Localized Manipulation of Martensite Transformation in Double-Sided Incremental Forming Through Deformation Path Control

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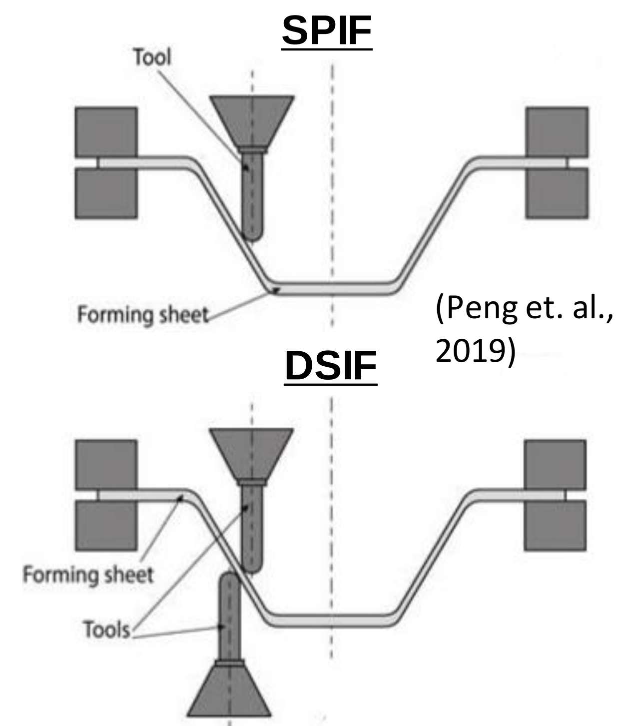
Introduction

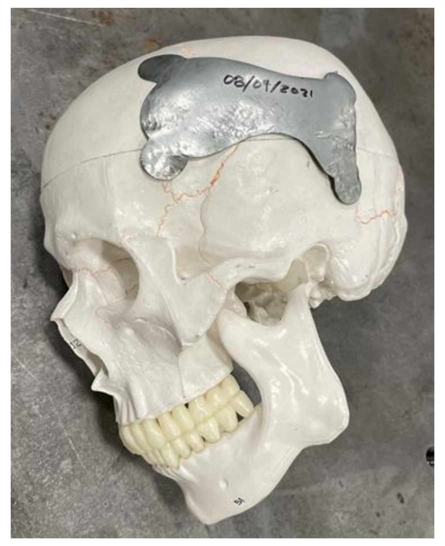
Single-point incremental forming (SPIF) is a process in which the spatial movement of a hemispherical-tip tool forms the sheet locally via Computer Numerical Control (CNC), thus eliminating the need to fabricate specific dies for each workpiece. However, geometric inaccuracies can occur. To address this limitation, double-sided incremental forming (DSIF) incorporates a back tool, synchronized with the path of the front tool, to compress the sheet, thereby enhancing accuracy and increasing formability.

This highly flexible process could allow for rapid production of patient-specific trauma fixation hardware and provides the opportunity to alter the mechanical properties through austenite to martensite transformation in biocompatible stainless steel. By inducing localized martensite transformation, specific regions can acquire enhanced strength, e.g. screw locations, while other regions remain ductile.

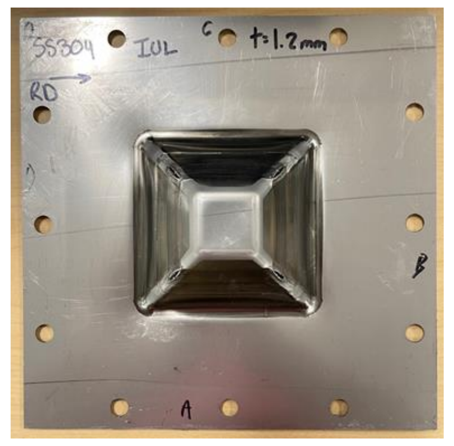
This research focuses on exploring a method to control martensite transformation locally at certain regions of the part. To this end, a truncated pyramid was formed using SS304L, a material known for exhibiting higher martensite phase transformations upon deformation compared to other stainless steels.



SPIF and DSIF process schematics



Cranial trauma fixation hardware model



Formed SS304L truncated pyramid

Hypothesis

The manipulation of DSIF tool paths allows for localized control of α' martensite volume fraction (MVF) at various regions of the part, leading to the regulation of mechanical properties in the final product.

