixture with conventional bitumen is shown, and on the left the same mixture with SBS-modified bitumen. It can clearly be seen that the modified material has not reached its peak in any of the four tests.

Another example is the introduction of Porous Asphalt and Stone Matrix Asphalt. These mixtures are now well known for their good resistance to

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permanent deformation in the field, yet they did not meet the permanent deformation resistance requirements for normal wearing courses like dense asphalt concrete.
For these reasons, there are many attempts to move towards pavement performance criteria that address specific damage mechanisms via laboratory tests. This will allow new materials to be evaluated directly in the laboratory.

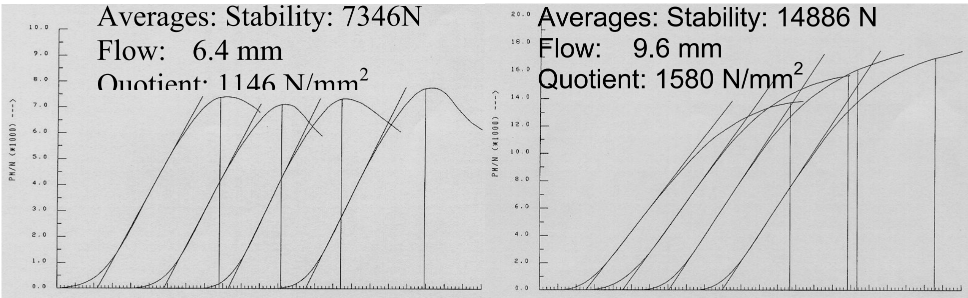

Figure 1: Marshall test results of modified mixes do not fit the standard

Rutting resistance in the European Standard

The European Standard (prEN 12697) that is currently under development will be ready for implementation early 2007. For rutting resistance, besides the wheel tracking test also the cyclic conventional triaxial compression (CTC) test will be incorporated as a means to asses the rutting resistance of a pavement mixture.

Results from numerical simulations of an asphalt concrete pavement of 150mm thickness and a stiffness of 3000 MPa subjected to repeated loads are shown in Figure 2 [2]. The pictures show a cross section of the width of the road. An actual pavement, including base and sub base, was modeled, but in the pictures only the area near the load is shown. In all the pictures, the left-hand side is an axis of symmetry, so both the load and the damage pattern are mirrored on the left side of this edge. The location of the load (r=150 mm) is marked by arrows in the top pictures. The gray areas in the graphs indicate the damage patterns that develop over the height and width of the pavement, the scale is shown on the right hand side of the graph. The load used in the simulation is a repeated FWD pulse on the same location and from top to bottom the damage development after 25000, 50000 and 75000 load repetitions is shown. The three columns of pictures each show a different representation of the damage in the pavement. The left-hand column shows the volumetric damage (volume change, related to hydrostatic stress, p), the central column shows the deviatoric damage (shape change, related to the deviator stresses, q) and, finally, the column on the right shows the total damage (combined volumetric and deviatoric damage). These different types of damage are used to explain the kind of damage that they represent in a pavement.

Two areas of volumetric damage concentration can be identified (pictures on the left). One is located directly under the load and another at the edge of the loaded area, where curvature reversal occurs. In the first case, the nature of volumetric damage is compressive indicating the gradual development of permanent deformation (commonly classified as rutting). In the second case, the nature of volumetric damage is tensile indicating the gradual development of a crack at the top of the pavement.

