Understanding Cold Work Needed for Recrystallization of 316L LPBF Material and its Effect on the Material's Performance in PWR Primary Water

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Background

Laser Powder Bed Fusion (LPBF) can provide benefits such as [1]:

- Faster prototyping
- Manufacturing process simplification
- More complex geometries

As-built LPBF 316L SS has a highly heterogenous microstructure

- Segregated elements (ex/ Cr, Mo)
- Atomic scale impurities (ex/ N and H) [2]

Additionally, cold work can be induced into the microstructure through varying post-processing techniques, increasing stress corrosion cracking (SCC) initiation. Heat treatments can be used to relieve the microstructure through:

- Dislocation density
- Grain patterning
- Texture
- Distribution and size of second-phase particles [3]

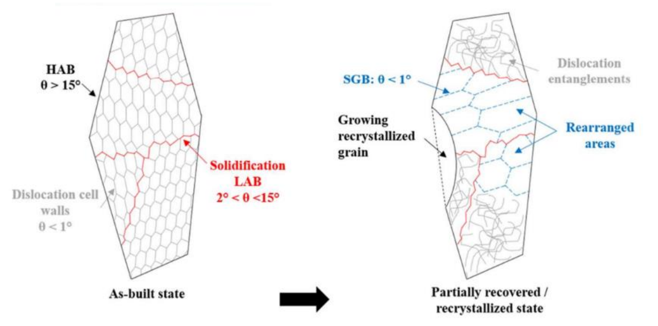
Recrystallization can occur through heat treating to form stress free recrystallized that sweep across the matrix and eliminate elemental segregation within the microstructure [4]

However, for PBF 316L material, heat treating the material is not enough to relax the material, with heat treated material retaining the as-built microstructure. This slower recrystallization kinetics has been attributed to:

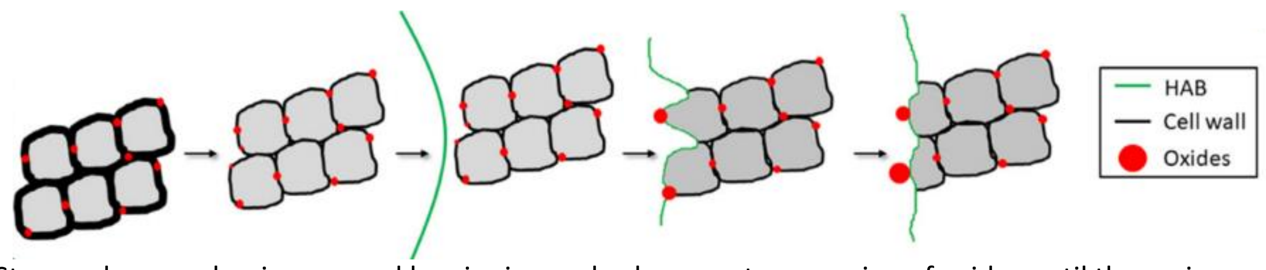
- nanoparticles
- solute drag

Driving force is the energy difference between two grains

- Increased with cold work [5]



As-built dislocation cells and solidification LAGBs (left) versus heat treated partially recovered/recrystallized material (right) [1].



Stop-and-go mechanism caused by pinning and subsequent coarsening of oxides until the grain boundary movement is released [5].

Aims and Objectives

1. Evolution of microstructure as a function of heat treatment to homogenize material microstructure with no internal stresses or elemental segregation
   - Allow for an understanding of the thermo-mechanical processing effect
2. Implication of how the thermo-mechanically processed microstructure affect SCC initiation
3. How shrinkage induced through cold work after the solution annealing treatment (i.e. welding) affects the SCC initiation performance

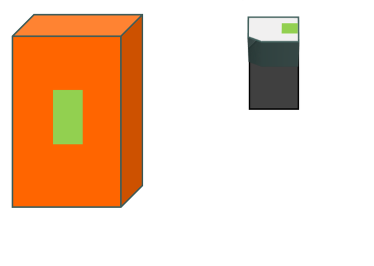
Experimental Approach

As-received material was compressed to the desired strain and had a subsequent heat treatment at either 1000°C, 1050°C, or 1100°C. The edge of the sample was ground to identify the middle of the sample for cross-sections perpendicular to the build direction. 5 hardness indentations were taken per cross-section.

