Two-Dimensional Electron Moiré Method Using Digital Thermal Field Emission Scanning Electron Microscope*

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Abstract

A novel electron Moiré method to measure the two-dimensional deformation at the same time has been developed. An electron Moiré fringes which indicate two-dimensional deformation can be observed by using a digital thermal field emission scanning electron microscope. For the demonstration of this method, two-dimensional strain distribution on the specimen of fiber reinforced plastic was measured by using this method. 5-micro meter spacing rectangular micro-grid was fabricated on the specimen’s surface by electron beam lithography. After deformation, the micro-grid on the specimen’s surface was observed by an thermal field emission scanning electron microscope. An electron Moiré fringe image which indicate two-dimension electron Moiré fringe was observed. From this image, two-dimensional strain (strain parallel to the loading axis and strain perpendicular to the loading axis) distribution was calculated by using the spacing of the electron Moiré fringe and the spacing of the electron beam scan.

Key words: electron beam Moiré fringe, Moiré, scanning electron microscope, strain

1. Introduction

It is very important to measure the local strain and stress distribution for understanding the mechanical properties of structural materials. Therefore, there are a lot of techniques to measure the strain or stress distribution such as strain gage method, photo elasticity method, optical Moiré method, etc. In these methods, the optical Moiré method [1] is one of the convenient methods to measure the deformation of the materials [1-8]. However, these methods are difficult to apply for the deformation measurement on a microscopic aspect. To measure the micro-deformation in very small area, authors are developed an electron Moiré method [9, 10] and J.W. Dally and D.T. Read advocated it [11-12]. This method keeps the main advantages of Moiré and laser Moiré interferometry methods [13-17], and has an additional ability of measuring deformation in a micro-area with high sensitivity [18]. However, these electron Moiré methods can measure the deformation of one direction. (x or y direction).

In this study, a novel electron Moiré method to measure the two-dimensional deformation at the same time has been developed. An electron Moiré fringes which indicate two-dimensional deformation can be observed by using a digital thermal field emission scanning electron microscope. For the demonstration of this method, two-dimensional strain distribution on the specimen of fiber reinforced plastic was measured. A 5-micro meter spacing rectangular micro-grid was fabricated on the specimen’s surface by electron beam.
After deformation, the micro-grid on the specimen’s surface was observed by a thermal field emission scanning electron microscope (FE-SEM). Also an electron Moiré fringe image which indicates two-dimensional electron Moiré fringe was observed. From this image, two-dimensional strain (strain parallel to the loading axis and strain perpendicular to the loading axis) distribution was calculated.

2. Principles

2.1 Observation of Electron Moiré Fringe

The principle of the electron Moiré method is shown in Fig. 1. A model grid is prepared on the surface of the specimen by electron beam lithography before deformation. An electron beam scan having spaces almost the same as that of the model grid can be used for the master-grid. If the amount of emitted secondary electrons per a primary electron of the model grid is different from that of substrate, these differences make the Moiré fringes (electron Moiré fringes) that consists bright and dark parts.

2.2 Observation of Two Dimensional Electron Moiré Fringe

A principle of this two-dimensional electron Moiré method is shown in Fig. 2. A cross model grid of different material from that of the specimen is prepared on the surface of the specimen before deformation. This model grid must be observed brighter or darker than substrate (specimen) by SEM. Therefore, the materials of this grid must have the different amount of secondary electrons per a primary electron from that of the substrate. A dots like electron beam scan (pixel) having spaces almost the same as that of the model grid is used for the master-grid. The difference in the amount of the secondary electrons per a primary electron makes the difference of the brightness of each square pixel. Then this phenomena makes two-dimensional electron Moiré fringes (x and y directions) that consists bright and dark parts (Fig. (c) and (d)).

