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Digital Speckle Correlation Test for Fracture of Thin Film

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ABSTRACT

The digital speckle correlation method (DSCM) is a rapidly developing new photomechanics technique used to measure the surface deformation. With its advantages of non-contact, real time, whole field and direct measurement, it can be used from macro-scale area to nano-scale area. This paper describes the use of this method in the experiment of the fracture of copper thin film. The displacement field and strain field in a crack tip region of a thin film are measured. Based on the displacement field and strain field of the crack tip region, the figure of plastic zone is determined. The experimental results indicate that DSCM is a useful method for studying the fracture behavior of thin film.

KEYWORDS

Digital Speckle Correlation, Thin Film, Displacement Field, Strain Field, Plastic Zone

INTRODUCTION

With the rapid development of microelectronics and communication technology, the thin film finds wide applications in microelectromechanical system, microelectronics and molectron, etc. As the mechanical behaviors of film materials are different from which of normal materials and they are directly relevant to the life span and the reliability of the subassembly, the study on mechanical behaviors of films, including fracture behavior, have become a necessary research field. Several techniques have developed to evaluate the mechanical properties of thin film, hardness, Young's modulus and fracture strength , Poisson's ratio [1,2,3], etc., but the study of the crack tip region of thin film remain not sufficiently documented. The difficulty lies in there's few techniques can be applied to thin film material. The formulae and theories of fracture mechanics yielded from macro-scale bodies and the traditional experimental measuring methods are also not always available for thin film materials as the influence of geometrical scale. Therefore, the study on displacement field and strain field in crack tip region of thin film material by experimental means is essential. How to measure the displacement fields and strain fields in crack tip region of thin film material is an unresolved issue till now. The DSCM is used in this paper to test the fracture behavior of thin film.

THE DIGITAL SPECKLE CORRELATION METHOD

The digital speckle correlation method was proposed in 1982 [4,5]. It can measure directly the surface displacement vector and strain tensor to subpixel accuracy [6,7,8,9] and captures wide attention in the development of experimental mechanics recently. This method involves recording, digitizing and processing a pair of speckle patterns of a specimen in different deformation states, one before deformation and another after deformation. If a speckle area in the speckle field before deformation is defined as reference subset and the speckle area corresponding to the subset after deformation is defined as object subset, what is required is to identify the corresponding relation between the two subsets. The difference between the two subsets includes the deformation information of the specimen. Then DSCM becomes a job of comparing subsets between the two digital patterns and the measurement process is converted to a calculation process.

The method for comparing the two subsets is commonly given by use of the correlation coefficient. The correlation coefficient for the two random variables $f(x,y)$ and $g(x^*,y^*)$ can be written in the discrete form as

$$S(\mathbf{X})=1.0-\frac{\Sigma f(x,y)\cdot g(x^*,y^*)}{\sqrt{\Sigma f^2(x,y)\cdot \Sigma g^2(x^*,y^*)}} \tag{1}$$

in which (x, y) and (x^*, y^*) are Cartesian coordinates of a material point in the subset of the undeformed pattern and deformed pattern, respectively. $f(x,y)$ and $g(x^*,y^*)$ are light intensities of that point in the corresponding pattern subsets. The correlation coefficient S(X) shows how closely the two random variables $f(x,y)$ and $g(x^*,y^*)$ are related with S(X)=0 corresponding to perfect correlation.

In general, the coordinates (x, y) are taken at a pixel location, but (x^* ,y^*) are normally not. The relations between x and x^*, y and y^* are given by the following equations:

$$\begin{aligned} x^* &= x+u+\frac{\partial u}{\partial x}\Delta x+\frac{\partial u}{\partial y}\Delta y \\ y^* &= y+v+\frac{\partial v}{\partial x}\Delta x+\frac{\partial v}{\partial y}\Delta y \end{aligned} \tag{2}$$

in which *u* and *v* are the in-plane displacement components of the center point of a subset, $\partial u/\partial x$、$\partial u/\partial y$、$\partial v/\partial x$ and $\partial v/\partial y$ are displacement gradients, and Δx and Δy are components of a distance vector between (x, y) and the subset's center point (x_0, y_0).

EXPERIMENT

The double edge-cracked specimen used in the test was made of copper that was produced in Shanghai smeltery. Its thickness was 40μm. The chemical composition of it is shown in Table 1. The film was made into double-edge cracked specimen in the rolling direction. Its geometry and dimensions are shown in Figure 1. In order to obtain a high quality speckle pattern and improve the sensitivity and accuracy, the speckle was made artificially. A random speckle pattern is shown in Figure 2.

