CRACK MONITORING AND STRAIN MEASUREMENT IN ASPHALT MIXTURE BY DIGITAL IMAGE CORRELATION

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ABSTRACT. *A full field method for the description of in-plane strain fields is applied for improving Asphalt Mixture cracking behaviour insights. A Digital Image Correlation (DIC) system based on the Least Square Matching technique is used to compute strains and depict crack path in the process from microcrack initiation to failure. A Brazilian test was performed using hole-notched specimens. The test generates tensile stresses in a known and limited portion of the specimen simplifying test monitoring and image capture for subsequent application of the DIC system. The results show the capability of the DIC system to allow a dense description of the field all over the cracking process involving the peak and the post-peak softening slope. Compared to traditional strain devices, the system provides a wealth of information, as well as an easier and faster setting process.*

INTRODUCTION

Asphalt mixtures are particulate composite materials consisting of interspersed aggregates, asphalt binder and air voids. Asphalt mixtures vary significantly as a result of using different binder-aggregate combinations, aggregate gradations, and binder modification techniques. The constitutive behaviour of these mixtures depends largely on the physiochemical interaction between the aggregate and the binder, which are drastically different in nature. The heterogeneity of the material affects its cracking behaviour leading to a significant complexity in crack propagation analysis. In asphalt mixtures a tensile fracture zone starts to develop as soon as the strain corresponding to the tensile strength is exceeded. It consists of microcracks mainly perpendicular to the maximum tensile stress direction. Within this zone some tensile stress can still be transferred. With increasing tensile deformations in the transverse to the microcracks direction, the tensile strength of the fracture zone is exhausted, and the microcracks coalesce into a single crack. Available experimental evidence indicates that the length of the fracture zone can be considered as a material parameter and that it is related to the fracture-energy of the material.

Lately, many research programs based on fracture mechanics approaches have been initiated aiming at a better understanding of the mechanism of crack growth and propagation in HMA mixtures. In the recent past, new crack growth simulators have been studied to combine fracture modeling capability of Boundary Element Methods to fracture mechanics-based crack growth laws (1) but more details concerning the behavior of the material in the tensile fracture zone are requested, in particular in the field of experimental strain analysis. Detailed and accurate strain measurements in the fracture zone can lead to important improvements in fracture parameters detection and in fracture laws development. Unfortunately, traditional strain measurement devices are not flexible since they provide only the strain measurements at the restricted area in which the device is mounted. Essentially, strain analysis performed by traditional measurement devices may become highly restricted leading to inaccurate results and statements.

Recent works at University of Parma focused on the application of vision metrology to the description of in-plane_displacement/strain fields in composite material testing; specifically in asphalt mixture testing (2). A Digital Image Correlation (DIC) System was developed for providing a dense and accurate full displacement/strain field of composite materials and for detecting the cracking behavior of materials at each instant of interest (i.e. at crack initiation within the tensile fracture zone).

This paper presents fracture experiments on asphalt mixtures enhanced by the DIC system. The Brazilian disk test (indirect tensile test) was performed using notched specimens. The test generates tensile stresses in a known and limited portion of the specimen simplifying test monitoring and image capture for subsequent application of the DIC system. The notch serves to concentrate the stress in order to make cracks initiation propagating along determined paths. A 8 mm diameter circular hole was drilled at the centre of the specimen to assure the crack will initiate and propagate along the desired path.

DIGITAL IMAGE CORRELATION SYSTEM

The DIC System consists in a photogrametric-based method which applies the *Least Square Matching* image matching technique to an image sequence recorded during specimen conditioning. The system is made of three elements: the hardware (digital camera Basler AF 101 and illumination devices), the software (image acquisition and processing) and the specimen set up (Fig. 1).