Measurement

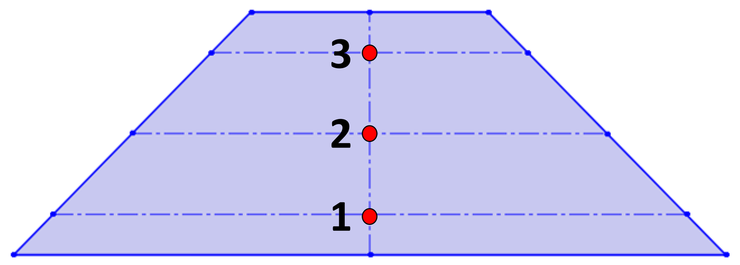
MVF measurements

- MVF was measured using a Fischer Feritscope FMP30 at three deformation locations in the middle of each of the four pyramid walls.

Fischer Feritscope

Pyramid measurement locations

1. ~5.00 mm from base
2. ~15.00 mm from base
3. ~25.00 mm from base

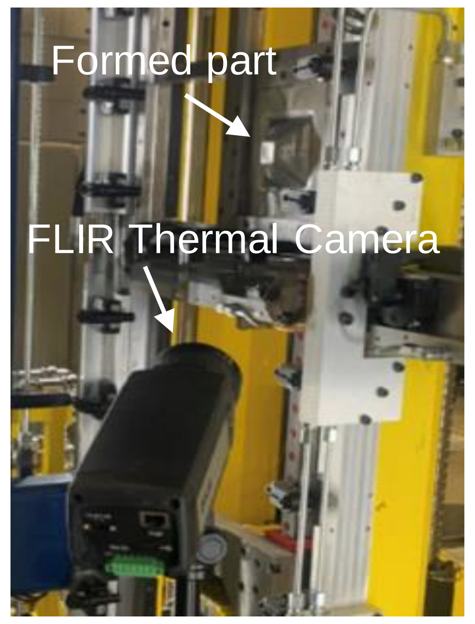


Forming Process

Process parameters

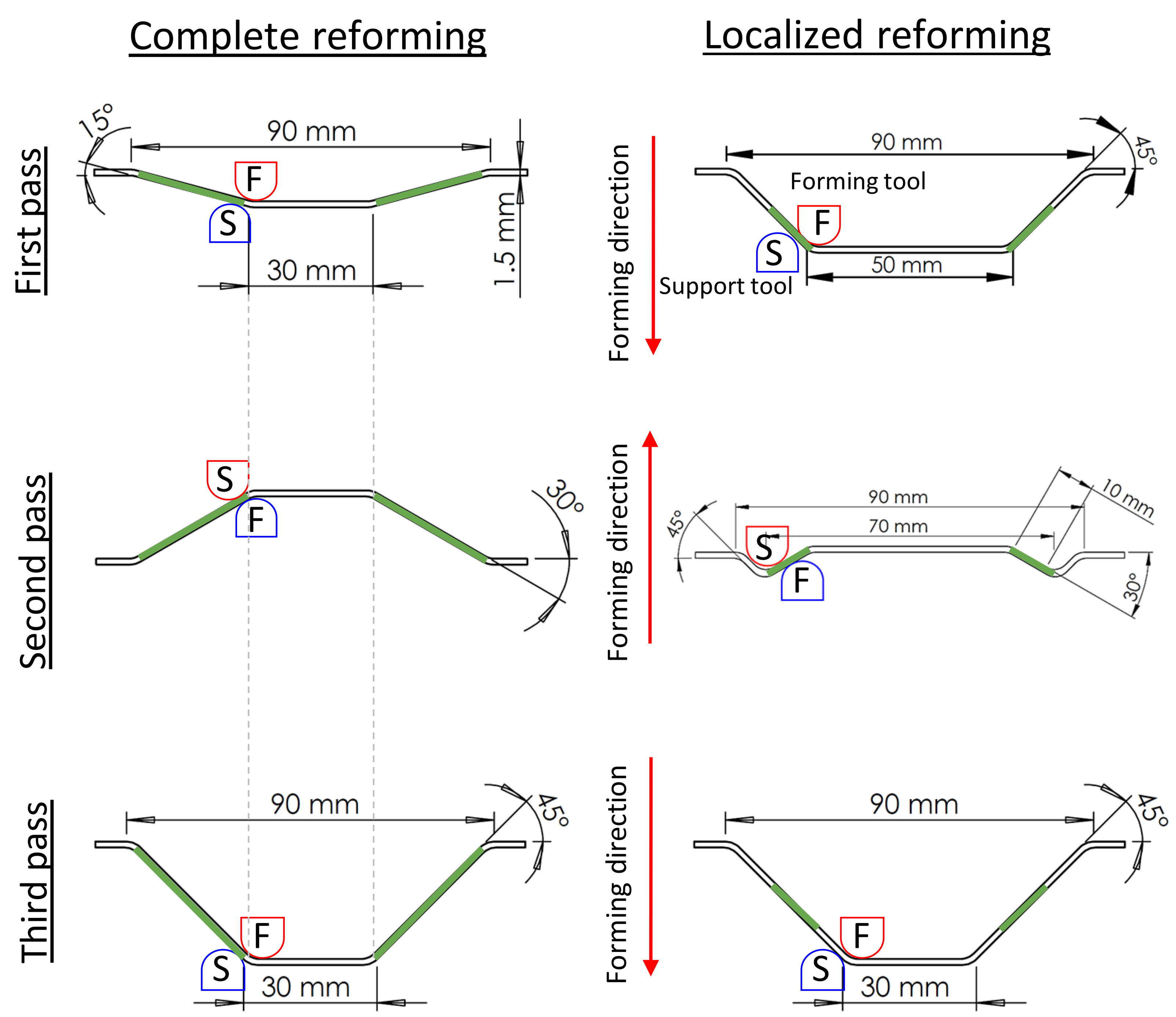
- Deformation control: complete reforming, localized reforming
- Lubricant: Super Lube Multi-Purpose Synthetic Grease with Syncolon (PTFE)
- Tools diameter: 10 mm
- Maximum feed rate: 1,500 mm/min
- Tool path: Bidirectional Standard
- Vertical step: 0.1 mm

