STUDY OF MICROSTRUCTURAL FINITE ELEMENT MODELLING OF ASPHALT MIXTURE

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ABSTRACT

A digital image processing technique was applied to convert Computerised Tomography (CT) images into a digital format that can be incorporated into finite element modelling. CT discrimination based on finite element modelling is used to analyse the mechanical behaviour of asphalt mixture with an indirect tensile test by taking into account the actual heterogeneity and microstructures, especially air void distribution. It is pointed out that the material heterogeneity and air void distributions have significant effects on the tensile stress distribution along the loading directions of the specimen in this paper. The results indicate that the proposed method can be extended to the numerical simulations of the micromechanical behaviour of asphalt concrete with viscoelastic and fracture mechanics.

Keywords: asphalt mixtures; CT discrimination; finite element method; digital image process; micromechanics behaviour

1. INTRODUCTION

Asphalt mixture is composed of aggregates, asphalt binders and air voids. The volumetric properties of the three components and the viscoelasticity of asphalt cause the complexity of asphalt mixture’s mechanical behaviour. However, the variations in vehicle speed, axle weight and environmental conditions of actual asphalt pavement directly exacerbate the complexity of the behaviour.

Recently, a technique known as “computer-aided virtual experiment” has been attracting growing interest by mechanics researchers. It is considered to be a promising technique to reveal the complex mechanical behaviour of asphalt mixture (Masad, 2002). The computer-aided virtual experiment technique for asphalt mixture mainly includes digital image processing, self-adapting meshing and finite element analysis. Digital image processing is used to acquire digital images of the asphalt mixture (Zhang Xiao-ning, 2002) and the self-adapting meshing technique is used for pre-processing prior to finite element modelling. A non-linear finite element analysis (FEA) of the asphalt mixture can then be done taking into consideration the viscoelastic property using FEA software such as ABAQUS, ANSYS, and FRACE2D, etc. (Masad, 2002).

Conventional finite element analyses of asphalt mixtures mainly focus on the analysis of the influence of aggregate shape, distribution and gradation on the mechanical performance of asphalt mixtures. However, few analyses have been done taking into consideration air voids and their distribution, which are believed to be important factors influencing mechanical performance of asphalt mixtures. The main reason is the limitation of common digital image-acquisition methods. Scanners and digital cameras have been widely used in conventional image acquisition, but the images acquired in these ways are unable to identify the air voids and asphalt mastic from the colours of the images. Computerised Tomography (CT) is considered to be an effective imaging method to overcome this limitation (Yue Q. Z. Q., 2003; Li Xiaojun, 2000). With the CT image and digital imaging processing techniques, the three volumetric compositions of asphalt mixtures (namely aggregate, asphalt binder and air voids) can easily be identified. In this study the finite element model of asphalt mixtures was established taking into consideration the air voids, and then the indirect tensile test was simulated.

2. PRINCIPLE OF DIGITAL IMAGE PROCESSING WITH CT

Computerised Tomography (CT) imaging, also known as “CAT scanning” (Computerised Axial Tomography) provides a detailed cross-section of various objects. The CAT scan combines the use of a digital computer and a rotating X-ray device. The X-ray principle governs CT: as X-rays pass through the object, they are absorbed or weakened at different levels, creating a profile of X-rays of different strength. The differences in black, white and grey in the final image shows the different densities of the objects in a two-dimensional image. Figure 1 is a CT image acquired from a Marshall specimen. The whiter areas are aggregates, the grey areas are asphalt mastics and the black areas are air voids. The different grey scales in the CT image made it possible to apply the digital image processing technique for identifying the three volumetric compositions in asphalt mixtures.

