Microscale Residual Stress Measurement In Rolled Materials

Cesar Ortiz Rios, Dr Joseph W. Newkirk
Materials Science and Engineering

Abstract

Residual stress exists within a material without an applied external force. Depending on its direction, it can improve or deteriorate a material's mechanical performance. A microscale residual stress measurement technique, micro-slotting, was developed at MS&T and has been applied to rolled steel bars. Micro-slotting makes use of a focused ion beam (FIB) system, digital image correlation (DIC), and finite element analysis (FEA) to evaluate residual stresses with measured relief strains. Limitations to the technique that were not previously considered have been studied as well.

Introduction

- Compressive residual stress at a surface is desirable for inhibiting crack propagation.
- Microscale residual stresses lack reliable measurement techniques.
- MS&T has developed micro-slotting for microscale residual stress measurement.
- The technique was applied to rolled steels for their high surface stresses.
- FEA was used to estimate the limitations of the method.

Micro-Slotting

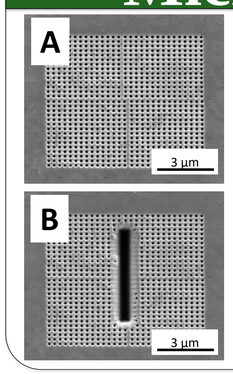
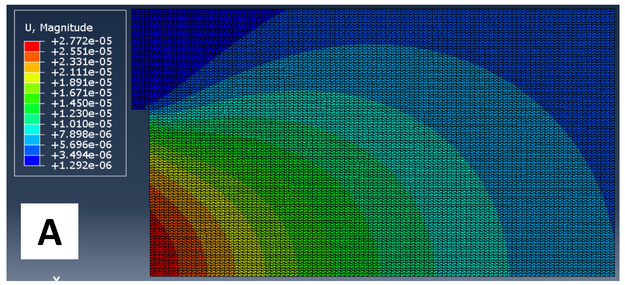


Figure 1: A FIB system is used to mill a grid of points and a slot. The before (A) and after (B) images are input into a DIC program to measure strain from the stress relief. Accuracy of the method is dependent on knowledge of the grain structure.

Lower Limit of Detection



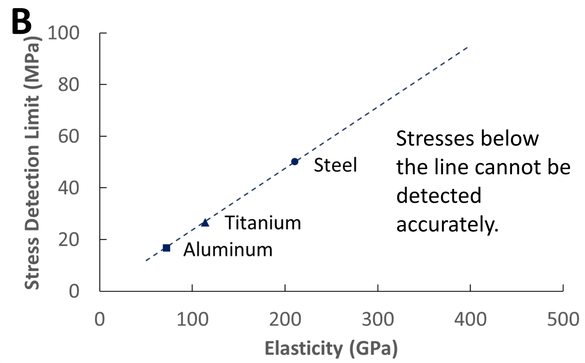


Figure 2: FEA results used to correlate measured relief strains to residual stresses (A). Properties are varied to generate the detection limit of this technique as a function of Young's modulus for application to other materials (B). Stresses below the line cannot be accurately measured, so ~50 MPa is the lower limit of detection for steels. Factors considered in the calculation of the lower detection limit include imaging resolution and magnification, DIC subpixel accuracy, and slot geometry.

Residual Stress in Rolled Materials

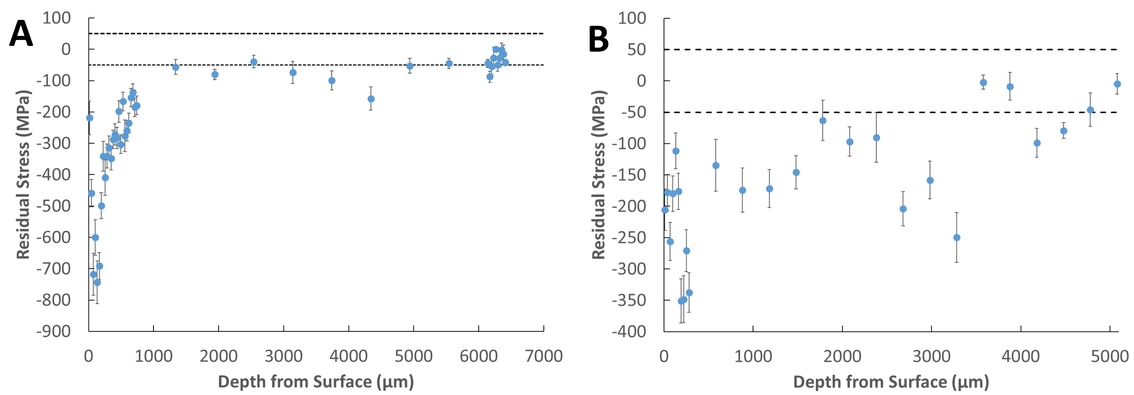


Figure 3: Residual stress as a function of depth from surface for hot-rolled 304 stainless steel (A) and cold-rolled 4140 steel (B). Both steels exhibit a compressive surface stress. The dotted lines represent the detection limit for these steels. Measurements were taken from the surface to the centerline of each bar. A tensile stress is expected near the center line, but was not detected. The tensile stress may be too low magnitude to be measured with the current method.

Conclusions

- Micro-slotting is a reliable method for qualitatively evaluating residual stresses in rolled materials.
- The limitations of the current method have been quantified.
- Low magnitude stresses are difficult to evaluate in stiffer materials.
- Compressive stresses were detected in rolled steels, but tensile stresses may be too low magnitude to detect with the current method.

Future Work

- Optimization of imaging parameters and slot geometries to minimize the detection limit for stiffer materials.
- Re-evaluation of the rolled bars with a minimized detection limit to find the expected tensile stress.
- Investigation of the grain structure to generate accurate, quantitative results.
- Calibration of the method using a known applied stress.
- Application of the method to additively manufactured components.

Acknowledgements

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