
Fracture Parameter Evaluation Using Digital Image Correlation Technique

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ABSTRACT

Fracture and failure characterization of materials have been a crucial issue regarding reliable structural design. Stress Intensity Factor (SIF) is one of the most commonly used material parameters for more purpose. This study utilized Compact Tension (CT) Specimen test to determine mode-I SIF of polycarbonate material. Force, displacement and images of the near crack tip region were simultaneously recorded during the tests. In addition, digital image correlation (DIC) technique was successfully employed to obtain full field measurement of displacements and strains in the vicinity of the crack tip. The mode-I stress intensity factor was then calculated from the crack surface displacements obtained experimentally from DIC measurements and the results were verified by empirical formulae. These results are validated with theoretical and numerical values.

Keywords: *Fracture mechanics, Experimental mechanics, Digital image correlation, Stress intensity factor*

INTRODUCTION

Digital Image Correlation (DIC) is a non-contact optical technique for measuring strains. In principle, DIC compares a series of grey-scale images of a sample at different stages of deformation, tracks pixels movement in the Region of Interest (ROI) and calculates displacement and strain by the use of correlation algorithm.

DIC consists of at least digital camera, zoom objective and PC software. Before mechanical tests, specular markers should be applied on the sample surface in order to let the camera capture their movement and track them. Therefore, the markers are of great importance and can be obtained by spraying, etching or self-roughness (or texture). During the test, consecutive pictures are taken by one or more cameras while samples are under deformation tests, the number of cameras depends on whether the analysis is 2D or 3D and the precision one wants to achieve. Images are later transferred to PC and are analyzed through correlation algorithm by using software like Matlab and ARAMIS. As shown in Figure (1.1), images are taken by camera, before analysis, ROI was selected by user and grid will be applied over the whole ROI, then the displacement of this grid is calculated.

The basic principle of digital image correlation for measuring surface displacement is described. The displacement component on the surface of an object are easily obtained using this method by recording the images of the surface before and after deformation. The effectiveness of this method is demonstrated by applying the method to the measurement of the displacement field around a crack tip and the measurement of strain distribution of shape memory alloys.

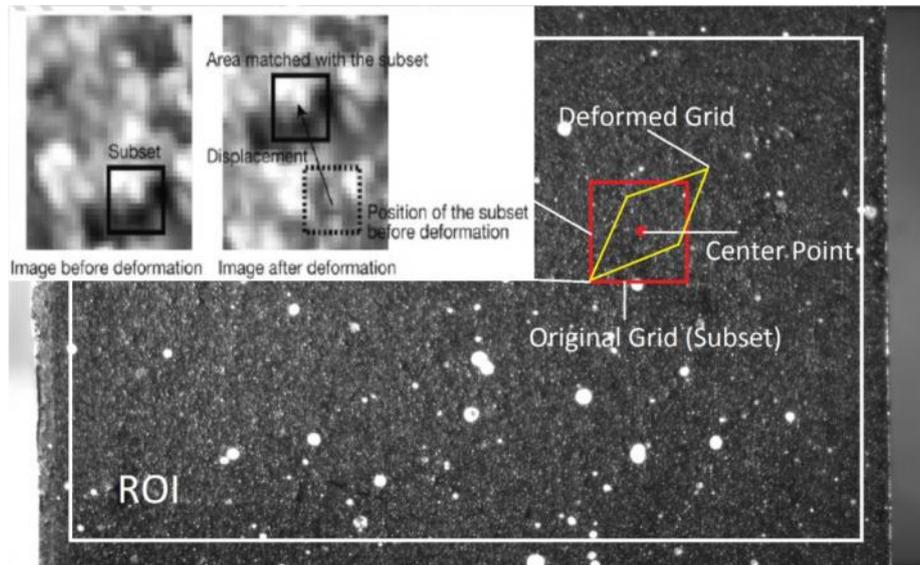


Figure 1 DIC Image with illustration of grid

1.1 TWO-DIMENSIONAL DIGITAL IMAGE CORRELATION

In two-dimensional digital image correlation, displacement is directly detected from digital images of the surface of an object (specimen). Figure 1.2 shows a typical experimental setup for two-dimensional digital image correlation. The plane surface of an object is observed usually by a CCD camera with an imaging lens. Then the images on the surface of the object, one before and another deformation. Images are recorded, digitized and stored in a computer as digital images. These images are compared to detect displacement by searching a matched point from one image to another. Here, because it is almost impossible to find the matched point using a single pixel, an area with multiple pixel point (such 20x20 pixels) is used to performed the matching process. This area usually called subset, has a unique light intensity (grey level) distribution inside the subset itself. It is assumed that this light intensity distribution does not change during deformation. Figure 1.3 shows the part of the digital image before and after deformation. The displacement of the subset on the image before deformation is found in the image after deformation by searching the area of same light intensity distribution with the subset. Once the location of this subset in the deformed image is found, the displacement of this subset can be determined. In order to perform this process, the surface of the object must have a feature that allows matching the subset. If no feature is observed on the surface of the object, an artificial random pattern must be applied. Figure 1.4 shows a typical example of the random pattern on the surface of an object produced by sparying paint. The above concept is common among other techniques in digital image correlation.