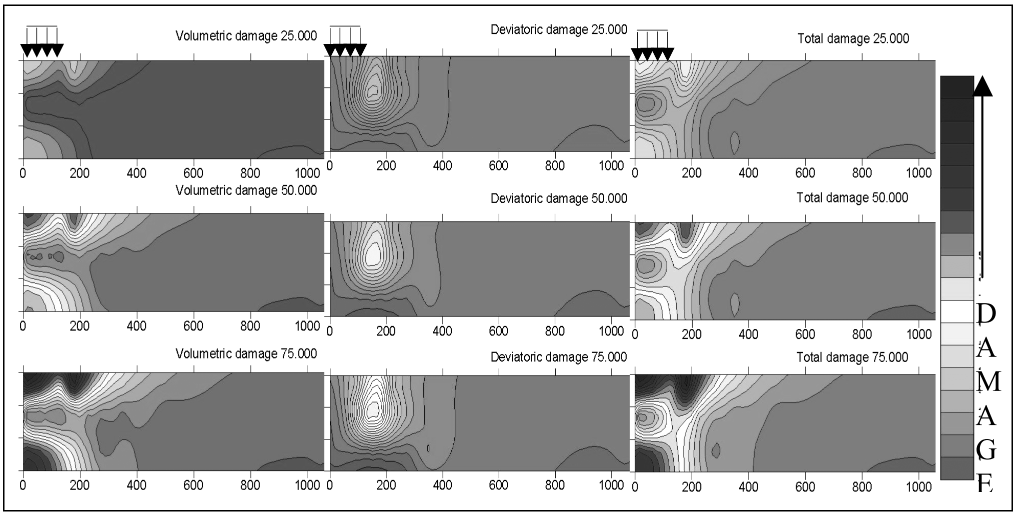

Figure 2: Development of damage in pavement top layers

Deviatoric damage was initiated in the region near the periphery of the loaded area and spreads gradually towards the top and the bottom surfaces of the asphalt layer (pictures in the middle). Finally, the pictures on the right show the development and the extent of total damage (combination of volumetric and deviatoric damage). Combining the information of this figure with the individual components of damage discussed in the above, it can be concluded that in this pavement a surface crack appears to be developing near the edge of the loaded area where the curvature reversal occurs. The tensile volumetric damage at the top indicates that the crack opens in mode I (pure tension), but it propagates downwards in a combination of Mode I and II (tension & shear). At the same time, rutting type damage occurs at the center of the loaded region.

From the above results it can be seen that triaxial compression under the wheel causes volumetric compression while high shear directly beside the wheel causes shape distortion. Together, this yields the typical rutting profile observed in pavements. Clearly, the shear (tension-compression) state of stress cannot be captured in a Conventional Triaxial Compression test. What is simulated in this test is, therefore, the material response to triaxial compression, as it occurs directly underneath a passing wheel.

Ranking mixtures using Conventional Triaxial Compression test results

As mentioned in the previous section, it has been shown that in general the permanent deformation response of a material in the CTC test is generally quite consistent ([3], Figure 3).

$$p = (\sigma_v + 2 \cdot \sigma_c)/3 \qquad (1)$$

$$q = (\sigma_v - \sigma_c) \qquad (2)$$

with: p= maximum hydrostatic stress (MPa)

q= maximum deviator stress (MPa)

σ_v= maximum vertical stress (= σ_{vcycl} + σ_c, with σ_{vcycl} the maximum vertical cyclic load) (MPa)

σ_c= constant confinement(MPa)

