

High accuracy in micro-mechanical deformation measurements: Eliminating SEM artifact-induced errors

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Introduction

The emergence of small scale mechanically-active devices, such as M(O)EMS, N(O)EMS, flexible and stretchable micro-electronics, introduced the necessity of better understanding about mechanical properties at the micro- or nano-scale. This requires a variety of miniaturized mechanical tests ranging from tension, compression and bending to FIB-based hole drilling for residual stress measurement. In-situ visualization capabilities based on different microscopy methods has played an important role in this field. What is also important are good techniques to extract quantitative full-field mechanical deformation data from the images provided by these methods, notably SEM which provides high resolution as well as relative ease of use.

SEM images, however, exhibit complicated artifacts that result in considerable errors in deformation measurements, unless they are corrected for. Correction algorithms are available in the literature, which prove to be effective to a certain extent, however, a generic framework for dealing with these artifacts is lacking.

Here we present a general methodology based on DIC that includes the evaluation of all SEM artifacts alongside the mechanical deformation measurement. This ensures the elimination of the artifact-induced errors in a mathematically consisted framework. This framework has been verified on virtual images showing the effectiveness of the procedure and the high accuracy is demonstrated. As an example, SEM images captured during an in-situ micro-tensile test on an IF steel specimen are correlated by this method, demonstrating the robustness in practice.

Results

Virtually generated patterns were deformed by an inhomogeneous mechanical deformation field, alongside three different distortion fields representing SEM artifacts. The images were then correlated using the proposed Global DIC (GDIC) framework. Figure 1, depicts the total deformation and distortion field applied in x direction as well as the error in the evaluation of the deformation field in case of correcting for the artifacts and not.

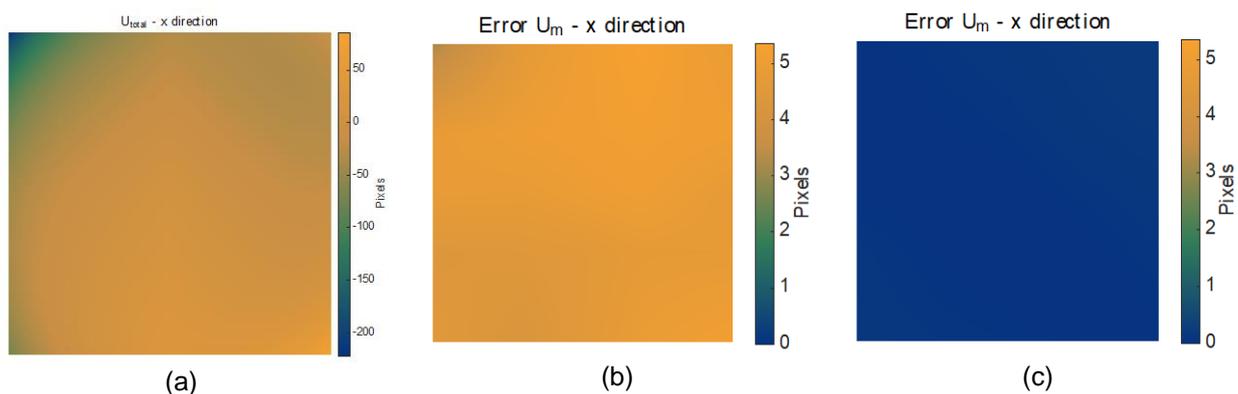


Figure 1. Results of the virtual experiment, (a) total deformation and distortion field in x direction, (b) error of the evaluation of the mechanical field in x direction without correcting the artifacts, (c) error of the evaluation of the mechanical field in x direction with correcting the artifacts.