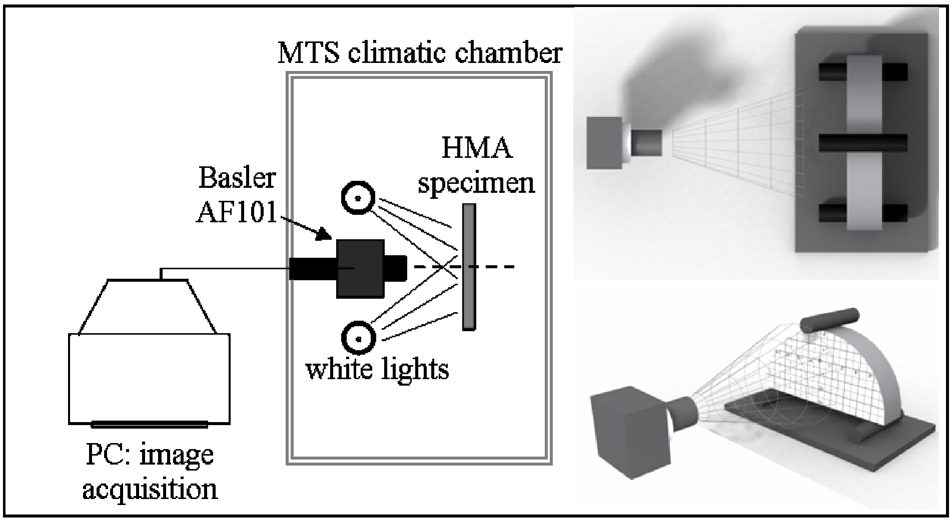


Figure 1: Digital Image Correlation System Setup

Image correlation analysis involves measurement of the grey scale values at each pixel location in the grabbed area. The grey values of deformed specimen images are compared with the initial, undeformed image, determining its movement and deformation and consequently the displacement of its central pixel.

An image sequence of the specimen is acquired with a digital camera during HMA fracture testing; a set of features, artificially generated on the specimen surface, is accurately tracked by the algorithm along the sequence.

From the image coordinates, displacements and deformations can be evaluated in image space and, with an appropriate scale factor, in object space.

A large number of test were performed to pinpoint the accuracy achievable by the DIC system in detecting strain measurements resulting in an average accuracy for HMA of 0.03%. Further details on the image processing and data extraction are discussed by Roncella and Romeo (2,3,4).

ASPHALT MIXTURE FRACTURE TEST

The Brazilian Disk Test (or IDT) is an indirect tensile test performed using circular shaped specimens (diameter = 150mm; thickness = 25mm).

Traditionally, two strain gauges with a length of 38.1 mm are placed at the centre of the circular specimen to measure vertical and horizontal deformations during loading. The test is performed inside the Material Test System (MTS) climatic chamber to guarantee the temperature control of the mixture since it asphalt mixture are highly sensitive to temperature.

The Brazilian Disk Test was performed at 10°C on notched specimens. Actually, at this temperature, asphalt mixture behaves almost brittly, not assuming a really visco-plastic trend.

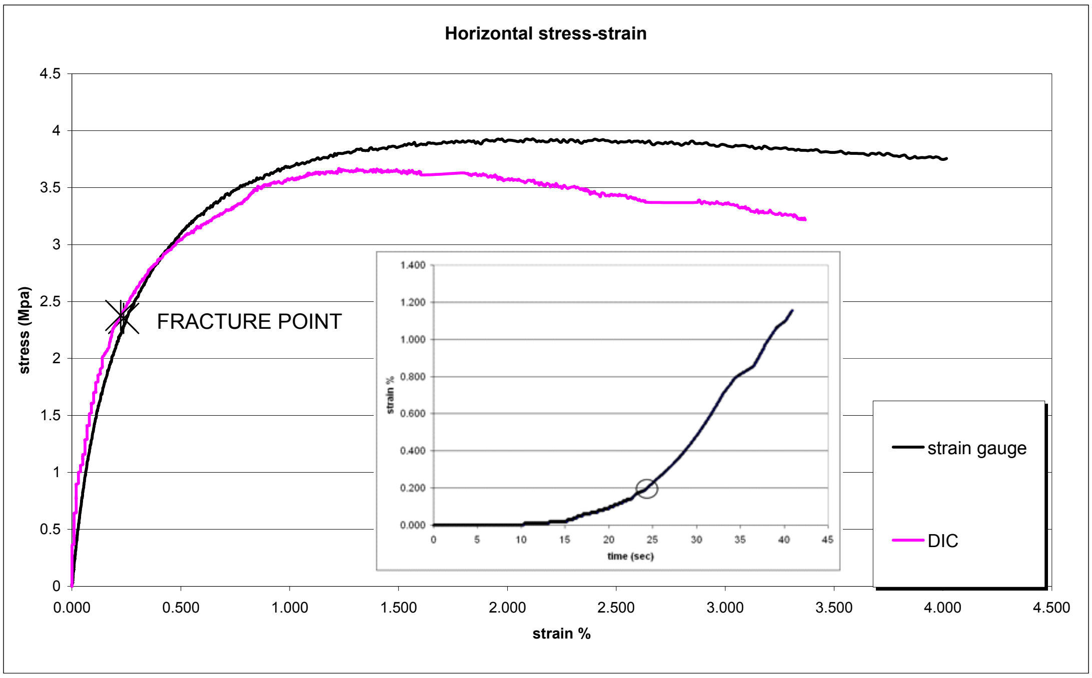
An 8-mm diameter hole at the centre of the specimen was selected as notch to concentrate the stress and make crack initiation propagating along determined paths, as discussed by Birgisson et al. (5). The load was applied on a centered loading plate with a displacement-controlled system moving at 0.08 mm/s speed.

