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Research on local deformation property of asphalt mixture using digital image correlation

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HIGHLIGHTS

- DIC deformation calculation with natural surface images can satisfy the precision requirement.
- Subset size of 31 can be selected as the optimal DIC test parameter.
- R^2 obtained by the least squares fitting method can identify the critical steady strain.

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ABSTRACT

Failure behavior of asphalt mixture is the process of local deformation accumulation, therefore, local deformation investigation is the base work of failure behavior. Digital image correlation (DIC) method is an optical method which can calculate the local deformation in the failure process. This paper aims to evaluate the precision, select the optimal test parameters for DIC deformation measurement based on natural speckle image, and investigate the local deformation characteristic in the failure process for different mixtures. The results show the image quality of AC with smaller normal maximum aggregate size (NMAS) is better for DIC deformation calculation, the relative deviation of virtual translation and shear test can satisfy the precision requirement, the optimal subset size is 31. Based on the strain distribution, the optimal local deformation measure length for indirect tensile test is set as 50 mm, the critical steady strain is proposed based on R^2 obtained by the least squares fitting method, according to local deformation characteristic, the results show SMA can bear more deformation before unstable deformation stage and failure.

1. Introduction

Asphalt mixture is regarded as a multi-phase composite material system including aggregate, asphalt binder and filler, the difference of modulus between asphalt mastic and aggregate is the main reason of strain localization phenomena and complex stress state [1–3]. The failure behavior of asphalt mixture is the process of local deformation accumulation, the damage appear in the interface and asphalt mastic[4,5] when local deformation is larger than that material can cope with, damage accumulation will cause failure of asphalt mixture, therefore, local deformation investigation is the base work of failure behavior.

Traditional deformation sensors such as linear variable differential transformer (LVDT) are widely used in material deformation measurement, for local deformation measurement, traditional sensor has some disadvantages:

(1) The unpredictability of local damage position make the sensor setting difficult, the sensor glued on the surface will also influence the deformation of material.
(2) The strain obtained by traditional sensor is the average strain of a line segment, no strain field information make it hard to identify the damage area which will affect the measured length selection.

Technology of optical measurement have been proposed for local deformation measurement, digital image correlation (DIC) as one of optical measurements was proposed in the 1980's [6,7], it was a direct displacement and strain fields measurement method with advantages of full-field, real-time, non-contact, flexibility and so on. Seo [8] first used DIC technique as a possible displacement/strain measurement method for asphalt mixture. Tan

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[9,10] compared DIC method with LVDT and determined the minimum calculation gauge length of the indirect tensile (IDT) test, according to the strain field obtained by DIC, it was found that the Poisson ratio was not a constant. Many researchers [11–14] investigated fracture phenomena in asphalt material based on DIC method.

In general, the surface of measured material for DIC should be covered by artificial speckle, the artificial spackle can improve calculation precision, however, it will also cover the aggregate and asphalt distribution information which is important for local damage identification. The natural surface of asphalt mixture includes natural speckle duo to different material inside, if the measured result based on the natural surface can satisfy the measured precision requirement, the image of natural surface can be used for deformation measurement.

Based on the problems above, this paper aims to evaluate the precision, select the optimal test parameter for DIC deformation measurement based on natural speckle image, identify the local deformation area, propose the critical deformation determination method, finally, investigate the local deformation characteristic in the failure process for different mixtures.

2. Materials and methods

2.1. Materials property

Basalt aggregate is used in this research, two asphalt binders are used to produce the different mixtures: one neat asphalt for AC asphalt mixture and one SBS polymer-modified asphalt for SMA asphalt mixture. Details of the asphalt binder properties are listed in Tables 1 and 2.

