DETERMINATION OF DRIFT DISTORTION IN SEM MICROGRAPHS ACQUIRED AT DIFFERENT MAGNIFICATIONS AND ACQUISITION TIMES

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Summary: *In the experimental mechanics wide variety of optical methods including measurement of deformation at reduced length scales using combination of computer vision and scanning electron microscopy (SEM) have been recently applied. One of suitable methods for in-plane measurement of displacements and deformations in the micrographs obtained by SEM is the 2D digital image correlation. In contrast to images obtained in visible spectrum by classical optical devices temporally-varying distortions known as drift distortion are present in the SEM micrographs. These distortions are caused by positional errors of electron beam during scanning process. Magnitude of this effect decreases with higher conductivity of the sample and is also influenced by magnification and scanning time. For this purpose measurement of distortion was performed on a series of micrographs of conductive samples acquired at different magnifications and acquisition times. Surface of each sample was covered with liquid silver to ensure adequate contrast pattern necessary for determination of distortion's magnitude and distortion magnitudes were assessed.*

Keywords: *drift distortion, scanning electron microscopy, digital image correlation*

1 Introduction

In experimental solid mechanics many of studies are focused on investigation of large variety of materials under mechanical or thermal loading at micro-scale [1, 2, 3]. Both interferometric and non-interferometric optical methods can be successfully applied for this purpose. Nevertheless classical optical imaging system has limited magnification (approx. $1000\times$) due to nature of the visible light. Hence scanning electron microscopy (SEM) and 2D digital image correlation (2D-DIC) are suitable methods for in-plane measurement of shifts and motions in loaded materials below the optical magnification limit. In contrast to images obtained by optical camera, SEM micrographs are acquired by line scans of an electron beam across surface of a sample. Electron beam shift is controlled by electromagnetic lenses and therefore the micrographs also contain positional errors caused by environmental and system variables - phenomenon is known as a drift distortion. One of the most common causes of drift distortion is charging of the specimen. For this reason it is necessary to coat insulator specimens with thin conductive layer to prevent the charge accumulation in the scanned area. In this paper drift distortion measured on samples covered with thin silver layer forming stochastic speckle pattern is assessed by utilizing custom 2D digital image correlation (2D-DIC) algorithm to show that shape and dimension measurements may lead to significant error when effects of specimen charging during SEM imaging are not taken into account.

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2 Materials and methods

In this paper drift distortion in micrographs recorded using BSE mode to achieve high contrast between phases due to difference in backscattering coefficient dependent on the atomic number Z were assessed. Aluminium sample holder normally used for mounting samples was used as specimen. The holder was coated with thin layer of silver paint chosen due to its excellent conductivity. Dried specimens were scanned by SEM MIRA II LMU (Tescan, CZ) in high vacuum mode at different magnifications and acquisition times. The other imaging parameters including dwell time, acceleration voltage, probe current and working distance were kept identical (see Tab. 1).

Table 1: SEM imaging parameters

Parameter	Value	
Scan mode	Resolution	
Accelerating voltage	15	kV
Working distance	15	mm
Spot size	37.9	nm
Probe current index	1	
Dwell time	1.76	$\mu\mathrm{s}$
Image size	1024×1024	px
Pixel size	$17.86 - 178.6$	nm

Determination of time and magnification dependence of distortion was performed on set of consecutive micrographs recorded after 100, 200, 300, 400, 500 and 1.000 s and each set was acquired at $667\times$, $1333\times$, $4000\times$ and $6670\times$ magnifications. The distortion rate was computed using custom 2D-DIC tool for Matlab identifying horizontal and vertical displacements using first order transformation equation [4]. The principal of image matching is based on correlation of grayscale values of independent groups of coordinates (subsets) in reference image with the corresponding subsets in the current image [5] according to the following relations:

$$x'_{\mathrm{cur,i}} = x_{\mathrm{ref,i}} + u_{\mathrm{rc}} + \frac{\partial u}{\partial x_{\mathrm{rc}}}\left(x_{\mathrm{ref,i}} - x_{\mathrm{ref,c}}\right) + \frac{\partial u}{\partial y_{\mathrm{rc}}}\left(y_{\mathrm{ref,i}} - y_{\mathrm{ref,c}}\right) \quad (1)$$