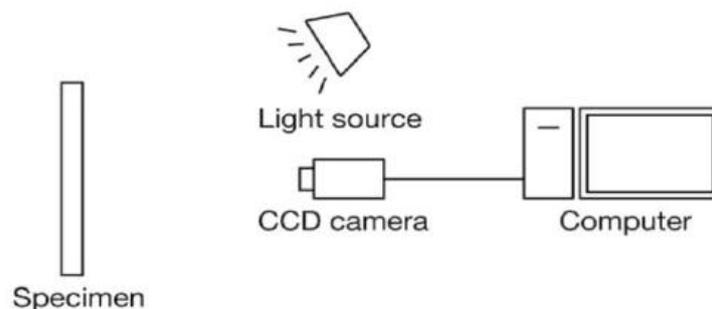


Figure 2 Setup for displacement measurement using digital image correlation

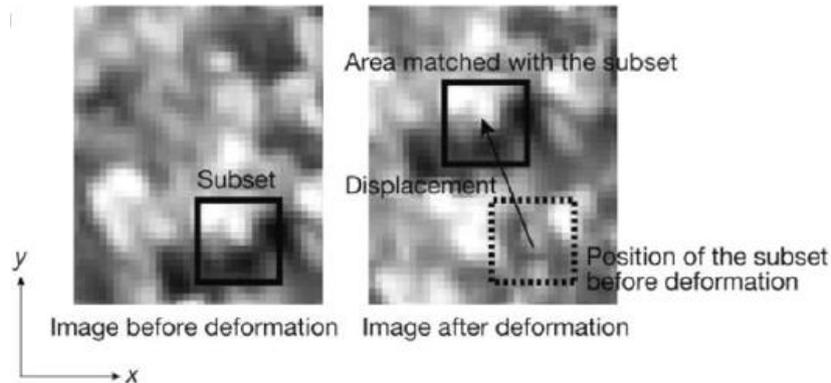


Figure 3 matching the subset before and after deformation

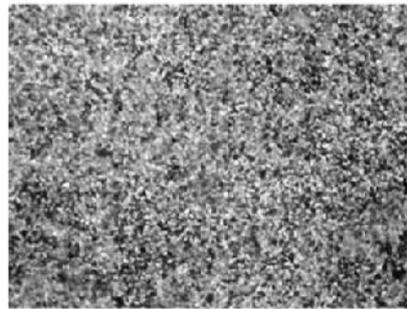


Figure 4 Typical example of random pattern on specimen surface

EXPERIMENTAL PROCEDURE

Compact tension specimen testing to determine stress intensity factor is described in this section together with specimen preparation. Details of DIC method and post-processing are discussed.

SPECIMEN PREPARATION

Before using the DIC system on the CT specimen sample testing occurred, painting a thin white layer and applying black speckle pattern with spray-paint. The preparation process can be seen in Figure 4.2. After the preparation was done the specimens were tested until failure in a loading device. These test methods based on ASTM E 399 involve loading a notched specimen that has been precracked, in either tension compact tension specimen. The significance of test methods and many conditions of testing are identical to ASTM E 399. The specimens for fracture toughness testing is either Compact Tension was machined from the laminates in accordance with the dimension given by ASTM E399 as shown in Figure and respectively.

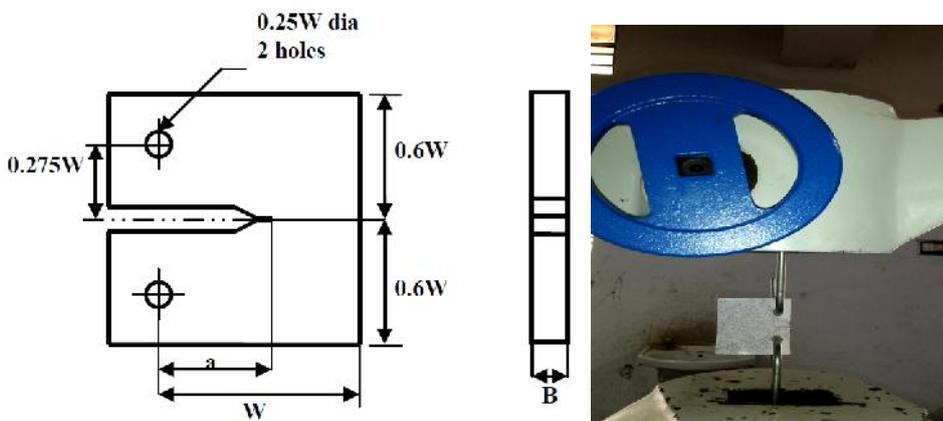


Figure 5 CT specimen sample geometry and tensile loading configuration and (b) tensile loading test set-up.