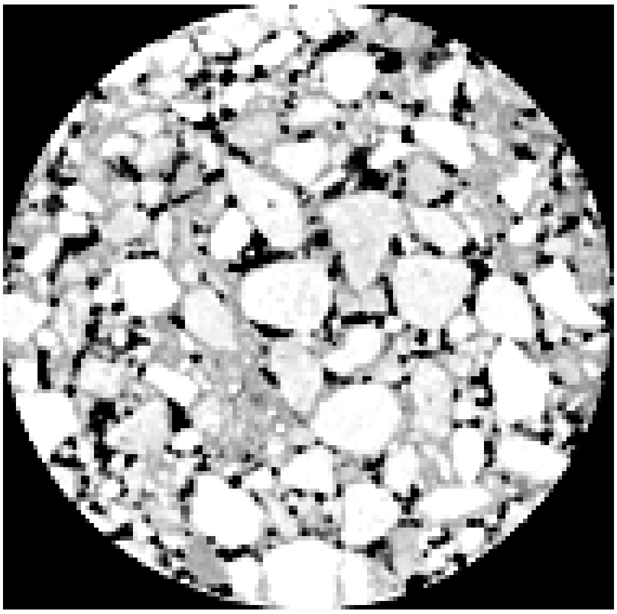

Figure 1. CT image of an asphalt mixture.

The digital conversion of CT images must be done before the finite element analysis. The steps of digital conversion of a CT image of an asphalt mixture are as follows:

1. Acquire the CT image of the asphalt mixture by CT scanning.
2. Decide on the division value T_1 to identify the asphalt mastic and air void, and T_2 to identify the asphalt mastic and aggregate.
3. Apply the computer-aided identification technique to identify the borders of asphalt mastics, air voids and aggregates.
4. Measure the real specimen size, and then convert the pixel coordinate into the real size coordinate.
5. Use the closed polygons to represent the air voids and aggregates, and convert the polygon model into a CAD file. A CAD picture of Figure 1 is shown in Figure 2.
6. Apply the self-adapting meshing technique to mesh the polygon model. The meshed model is shown in Figure 3.

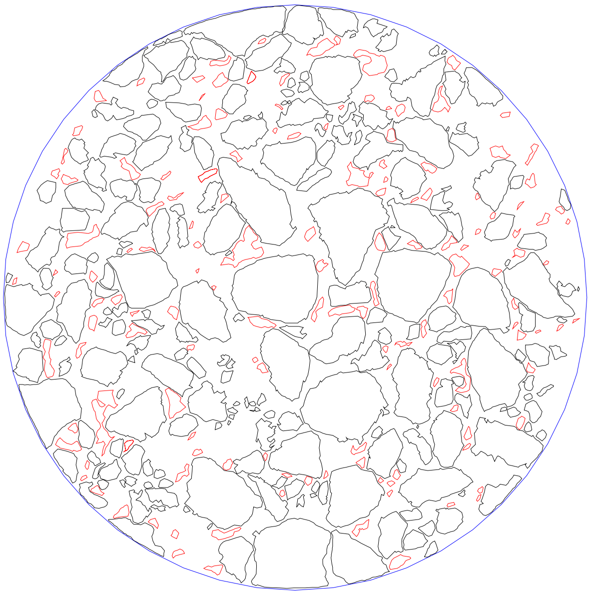

Figure 2. CAD image of a polygon model.

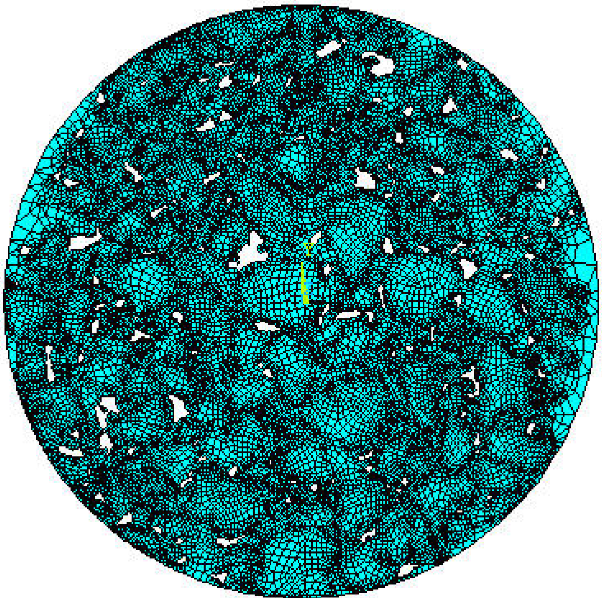

Figure 3. Digital model after self-adapting meshing.