$$y'_{\mathrm{cur,j}} = y_{\mathrm{ref,j}} + v_{\mathrm{rc}} + \frac{\partial v}{\partial x_{\mathrm{rc}}}\left(x_{\mathrm{ref,i}} - x_{\mathrm{ref,c}}\right) + \frac{\partial v}{\partial y_{\mathrm{rc}}}\left(y_{\mathrm{ref,j}} - y_{\mathrm{ref,c}}\right) \quad (2)$$

where $x_{\mathrm{ref,i}}$ and $y_{\mathrm{ref,j}}$ are the x and y coordinates of an initial reference subset point, $x_{\mathrm{ref,c}}$ and $y_{\mathrm{ref,c}}$ are the x and y coordinates of the center of the initial reference subset, $x'_{\mathrm{cur,i}}$ and $y'_{\mathrm{cur,j}}$ are the x and y coordinates of a final current subset point.

3 Results

The obtained results show increasing shifts of separate pixel subsets with increasing magnification and scanning time (Fig. 1). The highest shifts in both u and v directions were observed in the set of micrographs acquired at $667\times$ magnification while the lowest difference was recorded in the micrographs acquired at $1333\times$ magnification (see Tab. 2 and Fig. 2). Gradual increase of shift in dependence on the scanning direction of the electron beam in the case of the micrographs acquired at $667\times$ magnification is clearly visible. This trend however dissipates on higher magnifications and the displacement field is nearly homogeneous at the $6670\times$ magnification (Fig. 1).