2.2. Specimen preparation

The mix design procedure is determined as the Chinese specification JTG F40-2004, the Marshall design procedure is used in this research to optimize the asphalt content for the mixtures. Six types of asphalt mixtures (e.g., AC-10, AC-13, AC-16, SMA-10, SMA-13, SMA-16) with optimal the asphalt content are tested in this research, the grading of the mixtures are the mid-value of the grading limit based on Chinese specification JTG F40-2004. The aggregates, the asphalt binders and mixing equipment are heated for 4 h at 155 °C, the temperature for modified mixture is 175 °C, cylindrical specimens are obtained by compacting the mixtures 120 times using a gyratory compactor. In order to observe the failure position, each cylindrical specimen is sawn to obtain two effective plates by discarding the top and the bottom plates for reducing density gradient effect, the height of the treated sample is 63.5 mm, the specimens are used to perform the IDT test at 25 °C as the Chinese specification JTG E-20-2011.

2.3. Digital image correlation method

In this research, Vic-2D 2009 produced by Correlated Solutions, Inc. is employed. This system is a complete, turn-key system for measuring the shape, displacement and strain of surfaces. A digital camera, Point Grey GRAS-20S4C/M (2.0MP, Sony ICX274 CCD, 1/1.800, resolution 1624∗1224 at 30 fps), is currently employed. Accuracy of displacement is approximately 0.01 pixels on a point-to-point basis including translation and rotation measurements. Therefore, when observation area is 160 mm∗120 mm, the horizontal displacement resolution of this equipment can be calculated as: (160 mm/1600 pixel)∗0.01 pixel = 1 μm, as well as the vertical displacement resolution. A sequence of digital images depicting an area of finite extent in the specimen is acquired during testing, the capture speed is 1 piece per second. The images are automatically processed by the software, providing accurate displacement/strain field. An iterative least-squares algorithm (least squares matching) is applied for the extraction of image correspondences based on the similarities between grey values.

The camera which focus on the whole surface of the specimen is directly connected with a personal computer. A lighting system which is used to provide adequate illumination for the specimen surface should be placed at the proper position. The test equipment is shown in Fig. 1.

Table 1
Basic properties of neat asphalt.

Index	Unit	Test result	Technical requirements
Penetration, 25 °C, 100 g, 5 s	0.1 mm	79	60–80
Ductility 15 °C, 5 cm/min	cm	133.0	≥100
Softening point	°C	51.4	≥44

Table 2
Basic properties of SBS polymer-modified asphalt.

Index	Unit	Test result	Technical requirements
Penetration, 25 °C, 100 g, 5 s	0.1 mm	66.9	60–80
Ductility 5 °C, 5 cm/min	cm	43.3	≥40
Softening point	°C	66.5	≥50
Elastic recovery (25 °C)	%	82	≥60

3. Accuracy investigation and parameter selection

3.1. Image quality evaluation index

In order to get accurate strain field, the image obtained in the test process should include enough spackle pattern which carry the deformation information for strain calculation by DIC system. Typically, the specimen surface is covered by white color followed by spraying black painting dots on it, the aggregate and asphalt distribution in asphalt mixture is overlaid by the artificial speckle

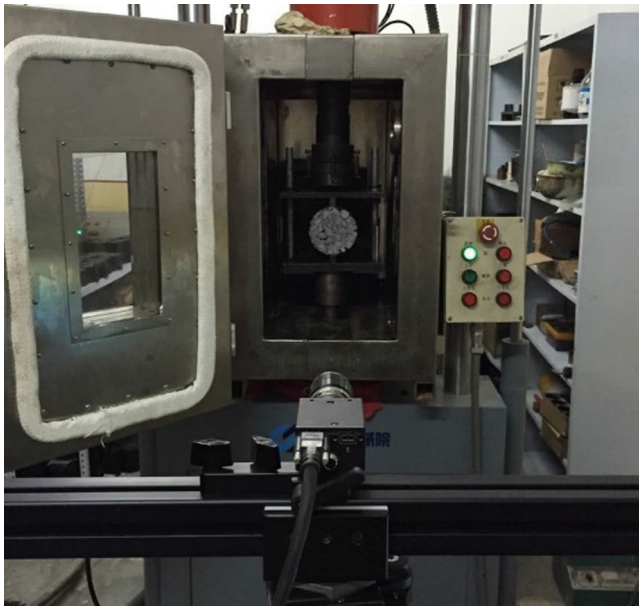

Fig. 1. Test equipment in this research.