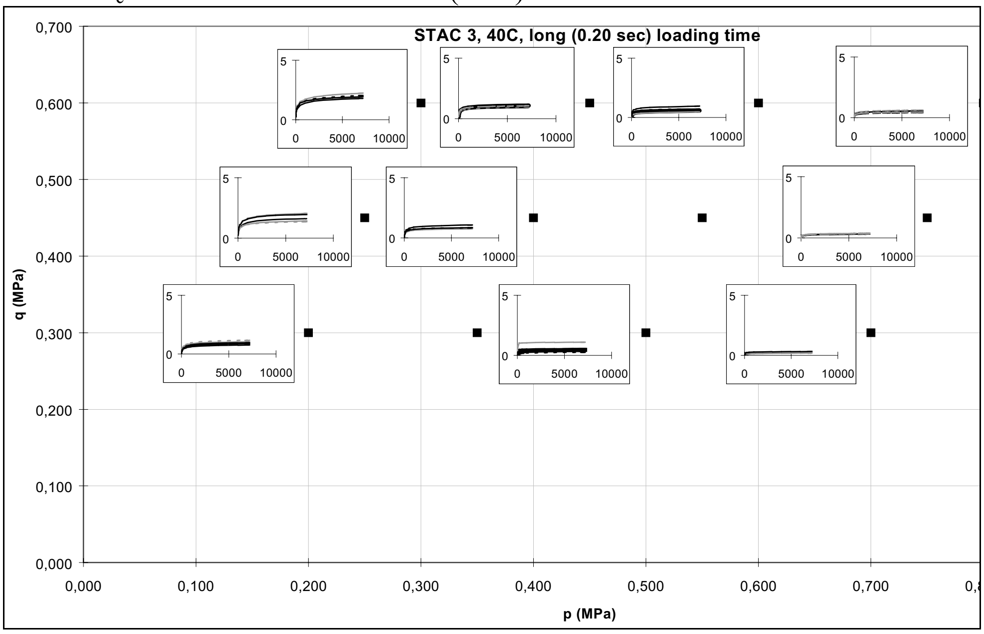

Figure 3: Permanent deformation of an SMA as a function of p-q

However, when comparing mixtures the ranking obtained from CTC tests in the above mentioned research was not always consistent with that observed in the accelerated pavement tests. Additional research is currently underway to explain the differences that were found. It is assumed that there are several mechanisms that can lead to rutting in a pavement and not all (aspects) of them are covered in the CTC test. This is based on the fact that for some mixtures at high p and q values a sudden decrease in resistance against permanent deformation was observed. This might be the result of the mixture getting over-filled due to the high triaxial confinement. In the past it was also found that for high confinements the obtained ranking followed the expected pattern, while the ranking for lower confinement levels was different. In the first case low dilatancy was observed, while in the second situation a highly dilatant response was found. Since the friction reduction system used in CTC testing in the Netherlands was improved significantly since these tests were run [4, 5], it is not possible to relate these results to the current situation.

Prediction of rut depth using CTC test results

As mentioned in Section 2.1, attempts to predict rut depths on the basis of Conventional Triaxial Compression (CTC) test results have so far not been successful, because they result in rut depths that are an order of magnitude smaller than those observed in pavement structures. There are, according to the authors, several possible explanations for this misfit:

1. The CTC tests that were used did not capture (all) the mechanism(s) that control(s) rutting in pavements, for example:
   a) Principal stresses in a point in a pavement not only change in magnitude but also in direction (rotate, see Figure 4) due to a passing wheel.

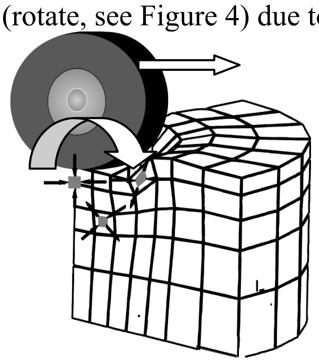

Figure 4: Rotation of principal stresses due to a wheel load

This rotation my lead to a kneading effect that will prevent the aggregates from reaching an optimal packing, as might be the case in CTC tests. Rotation of stresses also moves the material to different regions of strength and stiffness (different stress states) resulting thus to earlier degradation than a CTC test would predict.

   b) Conditions used in the test may lead to the dilatant mechanism (mentioned in the previous section), rather than the compressive one. Alternatively, high p's and q's may give rise to rutting due to over-filled mixtures

2. The multi-layer analyses (MLA) used do not accurately describe the structure, since material properties in it are constant in the horizontal direction. The material is modeled as a metal, with the same response in tension and compression. In reality, the response will vary both in the horizontal direction and, for a given point in the pavement, in time due to a passing wheel.

The above issues will be addressed by an elaborate combination of experimental and analytical (constitutive)-numerical work that is currently under way. The first point will be investigated by running tests on a series of mixtures with a known permanent deformation behavior. The conditions for the tests will be selected such that they address the possible mechanisms by complementing the information obtained from previous work [3].

Point 2a, will be addressed by performing rut depth calculations using programs that do allow variation of material response from point to point (e.g. Finite Element Method (FEM)). The Finite Elements code CAPA-3D could be used for this, since it incorporates both a 3D visco-elastic model [6] and an elastic, visco-plastic, fracturing model (the ACRe model, [2, 4]).

Conclusions and recommendations

The European Standard for Asphalt concrete will use CTC tests to assess the resistance of a mixture to rutting. Elaborate CTC test programs carried out in the Netherlands show that the ranking from CTC tests sometimes deviates from that in accelerated pavement tests. This might be due to the existence of various rutting mechanisms that are not all captured in the current CTC test conditions.

Rut depth predictions on the basis of parameters from CTC test have so far not been successful. Several possible explanations along with ways to verify them are presented in this paper.

It is stressed that confinement sensitivity is a crucial aspect of AC response, which is an important reason to move towards CTC testing. To fully exploit the possibilities of such tests, modeling of pavement behavior on the basis of the test results should also take all three dimensions into account.

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