2.3 Strain Measurement

The schematic formation of Moiré fringe is shown in Fig. 3. Using the Moiré patterns
corresponding to the x-direction or y-direction), the components of strain $\varepsilon_x, \varepsilon_y$ in the x-y plane can be calculated by equations (1).

\begin{align*}
\varepsilon_x &= \frac{a}{d_x} - \frac{a'-a}{a} \\
\varepsilon_y &= \frac{a}{d_y} - \frac{a'-a}{a}
\end{align*}

(1)

In case $a_x, a_y > a$,

\begin{align*}
\varepsilon_x &= \frac{a}{d_x} - \frac{a'-a}{a} \\
\varepsilon_y &= \frac{a}{d_y} - \frac{a'-a}{a}
\end{align*}

In case of $a_x, a_y < a$,

\begin{align*}
\varepsilon_x &= -\frac{a}{d_x} - \frac{a'-a}{a} \\
\varepsilon_y &= -\frac{a}{d_y} - \frac{a'-a}{a}
\end{align*}
where \( a \) demotes the pitch of the master grating (i.e. the spacing of electron beam scan), \( d_x \) demotes the spacing of the Moiré fringe in the \( x \)-direction, \( d_y \) denotes the spacing of the Moiré fringe in the \( y \)-direction. And \( a'_x \) and \( a'_y \) demote the pitch of the model grid in \( x \)-direction and \( y \)-direction before exerting the load, respectively.

3. Experimental Method

3.1 Grid Preparation

The procedure for producing a model is shown in Fig.4. The specimen must first be polished to a mirror-like finish (up to \( 0.05 \mu \text{m} \) \( \left( \text{Al}_2\text{O}_3 \right) \) powder), then it is covered with an electron-sensitive layer (electron beam resist, Nippon Zeon ZEP-520-22 and Toray EBR-9), spinning at a speed of 2,500 RPM for 60 seconds, and then baked in an oven for 30 minutes at 180 °C for ZEP-520-22 and spinning at a speed of 2,000 RPM for 60 seconds, and then baked in an oven for 30 minutes at 195 °C for EBR-9.

![Fig. 4 Schematic for fabrication of the model grid](image)

Fig. 4 Schematic for fabrication of the model grid
The specimen was then mounted on the specimen stage in a TOPCON SX-40A SEM for the electron beam exposure. After electron beam exposure, the specimen coated by ZEP-520 was developed in a solution of ZED-N50 for 60 seconds, and then immediately rinsed in ZMD-B for 30 seconds. The specimen coated by EBR-9 was developed in a solution of Type 1 for EBR-9 for 60 seconds, and then immediately rinsed in 2-propanol for 30 seconds. The specimen was coated with a very thin layer (10-20 nm) of gold by sputtering method.

The difference in the emitted amount of the secondary electrons per a primary electron between the surface and the deposited layer must be large enough to get produce a contrast in the electron Moiré fringe. After removing the electron beam resist using an organic solvent, a model grid is formed on the specimen surface. Fig. 5 shows an example (SEM images) of the model grid with pitches of 5 μm fabricated by this method.

4. Results and Discussion

4.1. Observation of two-dimensional electron Moiré fringes.

Figure 6 shows an electron Moiré fringe observed by a field emission scanning electron microscope (FE-SEM: SHIMADZU Quanta TM FEG). If we use suitable magnification, a cross electron Moiré fringe can be observed. Figure 6 shows an electron Moiré fringe observed before bending test. A rectangular electron Moiré fringe was observed with bright and dark parts.

Figure 7 (a) and (b) shows an electron Moiré fringe observed by FE-SEM during bending test. From these figures, the strain in the direction perpendicular to the loading direction, $\varepsilon_x$, and the strain in the direction parallel to the loading direction, $\varepsilon_y$, is calculated by using equation (1) and shown in Fig. 7 (a) and (b), respectively. The calculated strain in both directions is compressive strain in almost parts.

During three-point bending test, a crack initiated. In Fig. 7 (a), the strain, $\varepsilon_x$, upper side of the crack is larger than that under side of the crack.

![Fig.7 Electron Moiré fringe images during bending test and strain distribution of $\varepsilon_x$; (a) and $\varepsilon_y$; (b), respectively](image)

5. Conclusions

The two-dimensional electron Moiré method was applied to measure the strain distribution in the deformed specimens by three point bending test. And this method has been applied to measure the strain distribution. A scanning electron microscope was used to fabricate very fine model grids on the specimen surfaces and to observe the electron Moiré fringes. The strain distribution in FRP specimen was measured by the Moiré pattern produced by the interference of the grid and the scanning electron beam scan.

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References


