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DEVELOPMENT OF A COMBINED MICROMECHANICS & DAMAGE MECHANICS MODEL FOR THE DESIGN OF ASPHALT PAVEMENTS

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ABSTRACT

Asphalt is a complex, heterogeneous material that is composed of differently sized aggregates, binder and air voids: in other words, it is a particulate reinforced composite. The focus of the present work is to investigate the structural effectiveness of this material composition following the introduction of recycled asphalt pavement (RAP) into the mix. The virgin mortar mix (i.e., matrix) consists of an asphalt binder, sand and crushed rock fines (CRF), while the RAP-containing mix additionally includes fine aggregates ranging in size from fine dust ($\leq 75\mu\text{m}$ diameter) up to small particles ($\leq 3.35\text{mm}$ diameter). The stress distribution throughout such a material and the resulting mechanical response is strongly related to the interaction between the mix constituents. Previous work has shown that this performance is less influenced by the presence of larger aggregate than it is by the mortar composition and it is for this reason that the present work attempts to model damage evolution in various mortar mixes.

EXPERIMENTAL

A special laboratory procedure similar to [1] has been adopted to obtain material parameters required for simulation of asphalt pavement behaviour subjected to the Indirect Tensile Test (ITT). Also, a digital image mapping technique was employed to obtain graphical representation of the material mix: the specimens were cut in multiple horizontal plane cross sections using a circular masonry saw. The cut sections were dried and digitised using a desktop scanner. Subsequently, a series of greyscale images were imported into a graphical package and the edges of large stone aggregates were mapped as shown in Fig. 1 b). After the aggregates were mapped, a sieving algorithm was used to digitally remove all objects smaller than 3.35mm in diameter. The remaining surfaces were scaled and imported into ABAQUS CAE (see Fig. 1 d).

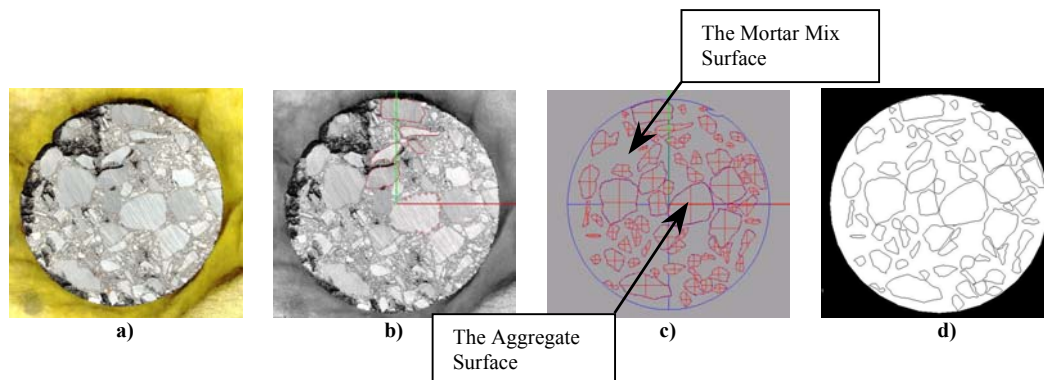


Fig. 1: Two-dimensional digital image processing. a) Scanned image of the cut specimen; b) mapping of the stone aggregates; c) created surface large aggregates and mortar mix; d) ABAQUS CAE 2D representation of the binder course asphalt pavement mix

COMPUTATIONAL

The composite behaviour was simulated by developing a micromechanics damage model in which the constitutive law has the form $\sigma = (1 - \omega)D\varepsilon = (1 - \omega)\bar{\sigma}$ where D is the elastic material stiffness matrix, ε is strain, $\bar{\sigma}$ is effective stress and ω is a scalar quantity corresponding to the amount of localised damage. Following the damage model developed by Mazars [2] for concrete analysis, two damage parameters are

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introduced in the model, ω_t and ω_c , the first of which is identified from uni-axial tensile tests and the latter from compression tests. For general stress states, the value of ω is obtained as a linear combination of these, i.e., $\omega = \alpha_t \omega_t + \alpha_c \omega_c$, where the coefficients α_t and α_c account for the character of the stress state. The damage model was implemented within the ABAQUS finite element code using a UMAT subroutine which calculates whether the local stress state exists within a linear loading regime ($\varepsilon \leq \varepsilon_0$), one close to a failure level ($\varepsilon_0 < \varepsilon \leq \varepsilon_1$) or in a viscoelastic softening regime ($\varepsilon > \varepsilon_1$), as is shown schematically in Fig. 2.

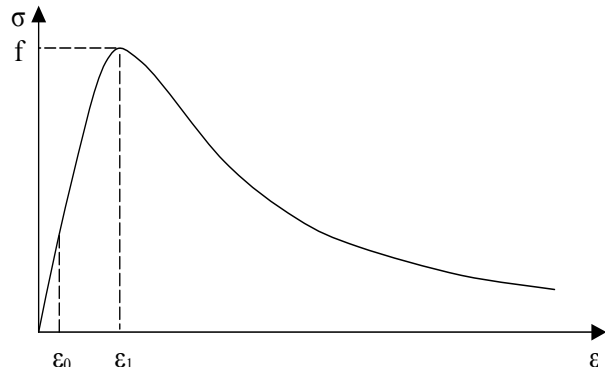


Fig. 2: Constitutive damage model.

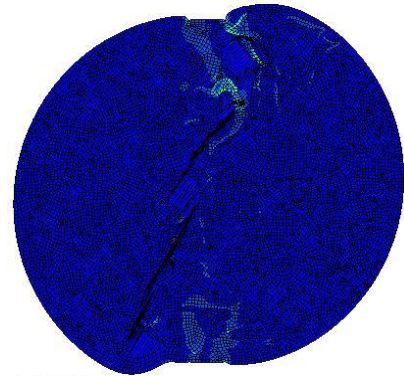


Fig. 3: Predicted damage in ITT mortar sample

The model accounts for the initiation and evolution of damage and is easily implemented in existing FE codes and only modest computational effort is required in addition to the usual elastic analysis. This model is suitable for the study of quasi-static problems where monotonically increasing loads are applied. Numerical predictions of damage and failure agree well with experiments, as illustrated in Fig. 3 using the Indirect Tensile Test (ITT).

CONCLUSIONS

A damage mechanics model has been developed in order to compare the behaviour of RAP-containing mortar with virgin mortar and to properly predict the post-failure softening response of such particulate-reinforced composites. The damage model developed successfully predicts quasi-static monotonic behaviour of mortar mixes within a binder course mix. However, if it is desired to simulate problems involving cyclic or dynamic loads, it would be necessary to formulate alternative damage models such as [3] or [4], which are capable of accounting for the recovery of stiffness and rate dependent effects. Future work will use this current model to characterise the performance of mortar containing varying compositions of RAP: this will form the basis of a subsequent publication.

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