Four test replicates were performed placing two strain gauges, with a length of 20 mm, above and below the notch along the horizontal axis of the specimen to account for tensile strains at tensile fracture zone. Four more replicates were performed without strain gauges applying the DIC method to achieve full/field strain analyses. The camera was placed inside the climatic chamber (5 fps settled) parallel to the specimen plane, acquiring a 4x3 cm region of interest located around the hole notch (tensile fracture zone).

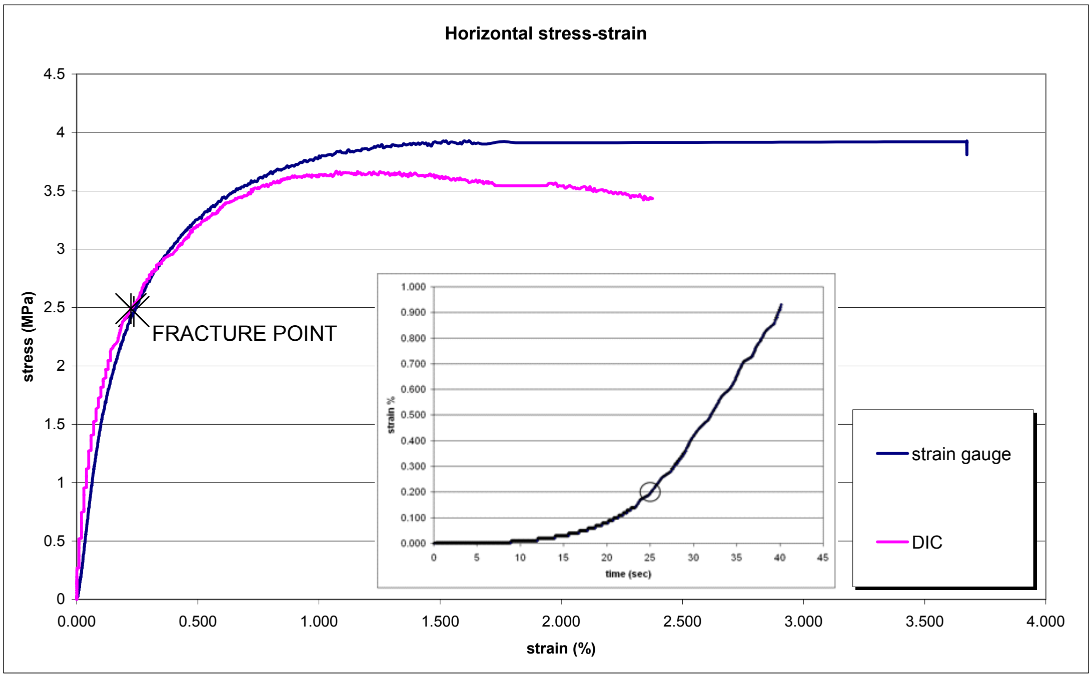
CRACKING ANALYSIS AND RESULTS

It must be acknowledged that visible macrocracks in asphalt mixture initiate after peak load, while microcracking and localized damage occur throughout the loading, next to peak load . The point at issue is to identify at what stress state microcracks start to develop and coalesce into larger band (fracture point) forming unhealable cracks in order to identify the energy parameters featuring the mixture itself. Unfortunately, the aggregate structure of asphalt mixtures could have an effect on the crack path and thus the softening response. The crack path can traverse through aggregates (when aggregate defects occur), between aggregate and asphalt binder interfaces, or through the asphalt binder.

