USE OF OPTICAL TECNIQUES IN THE ASSESSEMENT OF THE DISPLACEMENT FIELD NEAR THE CRACK TIP

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ABSTRACT

A crack tip represents a highly singular stress field existing in a structural component. The evaluation of the associate strain gradient is difficult using experimental discrete methods. An efficient alternative relies on optical methods which are non contact and give continuous information about displacements fields and its derivatives when strain evaluation is necessary.

This paper describes some experimental methods to fully characterize the displacement field near a crack tip existing in flat plates. Three optical field techniques based on image analysis were used in the present work; respectively ESPI (electronic speckle pattern interferometry), MI (Moiré Interferometry), and DIC (digital image correlation). These methods present different resolutions which can be adjusted according to the expected strain gradient. While the first method depends on the laser wavelength, the second depends on the grid pitch and the last on the surface texture.

KEY WORDS: optical techniques, ESPI, Moiré Interferometry, Digital Image Correlation

1. INTRODUCTION

1.1 OPTICAL METHODS

1.1.1 ESPI

All these techniques use light to codify the surface information before and after loading to enhance displacements or strains. ESPI and MI need coherent illumination to generate the fringe patterns which characterize the object behaviour. Both set-ups have capability for in-plane displacement measurement; however, the ESPI set-up can be adapted to simultaneously measure in-plane and out-of-plane displacements. The applications of this method to fracture mechanics has been carried out in previous work were the stress intensity factor in a part through crack was measured [1]. To achieve this step the experimental setup was designed to cancel rigid body motion and coupled with accurate image processing tools, obtain the above mention displacements and rotations of the plate along the crack line. Once calculated these parameters it is followed an hybrid methodology were the compliance factors of each line spring element placed along the crack plane allow the evaluation of the consequent stress field and further assessment of the stress intensity factor.

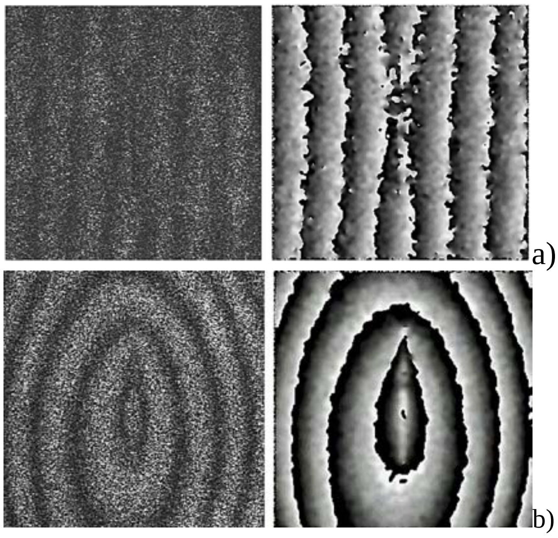


Figure 1. Fringe pattern and phase map obtained for in-plane a) and out-of-plane b) displacement measured with ESPI [1].

The problem of a part through crack is approached with precision using 3D Finite Element Techniques. However, this simulation is expensive, once it means a heavy computation effort near the singularity, were a highly refined mesh must be generated. To overcome this drawback a line spring model was proposed by Rice and Levy [2]. The model consisted in replacing the residual ligament along the part trough crack surface by a set of side edge cracked plates were each crack depth reconstructs the real crack profile, view fig. 2. Then, the structural behaviour of each side edge cracked plate of the model acts like a spring with coupled extensional displacement and crack edge rotations. Using optical techniques like ESPI it is possible to record with high precision the evolution of the conjugate crack surfaces along its length. After obtaining the mentioned displacements and rotations they can be input in the line spring equations to compute the stress intensity factor. All of these calculations are detailed in a previous work [1].

