Finite Element Modeling of Asphalt Mixture Based on Image Recognition

Yuejing Lv¹, Yunyun Jiang ¹∗ And Huan Wang¹
¹College of Automobile and Transportation Engineering, Wuhan University of Science and Technology, Wuhan, Hubei, 430000, China
∗Corresponding author’s e-mail: 1072328019@qq.com

Abstract. This study describes a method for establishing a mechanical model of heterogeneous finite element method. With the combination of digital image recognition technology and the theory of automatic mesh generation, it is possible to establish an inhomogeneous finite element model for mechanical calculation. Firstly, the micro-structure of the two-dimensional mixture is identified. Then all the boundary points are imported into ANSYS. Finally, the finite element mesh model of the micro-structure of the asphalt mixture is obtained by using the automatic finite element mesh generation technology. Taking Marshall specimen as an example, meshing the model proves that the method is feasible.

1. Introduction
Previous studies have assumed that asphalt mixture is a homogeneous material[1-2]. In fact, asphalt mixture consists of aggregate, asphalt mortar and pore. Conventional homogeneous finite element mechanical model is difficult to link the composition and structure of the material with its mechanical properties[3-4]. Therefore, in recent years, some scholars at home and abroad have tried to establish a heterogeneous finite element model of asphalt mixtures, and analyze the mechanical mechanism of asphalt mixtures from a mesoscopic point of view[5-6]. From the image characteristics, the aggregate of asphalt mixture is close to white, the asphalt mortar is dark gray, and the pore tends to black. Each group of asphalt mixture has good color contrast, and its image can well reflect the meso-structure of asphalt mixture. In this study, the micro-structure of asphalt mixture can be described in detail by using the software of MATLAB and the program of image processing and recognition. Combining viscoelastic theory with the method of automatic generation of finite element mesh, the two-dimensional finite element mechanical model of asphalt mixture can be established[7].

2. Digital image analysis
Digital image analysis technology mainly includes image acquisition, processing, recognition and output. Image acquisition is the process of image digitization. In this study, the cross-section image of Marshall specimen was taken by CCD camera. Image processing includes image transformation, image enhancement and image segmentation. In image conversion, the true color image (24 bits) is usually acquired by CCD. In order to reduce the computational complexity, the gray image is generally selected as the object of analysis. Since the gray scale image can only display 256 color gray levels, the true color image must be transformed into 256 color bitmaps first, and then 256 color bitmaps into 256 color gray levels.

The image acquired by CCD usually has some problems such as blur and noise[8]. Therefore, image enhancement is needed. Because aggregate particles are heterogeneous materials, their gray
level may be distributed in a wide gray scale area, or even into the gray scale area of asphalt. It is usually considered that the main low-frequency components of the image should be preserved by filtering first. For aggregates, this can also make the outline of aggregate particles clearer, and stitch the aggregate particles with slight slit, so that one aggregate particle remains intact, so as not to be divided into two aggregates in edge picking. Then the image is deblurred and the details are highlighted to make the image clear.

Image segmentation[9] is used to detect and separate objects from the background. The accuracy of image segmentation results is of great significance to image analysis and is a more complex step in image processing. Aiming at the bimodal characteristics of asphalt mixture image, this study uses threshold segmentation method to process the image. Let the original image be \( g(i, j) \). According to certain criteria, the eigenvalue \( T \) is found in \( f(i, j) \), and the image is divided into two parts. If the value is 0, it is black, and if the value is 1, it is white. That is what we usually call image binarization. Its mathematical description is as follows:

\[
G(i, j) = \begin{cases} 
1 & f(i, j) > T \\
0 & f(i, j) \leq T 
\end{cases}
\]  

(1)

Image recognition should be performed after image processing. In order to understand the actual distribution of aggregate in asphalt mixture, the edge of aggregate should be detected from the whole binary image. In this paper, Canny edge detection operator is selected to find the basic edge of the image, and then the image is refined. Thinning shrinks the region of binary image into a single-pixel wide line to approach the center line of the region. Its purpose is to reduce the image components until only the most basic information of the image is left. After image thinning, edge tracking is used to identify the coordinates of each particle edge position, which provides basic information for geometric modeling. Then all the edge points are imported into ANSYS by using self-compiled programming language.

3. Selection of Constitutive Model

The traditional finite element model regards asphalt mixture as linear elastic material. Many experimental data show that asphalt mixture is not a simple material and has viscoelastic plasticity in a certain temperature and frequency range[10-11]. In order to simplify the model, asphalt mixture is regarded as aggregate and asphalt mortar. The aggregate is regarded as linear elastic material, and the mechanical properties of asphalt mortar are characterized by Burgers model, while the Prony series is embedded in ANSYS. The conversion methods are as follows:

\[
G(t) = G_0[\alpha_0 + \sum_{i=1}^{n} \alpha_i \exp(-t/\tau_i)]
\]  

(2)

Where \( G(t) \) (shear modulus), \( G_0 \) (Initial shear modulus), \( n \) (term number of Prony series), \( t \) (creep time), and \( \tau_i \) (relaxation modulus) and \( \alpha_i \) (relative shear modulus).

Constitutive equation of Burgers model[12]:

\[
\begin{align*}
\sigma + p_1 \sigma + p_2 \sigma &= q_1 \dot{\varepsilon} + q_2 \varepsilon \\
\end{align*}
\]  

(3)
The expression of shear modulus Prony series is obtained by inverse transformation of Laplace and Laplace.

\[ G(t) = \frac{G_1}{\alpha - \beta} [\left(\frac{G_2}{n_2} - \beta\right) \exp(-\beta t) + (\alpha - \frac{G_2}{n_2}) \exp(-\alpha t)] \]

(4)

Then the following can be obtained:

\[ G_0 = G_1; \alpha_\infty = 0; \alpha_1 = \frac{1}{\alpha - \beta} \left(\frac{G_2}{n_2} - \beta\right); \tau_1 = \frac{1}{\beta}; \alpha_2 = \frac{1}{\alpha - \beta} (\alpha - \frac{G_2}{n_2}); \tau_2 = \frac{1}{\alpha} \]

\[ \alpha = \frac{1}{2p_2} (p_1 + \sqrt{p_1^2 - 4p_2}) \quad \beta = \frac{1}{2p_2} (p_1 - \sqrt{p_1^2 - 4p_2}) \]

\[ \alpha_1, \tau_1, \alpha_2, \tau_2 \text{ is the input value of ANSYS a1,1, a2,2.} \]

4. Establishment of mechanical model of heterogeneous finite element method

The image data is input into the finite element software, and the edge points of each particle are connected to form a line (aggregate edge) by the embedded programming language of the software, and then the surface is generated by the line. Plane182 element is used to simulate asphalt mortar, which can simulate the viscoelasticity of materials in two-dimensional plane. The aggregate is simulated by Plane42 element. The relevant material parameters are given to aggregate and asphalt mortar, contact elements are set at the edge of aggregate and asphalt mortar, and boundary conditions and external loads are applied to the finite element model to carry out the corresponding finite element mechanical analysis. In this case, Marshall specimen cross-sectional images are selected for processing, and d-map is its meshing map. It is proved that the finite element mechanical modeling method is feasible.
5. Conclusion
In this study, digital image processing technology, viscoelastic theory and finite element technology are combined to establish a two-dimensional real finite element mechanical model of asphalt mixture, which lays a foundation for the study of the micro-structure of asphalt mixture and its macro-mechanical properties.

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