3. FINITE ELEMENT ANALYSIS OF ASPHALT MIXTURE

An indirect tensile virtual experiment was simulated with the digital model after self-adapting meshing. The digital model for finite element analysis had 30 143 meshes and 93 222 nodes in total. The diameter of the specimen was 101.63 mm. A constant radial deflection with 0.5 mm on the top of the specimen was applied. Two loading directions (shown in Figure 4) were simulated in order to study the anisotropy of the asphalt mixture. The finite element analysis was conducted with the following assumptions: the asphalt mastic and aggregate were both considered as linear elastic bodies; the modulus of the aggregate was E_a = 15 000 MPa; Poisson's ratio was set at 0.3. The mechanical behaviour with different modulus ratios of aggregate-to-asphalt mastic were also studied - the ratio values were $\lambda = 1$， 10， 30 and 100 respectively. During analysis of the results, compression stress was set at a positive value and tension stress was set as a negative.

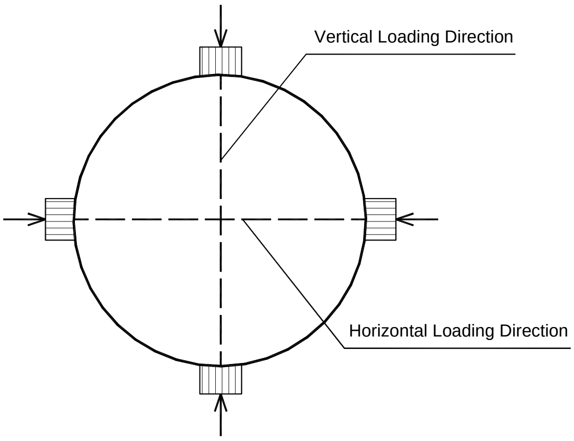

Figure 4. Loading directions applied in the finite element analysis.

3.1 Influence of Air Void Distribution on the Mechanical Behaviour of Asphalt Mixture

In order to study the influence of air void distribution on the mechanical behaviour of asphalt mixture, finite element analysis with a modulus ratio of λ = 1 was conducted. A cylinder with no air voids and the same modulus and size was also analysed for comparison. Figure 5 gives the variation of stress along the two loading radial directions. The following conclusions can be drawn from Figure 5:

- Compared with the analysis results of the cylinder with no air voids, the non-uniform distribution of air voids has a great influence on the stress distribution of asphalt mixture.
- With the influence of air void distribution, the distribution principle of stress differs with different loading directions.
- There are stress concentrations that occur at the junctions of aggregates, asphalt mastics and air voids.
- The maximum stress lies in the interface of air void and aggregate particle and not the centre of the specimen, with the maximum stress value being even 3.25 times (horizontal loading) or 2.86 times (vertical loading) higher than the specimen with no air voids.

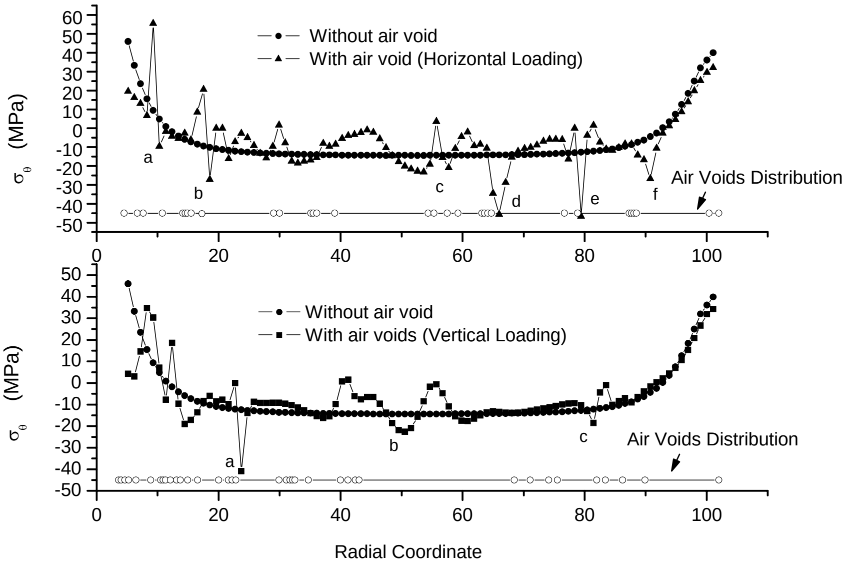

Figure 5. Stress distribution along different loading directions (λ = 1).