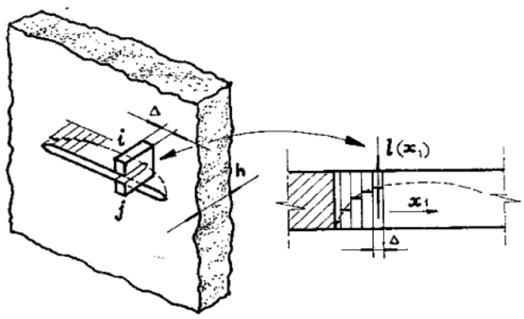


Figure 2. Line spring model replacing the structural behaviour of the remaining ligament along a part through crack [1]

1.1.2 MOIRÉ INTERFEROMETRY (MI)

Another optical method could be used to assess the displacement field near a singularity. MI relies on the superposition of two grids, being one the reference and the other following the deformation of the object surface. High frequency grids (up to 1200 lines/mm or more) are available and have to be recorded on the object surface, consisting on the object grid. The resolution depends on the grid pitch and can be adjusted to the expected displacement amplitude. This method is restricted to in-plane measurements, yet with accuracy to characterize structural singularities like a through crack [3]. As can be seen in fig. 3 the MI was used to characterize the displacements on the surface of a 3PB specimen giving results in good agreement with FEM calculation. In fig. 4 it is depicted a comparison with the numerical results obtained with FE ANSYS® [4].

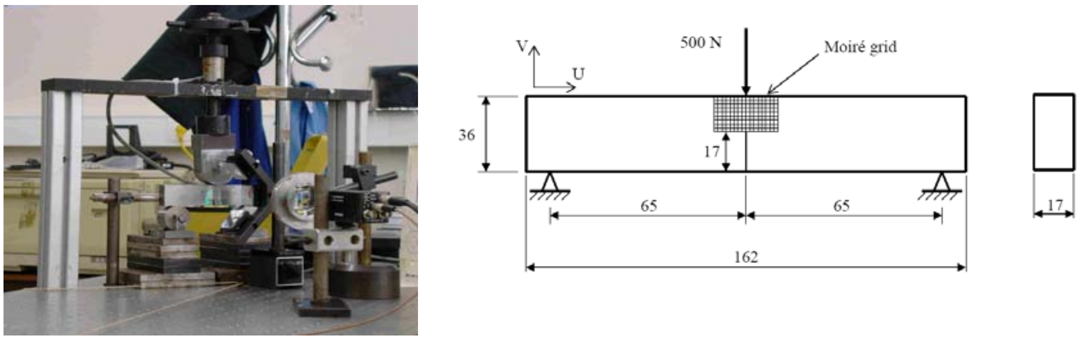
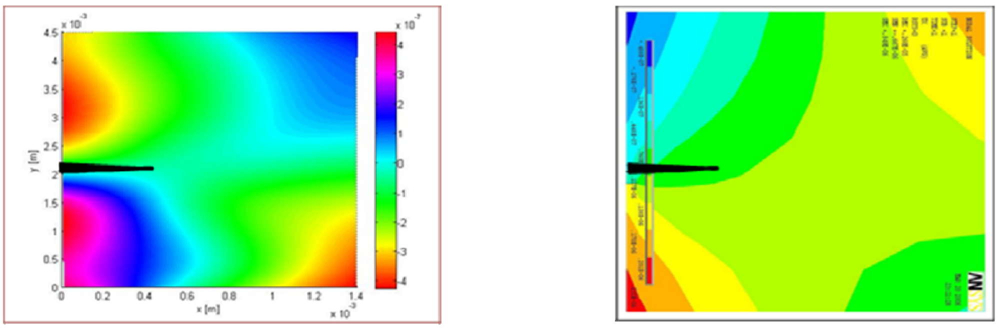


Figure 3. *MI setup to obtain the 2D displacement on a 3PB test specimen*

In spite of being a very accurate tool for the experimental measurement of displacements, this is restricted to in-plane measurements which leave the line spring method incomplete for the edge crack rotations. However, the MI can be used to adjust a numerical solution and in complement, use the surface rotation obtained with the FEM. Still the MI method is fully applicable to fracture mechanics problems dealing with through cracks or side edge crack. Also in this technique image processing techniques could be involved to obtain the continuous field displacement with temporal phase shift.