Testing Protocol

CT test was conducted using tensile loading fixture under displacement control, with a loading rate of 1 mm/min. Computer controlled Shimadzu 19kN screw-driven electromechanical tensile testing machine was utilized for testing. Fig. 2(b) shows the CT specimen in the tensile loading experimental setup. The specimen was loaded up to a maximum force of 19kN. During the test, force and cross-head displacement were simultaneously recorded. In addition, sequential images of near crack tip region were captured at each 100N increase in force using high resolution digital camera for DIC measurements.

Digital Image Correlation Method

Digital image correlation is based on the relation between two consecutive images of the material after deformation. It works based on the principle of the comparison of the digital images at different deformation stages. The system measures the displacement of the surface and determines the deformation and strain fields by tracking each pixel.

The image of the sample is described by a discrete function that represents the grey level of each pixel. The calculations of the correlation are conducted for each pattern. The initial image representing the sample before distortion is a discrete function and it is transformed into another discrete function after the distortion as shown in fig.1.[3] The correlation between the functions gives the displacements of the grey spots on the test specimen. According to this principle, deformation of the specimen is simply calculated from the displacement of the spots.

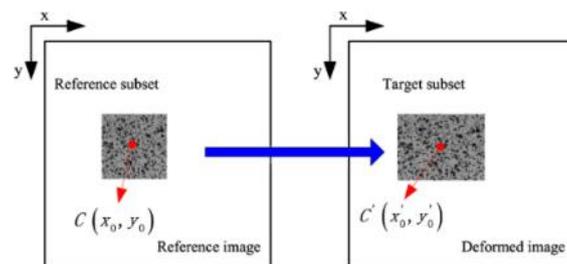


Figure 6 Discrete functions of C and C' showing the undeformed and deformed states of the surface

Post-Processing of the data

The sequential images obtained from the test were analysed using a commercial DIC software MATLAB. Figure. 3 shows the y-displacement contours around the crack tip with the crack surface taken out. The x-axis is taken at the crack tip in the direction of the crack surface and y-axis is perpendicular to the crack face. To calculate the SIF, 12 different stage points were taken on the crack surface near the crack tip as shown in Figure. 3. At these points, the relative y-axis displacements of each point were obtained from MATLAB software, which were used in the SIF calculations.

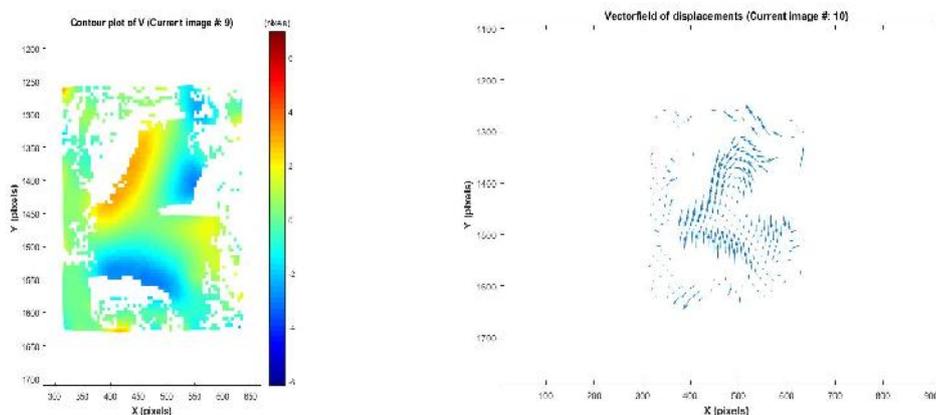


Figure 7 Stage point representation of the y-displacement and vector field near the crack tip in a CT specimen under load.