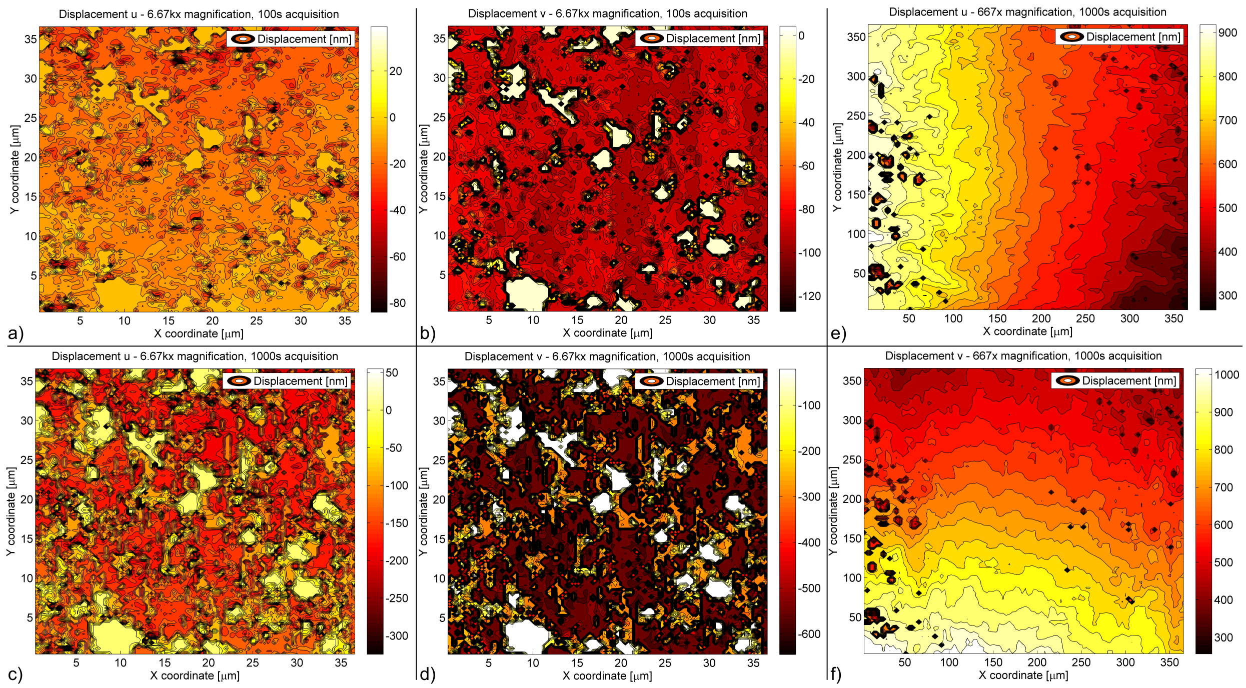

Figure 1: Comparison of the u (*a*, *c*) and v (*b*, *d*) displacement fields in $6670\times$ magnified micrographs acquired after $100\,\mathrm{s}$ and $1000\,\mathrm{s}$. Figures *e* and *f* show u and v displacements in the micrograph acquired at $667\times$ magnification after $1000\,\mathrm{s}$. (positive and negative trends represent the subset shifting to the right/left for u displacement and down/up for v displacement)

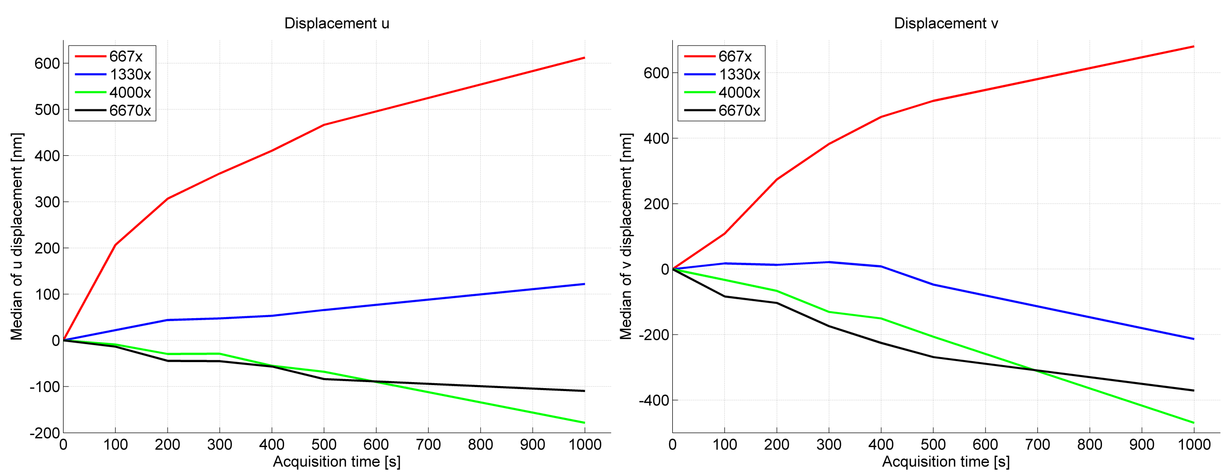

Figure 2: Diagrams showing dependence of the median values of u and v displacements on the acquisition time and magnification (positive and negative trends represent the subset shifting to the right/left for u displacement and down/up for v displacement).

Table 2: Median values of u and v displacements in nm recorded at different magnifications and acquisition times

	667×		1330×		4000×		6670×	
	u	v	u	v	u	v	u	v
100 s	206.78	108.76	22.00	17.59	-8.84	-32.98	-13.58	-83.46
200 s	306.69	274.03	44.06	13.25	-29.31	-66.49	-44.32	-103.23
300 s	361.27	382.60	47.62	21.63	-28.86	-130.78	-44.84	-174.22
400 s	410.67	465.37	53.24	8.47	-54.89	-150.65	-56.41	-225.38
500 s	466.56	514.31	65.80	-47.14	-67.91	-206.49	-83.78	-268.75
1000 s	612.02	680.66	122.18	-213.58	-178.38	-469.62	-109.45	-370.93

4 Conclusion

Displacement fields in series of SEM micrographs of silver coated specimen captured at different magnifications after various scanning times were calculated using custom 2D-DIC algorithm. Results show that for MIRA II LMU imaging system the highest distortion occurs for 667× magnification where the displacement field is also inhomogeneous showing gradual increase of drift along scanning directions. The acquired results provide basis for correction procedures that should be applied on geometrical information extracted from the micrographs to avoid errors due to drift distortion phenomenon.

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