3.2 Influence of the Modulus Ratio Value Λ on the Mechanical Behaviour of Asphalt Mixture

In order to study the influence of the modulus ratio of aggregate-to-asphalt mastic on the mechanical behaviour of asphalt mixture, finite element analyses with modulus ratios λ =10, 30, and 100 were conducted. Figure 6 gives the variation of stress along the two loading radial directions. The following conclusions can be drawn from Figure 6:

- Asλ = 1, stress concentrations still occur at the junctions of aggregates, asphalt mastics and air voids whenλ = 10, 30 or 100.
- Changes in aggregate-to-asphalt modulus ratios only influence the value of the maximum stress, not the location of the maximum stress.
- With the same strain load, the stress in asphalt mixture decreases with the increase inλ.

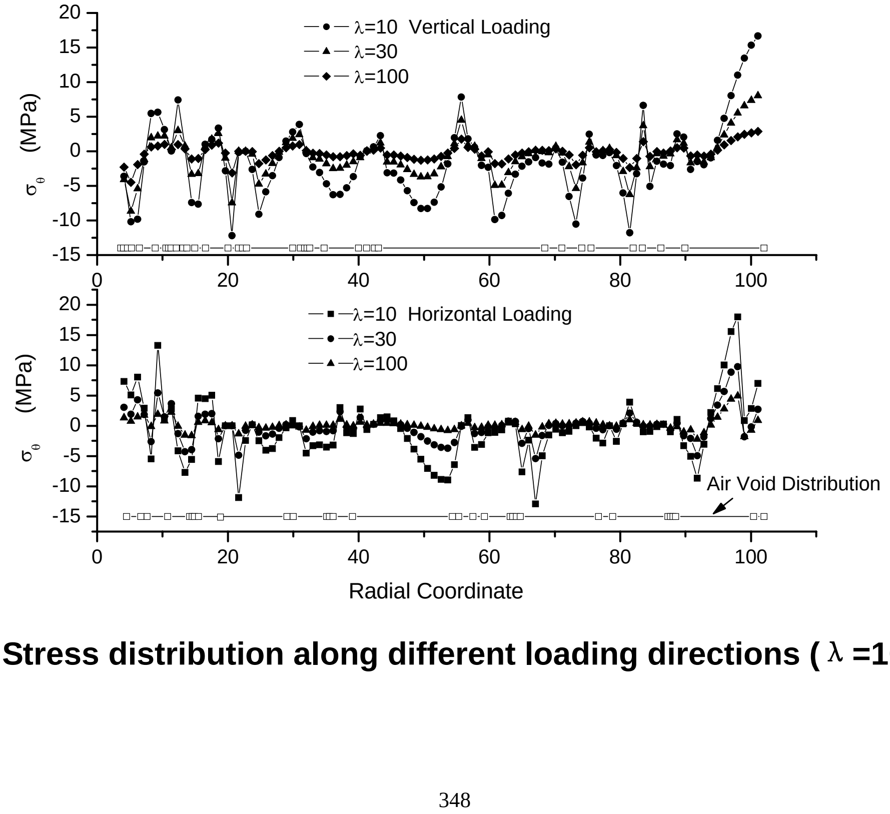

Figure 6. Stress distribution along different loading directions (λ =10, 30, 100).

4. CONCLUSIONS AND RECOMMENDATIONS

1. The digital structure of asphalt mixture with three compositions (aggregate, air void and asphalt mastic) can be modelled with CT image and digital image processing techniques.
2. Some new findings that differ from conventional views were obtained through the simulation of indirect tensile testing. Stress concentrations will occur at the junctions of aggregates, asphalt mastics and air voids, and the maximum stress location will be greatly influenced by the non-uniform air void distribution. This means that the position of the initial crack in the specimen during indirect tension may not occur at the centre of the specimen.
3. Combined with the theory of rheology, it is feasible to use the finite element model based on CT image and digital image processing techniques to study the viscoelastic property of asphalt mixture.

5. REFERENCES

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