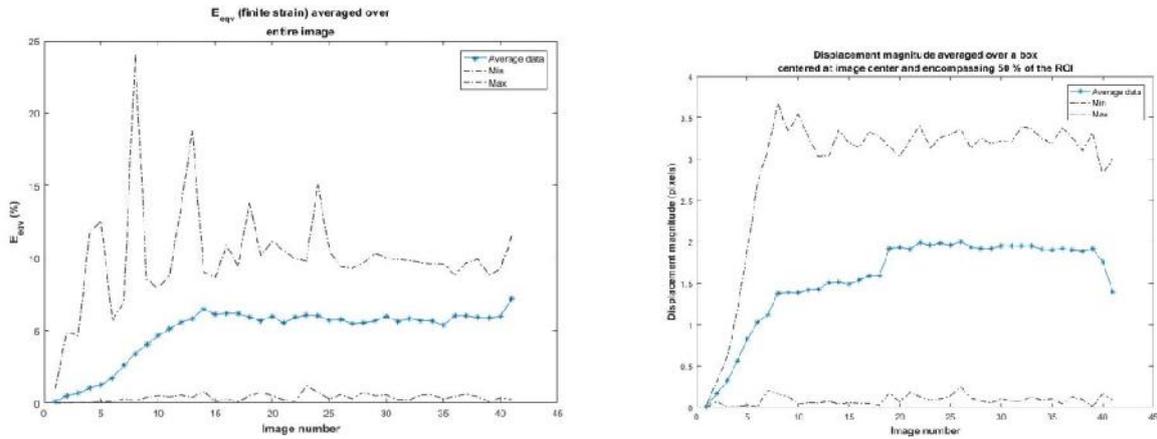


Figure 8 equivalent strain graph for all images correlation coefficient magnitude displacement graph

COMPACT TENSION SPECIMEN

$$e = \frac{10}{96} \times 25.4$$

strain $e = 0.03674$

$$= E \times e$$

$$= 2000 \times 0.03674$$

Stress = 73.48 MPa

$$\text{Stress} = p/A$$

load $P = 8817.6 \text{ N}$

$$K_{Ic} = \frac{P}{B} \frac{1}{\sqrt{2}} \times 8.34$$

$$K_{Ic} = 164.439 \text{ MPa}\sqrt{m}$$

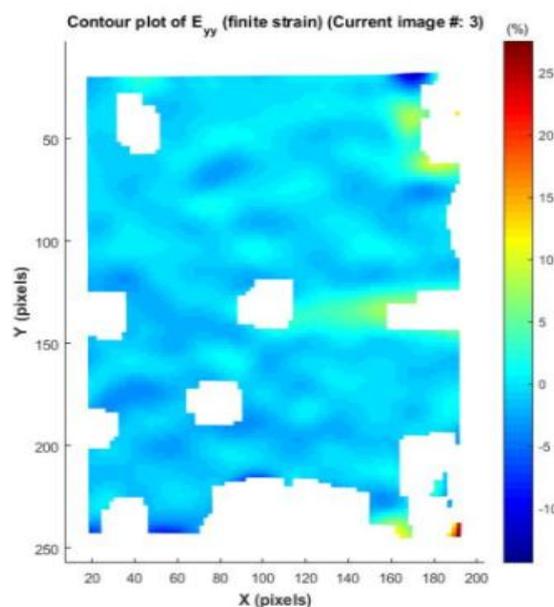


Figure 9 displacement for vertical contour plot

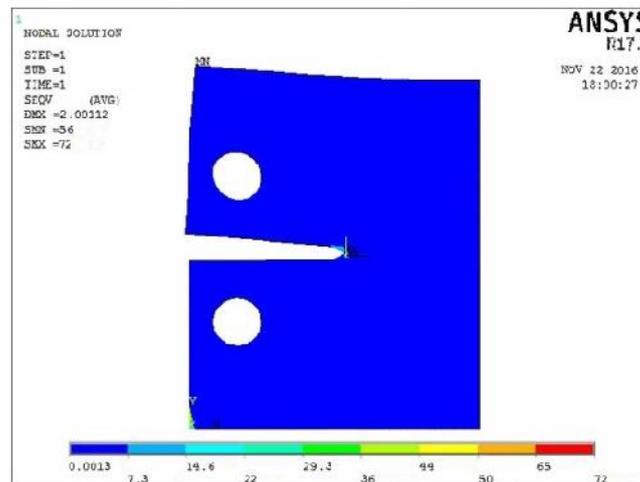


Figure 10 ANSYS compact tension specimen

RESULTS AND DISCUSSIONS

Three results are closer to one another, DIGITAL IMAGE CORRELATION method is nearer to the theoretical value compare to the ansys. The three results are show below

TABLE 1 COMPARISON OF RESULTS

Table 6.2 comparison of results S.NO	METHOD	STRESS INTENSITY FACTOR (K_{IC}) for CT specimen MPa m
1	Theoretical method	167.839
2	DIC method	164.439
3	Numerical method	161.843

CONCLUSION

In this study, displacement based stress intensity factor of a Compact Tension CT specimen polycarbonate plate is determined using digital image correlation method (MATLAB) for various loading conditions. First of all, displacement values obtained from DIC is compared with manually measured displacements from photographs. After observing the calculated SIF values are close enough, further calculations are continued using DIC results. Stress intensity factors obtained from DIC are compared with that obtained from the empirical formula using boundary load values. The results are within 8 % error admissibility. Furthermore, for various loading conditions, calculation of SIF of a CT polycarbonate sample by using displacement based DIC method is verified and results are compared with fracture mechanics derived empirical calculations. Validate the result numerical and theoretical value

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