The comparison between the horizontal stress-strain response obtained with traditional methods (strain gauge) and those ones obtained by the DIC system is shown in Fig. 2a and 2b which describe the horizontal stress-strain response in the fracture zone, respectively above and below the hole-notch. DIC measurements agree very well to strain gauges reading as far as the asphalt mixture behaves linearly (no macro-crack growth); from that point on, differences increase steadily. Actually the strain gauge leads to unreliable measurements especially after crack initiation due to the resistance yielded by the glue; moreover it tends to fail as soon as a macro-crack develops. On the contrast, DIC measurements describe in a better way the material behavior in the whole crack process, involving the peak and the post-peak softening slope. The DIC system also allows an accurate recognition of the fracture point which visibly corresponds to that point at which strains start to grow rapidly. At this point the local strain measurement registered by the DIC system become very high: crack initiation leads to large deformations concentrated in a small region of the specimen.



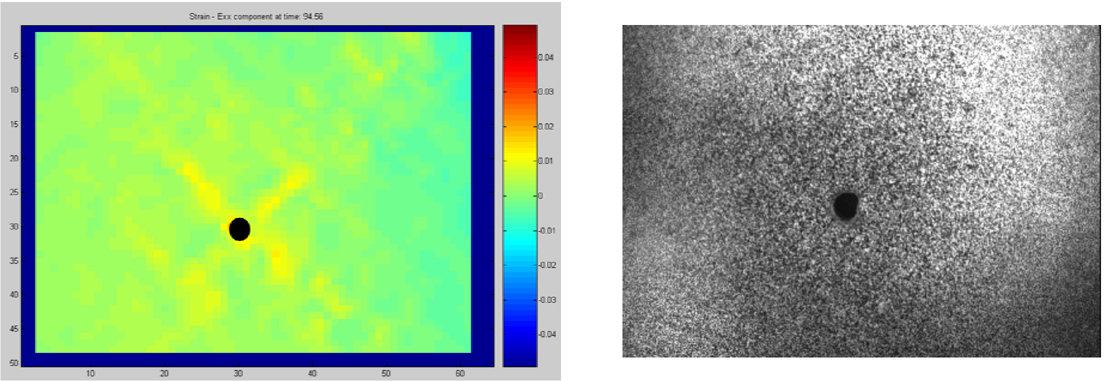
a) Horizontal stress-strain response in the fracture zone above the hole-notch



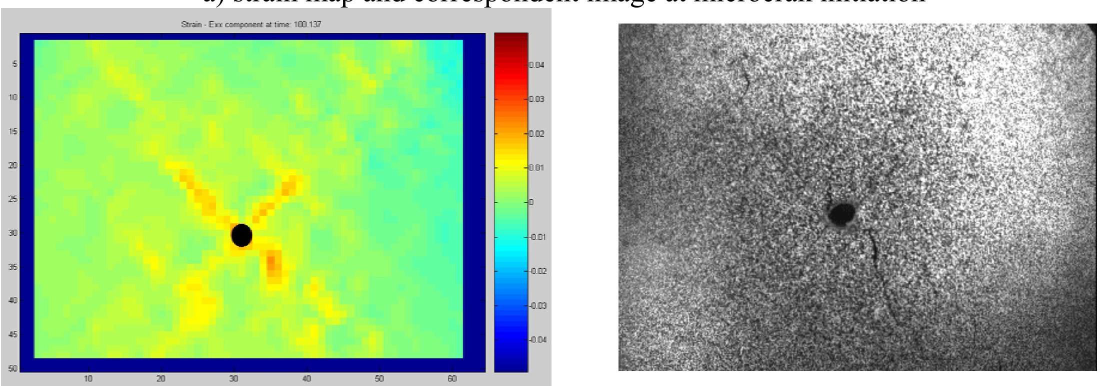
b) Horizontal stress-strain response in the fracture zone below the hole-notch

