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In-situ Testing to Acquire HR-EBSD and DIC Strain Data Within a Coincident Domain

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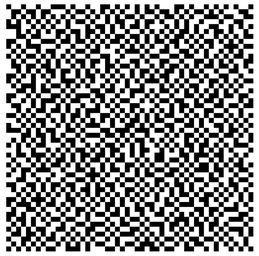
Abstract

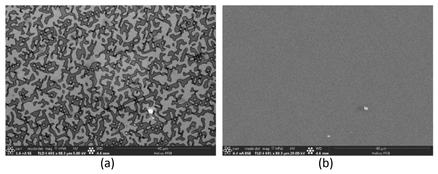
For this project, an inked rubber stamp was applied to a small Inconel 625 specimen. The stamp transferred a thin pattern with microscale features for digital image correlation (DIC). The pattern is easily visible at lower voltages and thin enough to not obstruct backscattered electrons. The unique characteristics of the pattern enabled the concurrent acquisition of DIC and high-resolution electron backscatter diffraction (HR-EBSD) data while the specimen was loaded in-situ. The challenges of in-situ testing and combining EBSD with DIC measurements are discussed. By combining the elastic strains (from HR-EBSD) and total strains (from DIC) the result of this approach is an estimate of stress-strain behavior at points across the specimen surface. This combined dataset can then be used as higher-fidelity data in the calibration of crystal plasticity models.

Background

- This project continues the methods of coupling digital image correlation (DIC) and high angular resolution electron backscatter diffraction (HR-EBSD) methods to characterize the role of microstructure on the deformation of polycrystalline materials by uncoupling contributions by elastic deformation gradients, slip, and rigid body rotations from the total deformation gradient [1,2]
- Typical methods of applying DIC patterns to a material are unsuitable for this method to be applied over a coincident domain for several reasons
  - Cover up important details, i.e., fatigue crack initiation
  - Prevent accurate collection of diffraction patterns via EBSD
- Micro speckle stamps can be created using urethane rubber, which exhibits the selectively electron-transparent behavior desired [3,4]
- The proposed methods allow for the design of speckle patterns for use as master patterns, removing the randomness of typical methods and allowing important characteristics of DIC patterns to now become design parameters while optimizing for accuracy and precision [5]



Example image of optimized DIC pattern used to create micro speckle stamps [5]

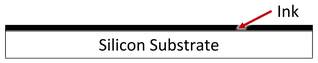


(a) (b)

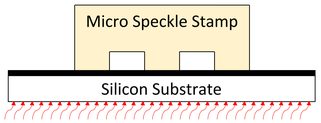
Comparison of ROI imaged a) using a secondary electron detector at 5 kV and 1.6 nA and b) backscatter electron detector at 20 kV and 6.4 nA [3]

Methods

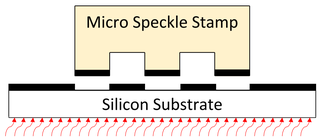
- Addition of ink to the residual layer method allowing for easier reproduction of DIC pattern and enabling the use of optical techniques [3]
- Master pattern designed to have even split of light and dark features, average speckle size of 1μm, and rounded features to prevent the joining of features



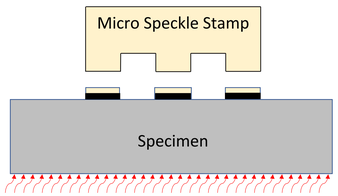
1. Create inkpad
   - A thin layer of ink is applied to a silicon substrate with a spin coater
   - The goal is to have an ink layer thinner than the feature depth of stamp



2. Ink stamp
   - Heat is applied to the inkpad to help transfer ink from inkpad to stamp
   - Stamp is adhered to surface and ink is allowed to transfer for two minutes



3. Remove stamp
   - Stamp is removed from inkpad and stored in desiccator and allowed to dry
   - Best results have come after letting the stamp dry for several days