TABLE 1
CHEMICAL COMPOSITION OF EXPERIMENTAL MATERIAL (%)

Cu	Fe	Zn	O	Pb	S	Ni
99.91	0.0035	0.001	0.003	0.001	0.001	0.001

The specimen was placed into the specially designed clamp. Then the locations of the CCD camera, lens and light source were adjusted until the speckle pattern was satisfied. The imaging system for the tests is shown in Figure 3. In order to diminish the out-of-plane displacement, an initial load F_0 was applied. Then the digital speckle pattern was recorded before and after a load F_1, respectively. The couple digital patterns were the original data for the digital speckle correlation method. The digital correlation technique was then applied to analyze the digital images.

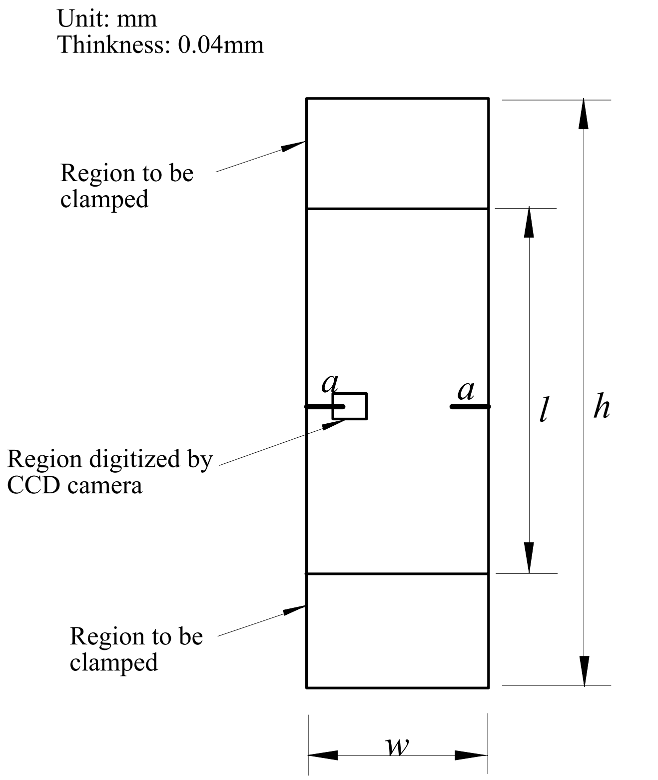


Figure 1: Dimensions of the specimen
(In which a =5, w=25, h=80 and l=50.)

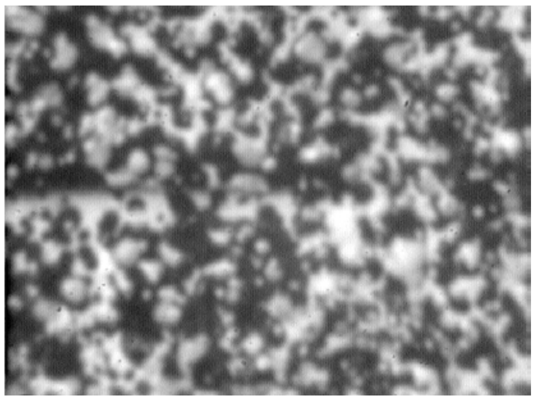


Figure 2: A Speckle pattern

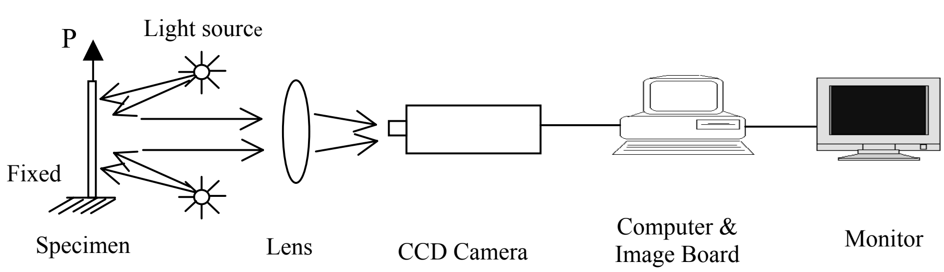


Figure 3: Image system used in the test

It is necessary to know the displacement field and strain field during studying the crack tip region and the plastic zone is the area of interest. Firstly, a pre-load 6.6N was applied, then the first speckle pattern was recorded. Secondly, a load 188.1N was applied and the second speckle pattern was recorded. At last, the digital correlation technique was applied to analyze the first and second digital images. The digitized region and the region calculated by DSCM are shown in Figure 1 and Figure 4. The distributions of the displacement v(x, y) and the normal strain ε_y of the crack tip region were obtained, as shown in Figure 5.