The proposed framework was implemented to a series of SEM images of an electrodeposited Cu specimen. Two examples of these images are presented in Figure 2, representing two different cases of

magnification. Three kind of SEM artifacts as categorized in reference [1] have been evaluated alongside the mechanical displacement field for these sets of SEM images. Figure 3(a) shows the measured drift artifact in x direction for a set of images with horizontal field of view of $25 \mu\text{m}$ and working distance of 10 mm , and figure 3(b) shows the spatial distortion field in radial direction for the set of SEM images with horizontal field of view of $200 \mu\text{m}$ and working distance of 15 mm .

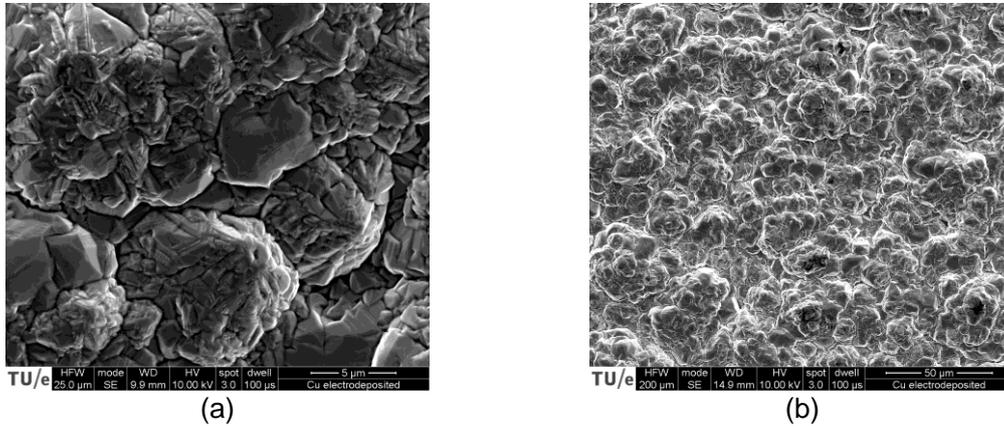


Figure 2. SEM micrographs of an electrodeposited copper specimen using secondary electron contrast mode, (a) horizontal field of view of $25 \mu\text{m}$ and working distance of 10 mm , (b) horizontal field of view of $200 \mu\text{m}$ and working distance of 15 mm

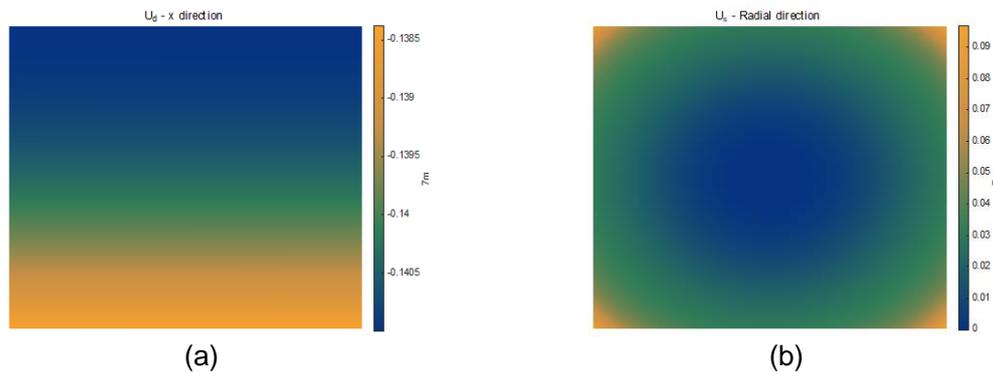


Figure 3. Evaluation of artifact fields, (a) drift distortion field (x direction) of SEM image with horizontal field of view of $25 \mu\text{m}$ and working distance of 10 mm , (b) spatial distortion field (radial direction) of SEM image with horizontal field of view of $200 \mu\text{m}$ and working distance of 15 mm

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References

[1] Sutton, M.A., Li, N., Joy, D.C., Reynolds, A.P. & Li, X. (2007). Scanning electron microscopy for quantitative small and large deformation measurements part I: SEM imaging at magnifications from 200 to 10,000. *Exp Mech* 47, 775–787