MULTI-SCALE MODEL FOR LOW-TEMPERATURE CREEP OF ASPHALT

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Summary Macroscopic material properties of asphalt are related to finer-scale information by means of a multi-scale model consisting of five observation scales. Having identified the different constituents (material phases) and their assemblages at the scales introduced within the multi-scale model, we present recent results on up-scaling information from the *mastic*-scale to the next higher, i.e., the *mortar*-scale focusing on the influence of the filler (aggregates with diameter smaller than 125 μm) on low-temperature creep. The Mori-Tanaka scheme is chosen to incorporate the effect of aggregates embedded in the viscous bituminous matrix. The good agreement between the material properties obtained via homogenization and the respective experimental results suggests that only the volume content of the filler affects the creep properties of the mastic material, explaining phenomena and problems recently encountered in asphalt pavement engineering.

INTRODUCTION AND MOTIVATION

Asphalt is composed of bitumen, aggregate, and air voids, showing a complex thermo-rheological behavior. E.g., the low viscosity of asphalt at high temperatures ($T > 135$ °C) is a necessary prerequisite during the construction and compaction process of high-quality asphalt layers. When the surface temperature reaches 70 °C during hot summer periods, however, this viscosity should be significantly higher in order to minimize the development of permanent deformations (rutting, see Figure 1). The desirable decrease of viscosity and, hence, increase of stiffness with decreasing temperature at hot and

Figure 1. Damage of flexible pavements by rutting (left) and fatique failure (right)

medium temperatures (0 °C $< T <$ 70 °C) are, on the other hand, disadvantageous at low temperatures ($T <$ 0 °C), causing low-temperature cracking in asphalt pavements. This optimization problem concerning the behavior of asphalt at different temperature regimes is a main objective of the Christian Doppler Laboratory "Performance-Based Optimization of Flexible Road Pavements" (TU Wien), headed by Ronald Blab. For the optimization process of a multi-composed material such as asphalt, three different modes can be distinguished:

1. variation of mixture characteristics (e.g., binder/aggregate-ratio),
2. change of constituents used (e.g. different bitumen or filler type), and
3. allowance of additives (e.g., polymers to modify the bitumen).

MULTI-SCALE MODEL FOR ASPHALT

In order to account for the wide range of asphalt mixtures, resulting from the large number of different bitumen, fillers, and aggregates used in engineering practice, the multiscale concept is chosen for the determination of rheological properties of asphalt. Within the multiscale concept, four additional observation scales are introduced below the macroscale, namely (i) the *bitumen*-scale (asphaltene and maltene morphology), (ii) the *mastic*-scale (bitumen+filler), (iii) the *mortar*-scale (mastic + aggregate with < 2 mm), and (iv) the *asphalt*-scale (mortar + aggregate with > 2 mm), see Figure 2. Within each observation scale, the characteristics (such as structure and material properties) of the constituents present at this scale can be considered.

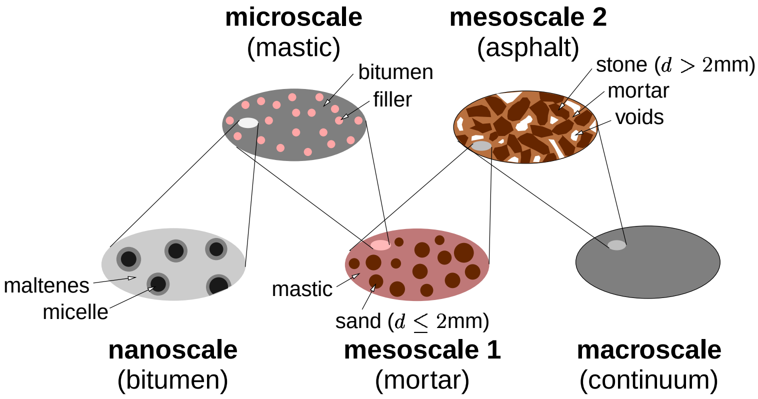

Figure 2. Multi-scale model for asphalt incorporating five scales of observation

LOW-TEMPERATURE CREEP – RESULTS AND CONCLUSIONS

The high viscosity of bitumen at low temperatures and, hence, the reduced capability of stress relaxation cause an increased loading during cold-temperature periods in consequence of both thermal strains and traffic loads. In order to improve the low-temperature behavior of asphalt and, hence, to avoid damage of the infrastructure, a multi-scale model is proposed, allowing to predict low-temperature viscous properties of asphalt at different scales of observation. Bending-beam-rheometer (BBR) experiments [3] were conducted on pure bitumen and mastic material, considering five different types of bitumen (characterized by a penetration depth [1/10 mm] [3] ranging for 10 to 220) and six different types of filler. While the temperature dependence of low-temperature creep is incorporated in the bitumen phase only, employing an Arrhenius-type law, the Mori-Tanaka scheme [2] together with the effective volume fraction for the filler (see, e.g., [1]) is used for consideration of the effect of the filler. Even though fillers characterized by a variation of the air-void content (obtained from Ridgen device) by the factor of two (30 vol-% for the limestone-dust filler and 64 vol-% for the hydrated-lime filler), the creep properties predicted by the multi-scale model are in good agreement with the respective BBR results. This is illustrated in Figure 3, showing selected results for the initial rate of the creep compliance obtained from BBR data of mastic with limestone-dust and hydrated-lime filler. The obtained results suggest that (i) the influence

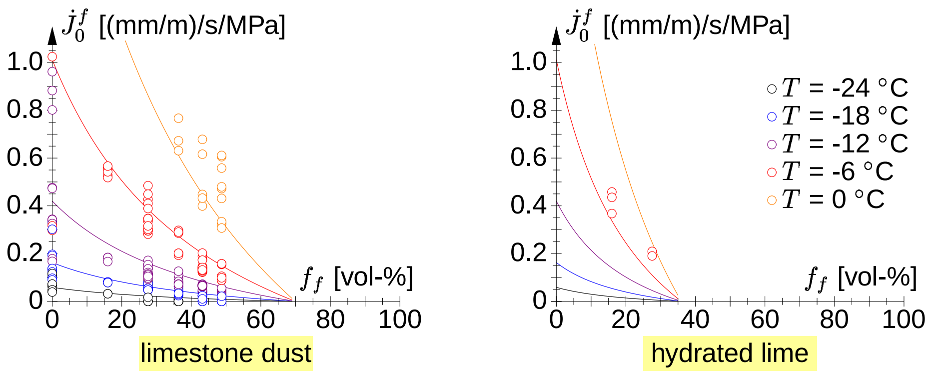

Figure 3. Initial rate of creep compliance for mastic with different filler content (experiments: circles; predicted by multi-scale model: lines)

of the type of bitumen on the viscous behavior of the mastic is marginal and (ii) the filler acts only by the its volume fraction; as a consequence of the good performance of the employed homogenization scheme which uses only the volume content as input, neither shape and grain-size distribution nor chemical composition of the filler affect the overall creep properties of asphalt.

Although the work presented inhere focussed on lower-scale properties, proposing an up-scaling technique from the *mastic*- to the *mortar*-scale, the gained information already allows to explain phenomena and problems recently encountered in asphalt pavement engineering.

References

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