Figure 2: Comparison between strain gauge and DIC measurements

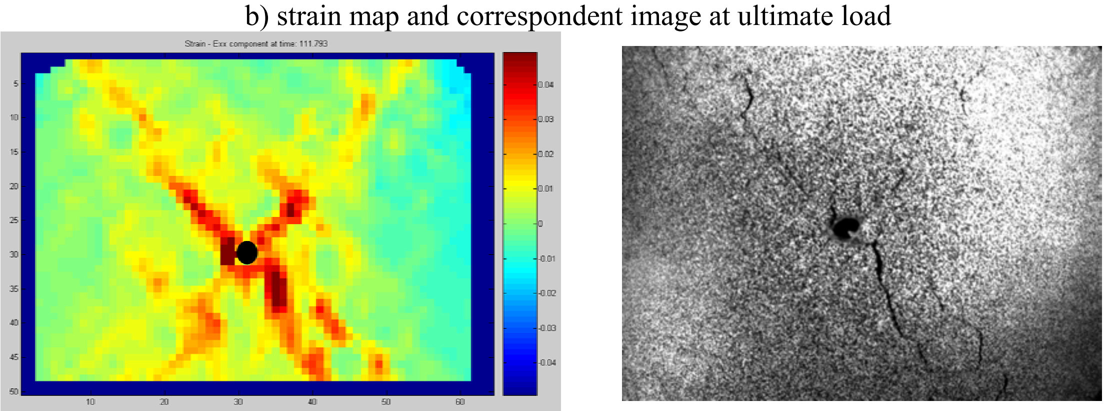
Figure 3 shows the measured horizontal strain map from crack initiation to major crack opening. Comparing the DIC strain map at microcrak initiation with the correspondent image (Fig. 3a), it's evident that fracture point always occurs before the ultimate load is reached. Actually, the visible fracture initiation in the image sequence appears considerably after the peak of the stress-strain response (Fig.3b). The comparison between e_{xx} strain map and the correspondent specimen image after fracture propagation empathizes the capability of the DIC method to catch strain values and to visualize crack patterns (Fig. 3c).



a) strain map and correspondent image at microcrak initiation



b) strain map and correspondent image at ultimate load



c) strain map and correspondent image after fracture propagation

Fig. 3: Comparison between strain map and correspondent images at different stages

CONCLUSIONS

A quite effective DIC measurement system was applied to a Brazilian disk test performed on notched asphalt mixture specimens to capture asphalt mixture cracking behavior. The test generates tensile stresses in a known and limited portion of the specimen simplifying test monitoring and image capture for subsequent application of the DIC system. Local strain inhomogeneities of the material due to microcrack initiations are easily detected as well as the stress state of the material during microcrak coalescing. Compared to the traditional strain devices, the DIC system allows a dense description of the field all over the cracking process involving the peak and the post-peak softening slope. It also accurately depicts the crack path which in asphalt mixture is hard to predict otherwise using a crack growth simulator.

Above all that, the system provides an easier and faster setting process than traditional devices.

REFERENCES

1. Soranakom C., Birgisson B., Napier J.A.L. and Roque R. (2003) Simulation of Fracture Initiation in Hot Mix Asphalt Mixtures. *In 82th Annual Meeting, TRB, National Research Council,* Washington D.C.
2. Roncella R., Romeo E., Forlani F. (2005) Image Based Microstructural Analysis in Fracture Mechanics. *Proceedings of the 7th Optical 3-D Measurement Techniques*. Vienna, Austria.
3. Romeo E.,. Roncella R, Tebaldi G. (2005) Image Based Method for Indirect Strain Measurement in Non Homogeneous Materials. *Proceedings of the 22nd Danubia-Adria Symposium on Experimental Methods in Solid Mechanics.* Monticelli, Italy.
4. Grolleau C., Nicoletto G., Romeo E., Roncella R. (2005) Determination of the Elastic-Plastic Strain Fields by Image Digital Correlation. *Proceedings of the 22nd Danubia-Adria Symposium on Experimental Methods in Solid Mechanics.* Monticelli, Italy.
5. Sangpetngam B., Birgisson B., Roque R. (2003) Development of an Efficient Hot Mix Asphalt Fracture Mechanics-Based Crack Growth Simulator. *In 82th Annual Meeting, TRB, National Research Council*, Washington D.C.