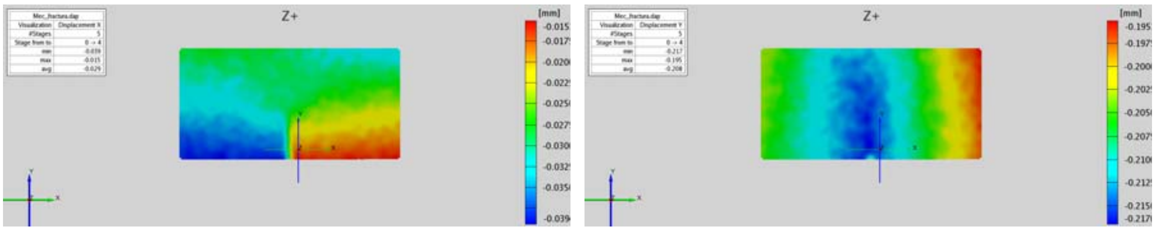
(a) (b)

Figure 4. Displacement field, in x direction, obtained with Moiré interferometry (a) and numerical results (b).

1.1.3 DIGITAL IMAGE CORRELATION (DIC)

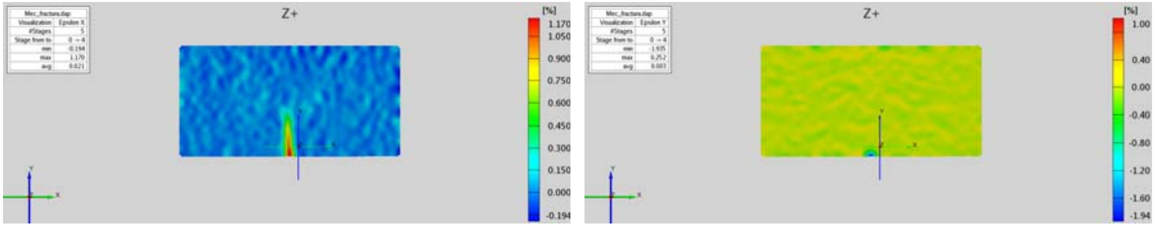
Recently a new optical technique is being spread in the scientific community, the DIC. In this technique the object is illuminated by a non coherent light and the intensity patterns are resulting from the surface texture. These intensity patterns, which should have a random distribution, will be divided into smaller areas. Each subdivision of the picture is initially recorded and compared, by correlation, with the obtained images for different deformation states of the object. The determination of displacement and strain fields are obtained by the correlation between the random pattern of initial image (reference) and the final one (deformed) [5].

The surface texture can be natural or prepared with special painting and its size influences the accuracy of the measurement. In this particular technique the software plays an important role as the displacements are calculated from image details. This method could be used to measure 2D and 3D strain or displacement fields. Recently there are available integrated systems offering good results with easy operation. A commercial code of DIC (ARAMIS) was used to characterize in-plane displacements and strains on the surface of a 3PB specimen, similar to fig. 3. The surface preparation was done by creating a random speckle using a spray of matt black paint. The results of displacement and strain measurements are represented in fig. 5 and 6.



(a) (b)

Figure 5. Displacement fields obtained with Digital Image Correlation in x direction (a) and y direction (b).



(a) (b)

Figure 6. Strain fields obtained with Digital Image Correlation in x direction (a) and y direction (b).

As can be seen in the previous figures the results obtained with DIC in spite of being discontinuous showed good accuracy and proved to be a good solution in future works. The increase of the video detectors resolution will improve this technique which is easy to use and doesn't need expensive equipment.

2. CONCLUSIONS

The procedures described appear as an interesting step in hybrid process in the evaluation of the stress intensity factor in cracked plates. The ESPI allows both in-plane and out-of-plane measurements, however it is complex, expensive and easily decorrelated; MI is less sensitive to rigid body motion and enough accurate for this application being the grid recording a difficult and longstanding task. Finally, the DIC appears to be the less expensive technique, also allows in-plane and out-of-plane measurements and the direct obtainment of strain fields, but is very demanding in the computation effort and for very high resolutions is difficult to create the speckle small enough.

All of the here presented methods can be used in fracture mechanics with good results not only in stress intensity factor assessment but also in the adjustment of numerical models for the same goal.

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