Microscale residual stress measurement in steel using focused ion beam slotting and digital image correlation

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This paper describes experimental procedure for measuring residual stress on sub-grain scale in metals using focused ion beam (FIB) milling and digital image correlation (DIC). In contrast to most previously published research in this area the authors applied the method to steel samples and used FIB for imaging as well as for milling.

In this work residual stress was simulated by uniaxial compressive applied stress. To this end a 20x5x3mm mild steel sample was compressed uniaxially below the elastic limit to 400MPa using a simple clamp loaded by M8 bolt. The loading strain was monitored with a strain gauge.

The sample was polished and positioned under the focused ion beam (FIB). The FIB principle is similar to the more conventional SEM with the exception that heavy gallium ions are used instead of electrons to bombard the metal surface. The FIB was used in this work both as a micro-milling and as imaging tool. The sample was positioned normal to the incipient ion beam. Initial surface preparation involved uniform exposure to the beam (so-called etching) to remove the oxide layer. A very useful side effect of etching is that it reveals identifiable surface features. After etching an image of the initial surface was taken with FIB. Then FIB milling was done normal to the sample surface which produced a 12x1x3.5 micron (length x width x depth) slot in the first experiment and a 20x1.5x6.5 micron slot in the second experiment. Finally the second image of the sample surface, capturing surface relaxation due to slotting, was registered with FIB. After that the slot profile was measured with a second cut across the slot.

The surface relaxation was measured with a 2D digital image correlation (DIC) method using FIB images. The raw output of the DIC method were displacement fields due to stress release after slotting. The maximum displacements on the slot flanks were only 20 nm.

The experimentally measured displacements were compared with those calculated with 3D finite element (FE) model of the test. A good qualitative and quantitative agreement was observed. Some disagreement between the FE model and the experimental results are attributed to the oversimplified FE model which used isotropic elastic material behaviour.

The paper will discuss ways of achieving optimal image quality with FIB imaging, creation and preservation of artificial surface patterns with FIB, effects of grain orientation on slot depth and measured displacement.

Keywords: focused ion beam (FIB), digital image correlation (DIC), slotting, steel, microscale, residual stress