DSIF machine at UNH



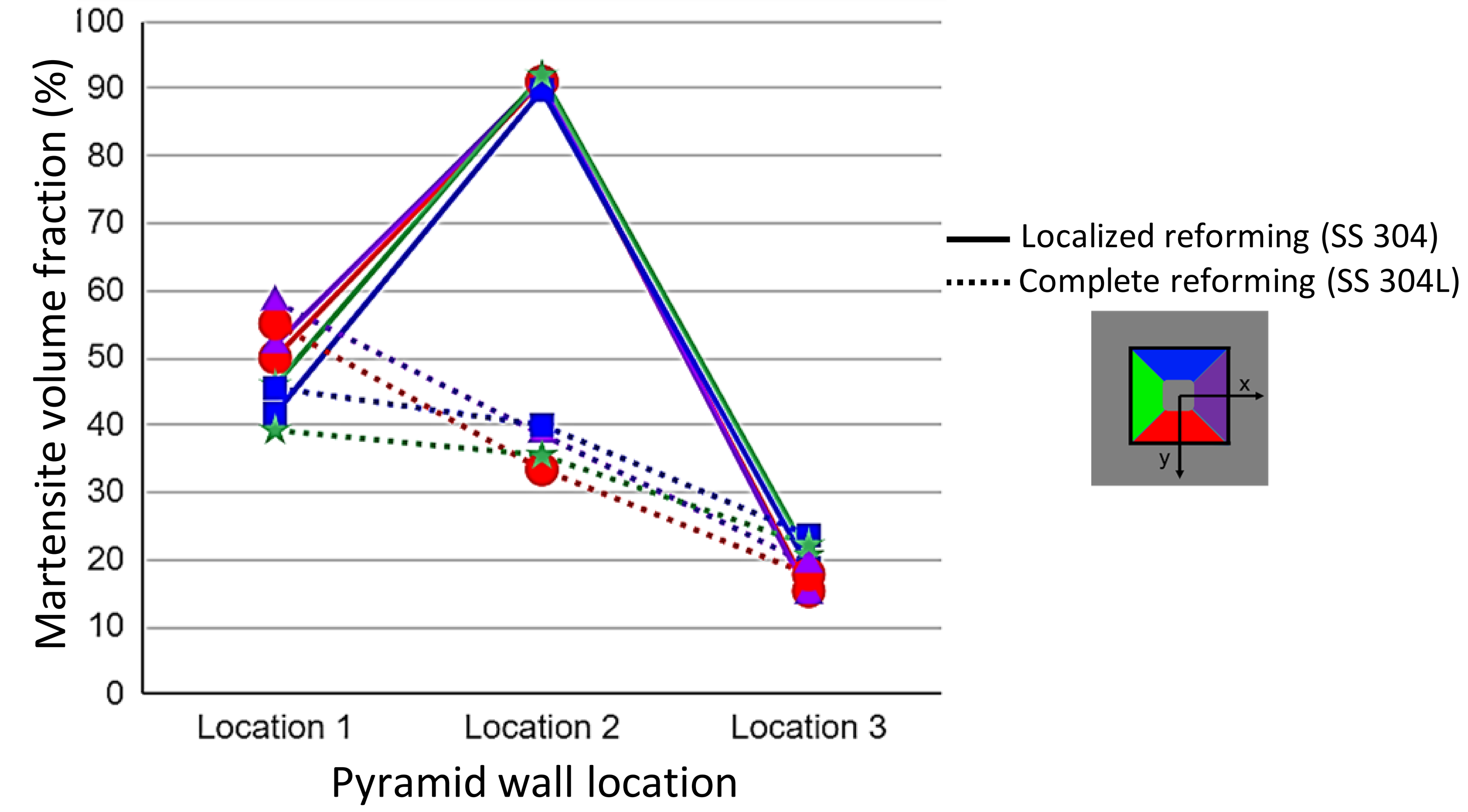
Temperature measurement with FLIR

Machine spindle, vortex tube attached



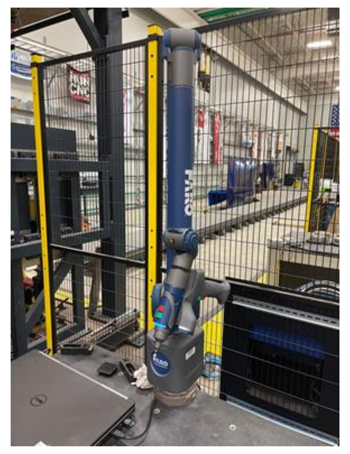
Results

- **Deformation method effect on MVF:** Localized deformation produced a distinct region of higher MVF at location 2.

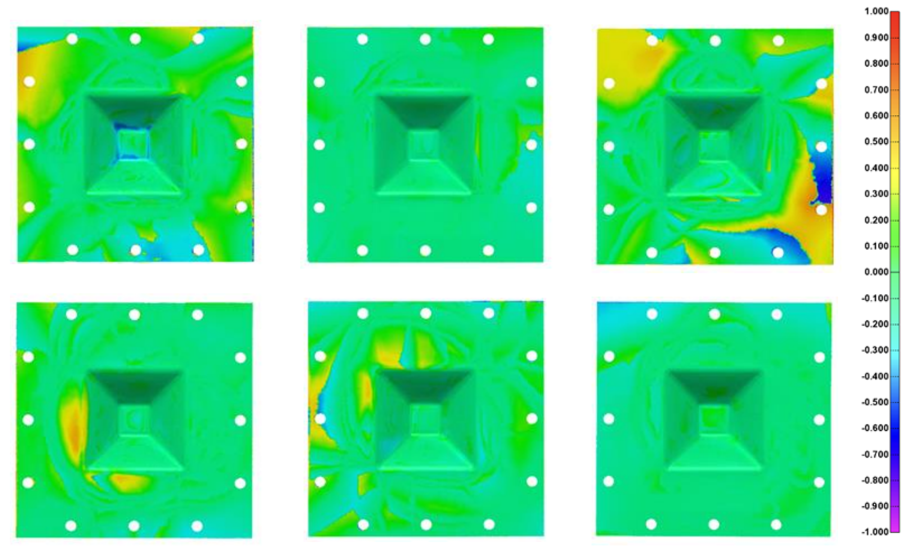


Future Work

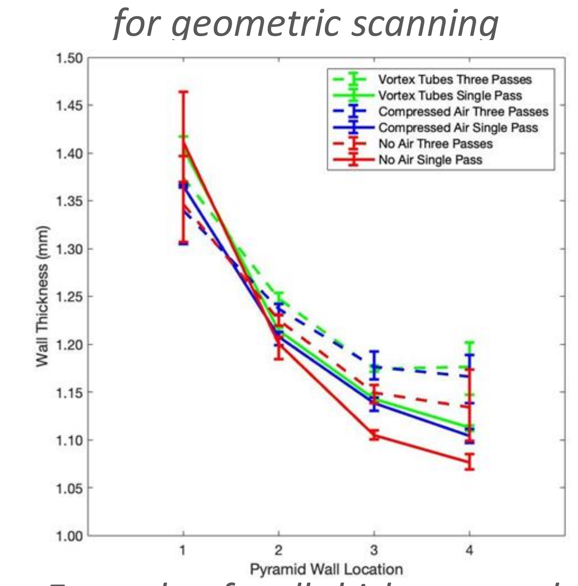
- Analyze effects of lower temperature on MVF using vortex tube
- Analyze wall thickness distribution
- Study geometric deviation of formed part from CAD model using laser scanning
- Solve splits observed at of final part by adjusting toolpath corners



Faro Quantum ScanArm for geometric scanning



Examples of geometric deviation



Example of wall thickness analysis

References

- Peng, W., Ou, H., & Becker, A. (2019). Double-sided incremental forming: a review. Journal of Manufacturing Science and Engineering, 141(5).
- Darzi, S., Adams, M. D., Roth, J. T., Kinsey, B. L., & Ha, J. (2023). Manipulating martensite transformation of SS304L during double-sided incremental forming by varying temperature and deformation path. *CIRP Annals*.

Acknowledgements

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