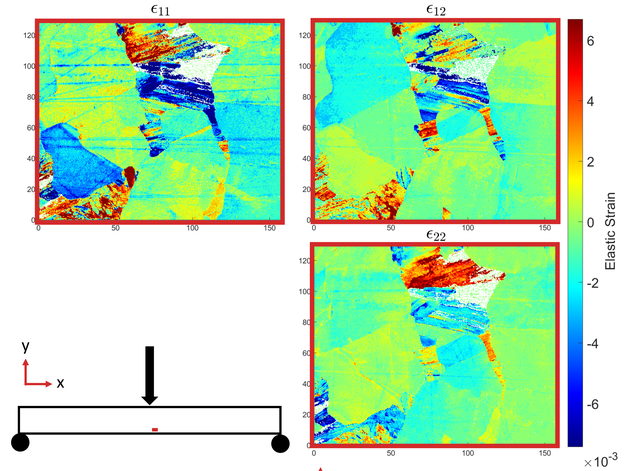


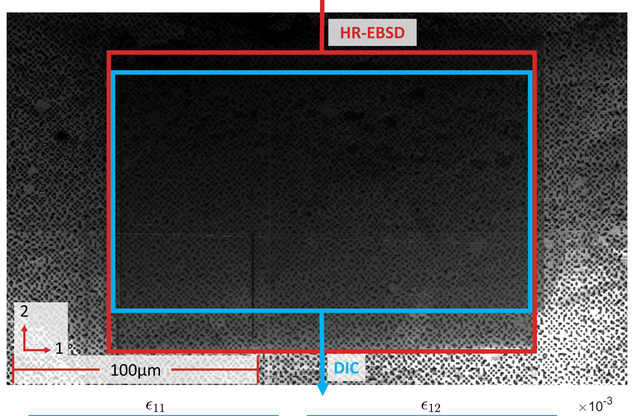
4. Apply stamp to surface
   - The specimen is heated to a temperature slightly below the melting temperature of the urethane rubber (110°-120° C)
   - Stamp is applied and lightly tapped with tweezers for 90 seconds
   - Residual layer of ink and urethane is deposited, stamp is removed
   - Specimen is left on heat for an additional eight minutes to cure rubber

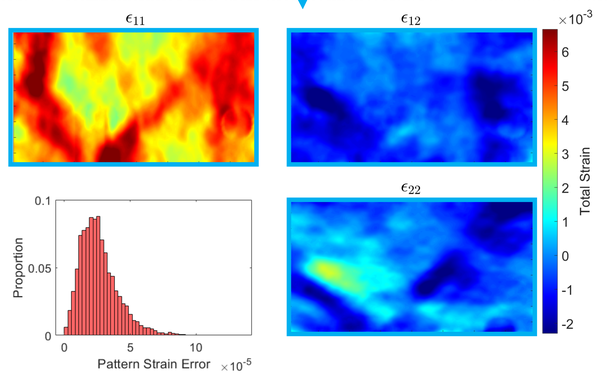
- After stamping the specimen is placed in a three-point bending fixture mounted to the stage of SEM
- DIC reference and calibration images are collected, and the specimen is deformed
- DIC images are collected for the deformed configuration
- SEM stage is rotated, EBSD camera inserted, and data is collected
- Perform data analysis

Results

- Data collected from an additive manufacture Inconel 625 specimen using the FEI Teneo SEM and EDAX Velocity Super EBSD Camera
- DIC images processed with open-source software Ncorr [6]
- HR-EBSD data processed offline with the open-source software OpenXY [7]







Conclusion

- Micro speckle stamps allow for easily repeatable, selectively electron-transparent DIC patterns to applied to a surface
- Addition of ink allows for easier replication of pattern and enables the method to be used with optical techniques
- Optimized, computer-generated speckle patterns enable important characteristics to become design parameters, increasing accuracy and precision while eliminating randomness of traditional DIC pattern methods
- The proposed method have the capability to collect DIC and HR-EBSD data over a coincident domain
- Results will allow further characterization and understanding of the role of microstructure on deformation of materials

Future Work

- Work to understand and minimize possible carbon contamination resulting from the application of DIC pattern
- Register DIC and HR-EBSD data to allow each data point to be used for uncertainty quantification and calibration of crystal plasticity models [2]
- Extending mechanical testing to include fatigue testing to expand understanding of crack initiation

Acknowledgements and References

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Micro speckle stamps are created by 1900 Engineering LLC. Information is available at researchmicrospeckle.com.

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