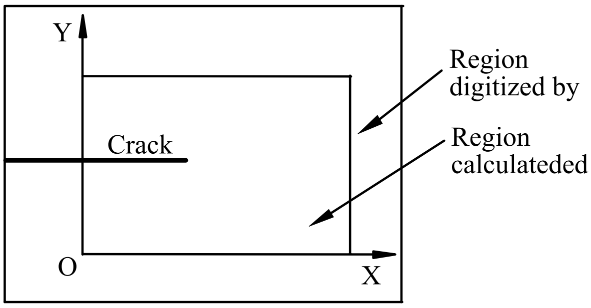
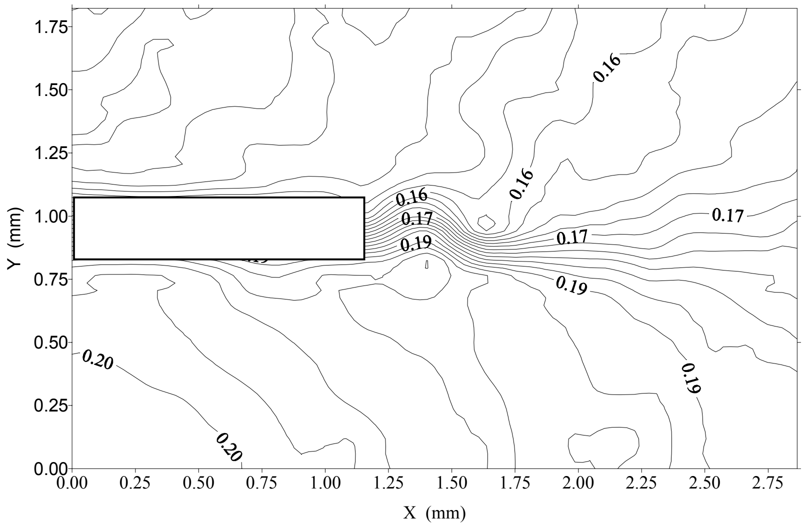
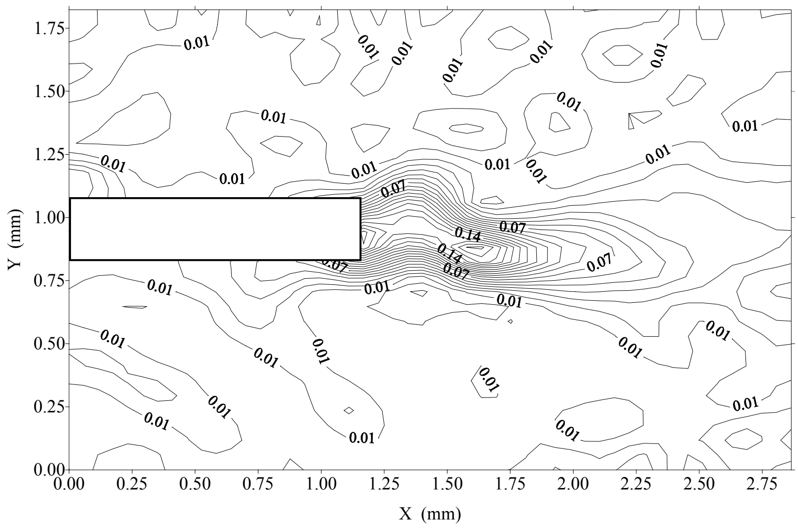


Figure 4: Illustration of the region calculated by DSCM



(a) Contour of displacement V field



(b) Contour of strain ε_y field

Figure 5: Distribution of displacement field and strain field at the crack tip

From Figure 5, we can see the shape and the size of the plastic zone at the crack tip under given a given load.

CONCLUSION

In this paper the digital speckle correlation method is applied to the experiment of mechanical properties of the copper film. The measurement of displacement field and strain field of the crack tip region is achieved and the contour maps of displacement field and strain field of the crack tip region under given load are shown. The figure and size of the plastic zone are also determined. The present experimental results indicate that DSCM is a useful test technique in studying the fracture behavior of thin film material in future. And it is possible using this technique to study the propagating of the plastic zone in the crack tip region with the loading increase.

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