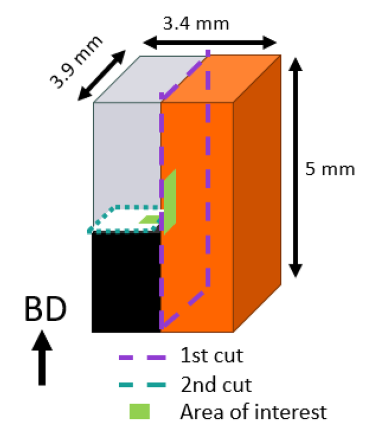
Initial microstructural characterization was done using hardness indentation, backscatter electron (BSE) detection, and electron backscatter diffraction (EBSD).

Variables for Recrystallization Treatment

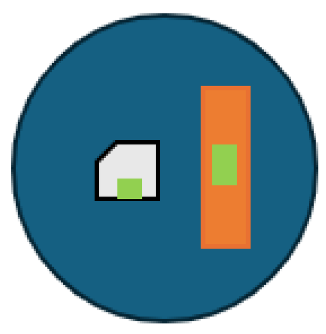
Temperature (°C) for 1 hr	Strain %		
	5	7	10
1000			
1050			
1100			



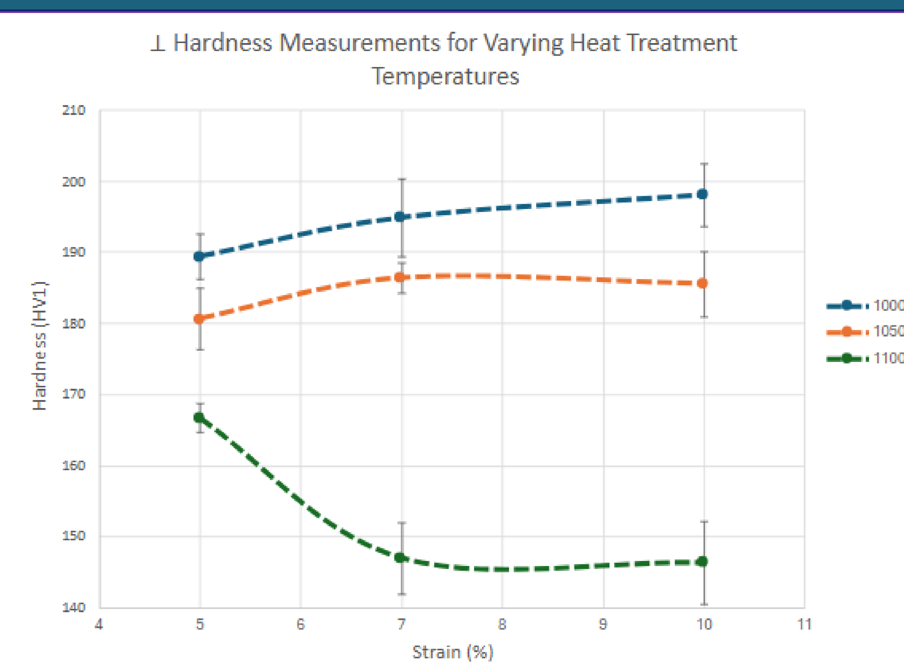
Sectioned as-received material



Mounted sample

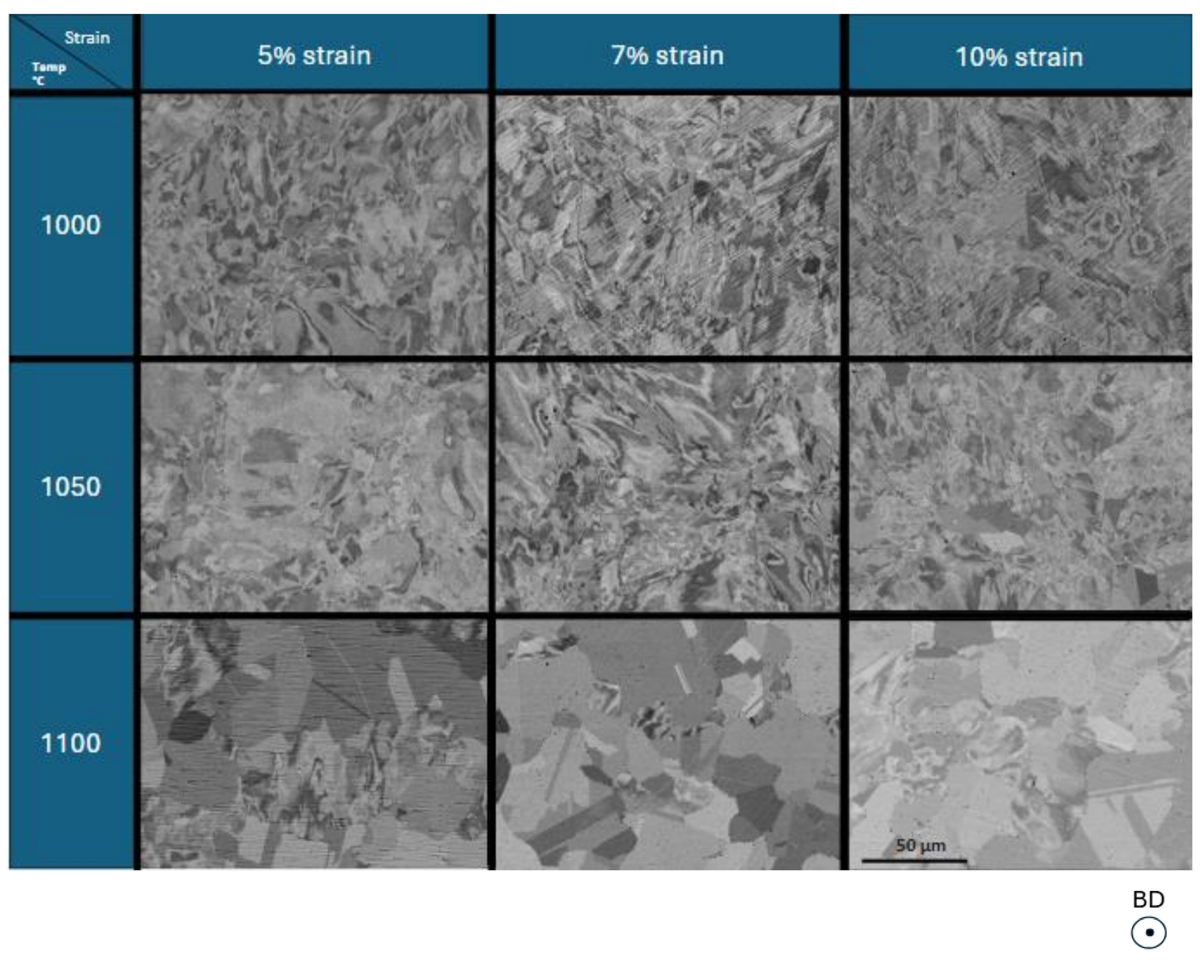


Results from Material Characterization



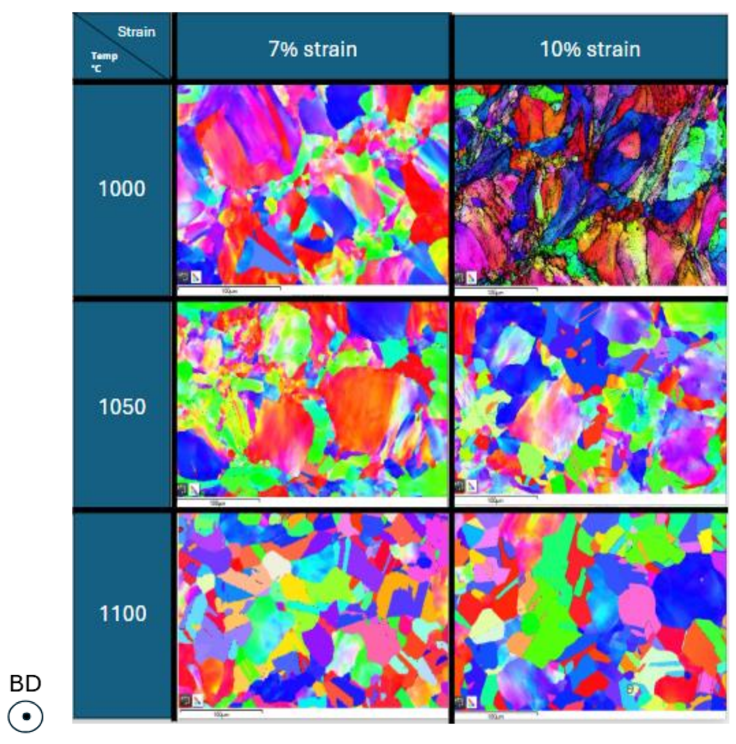
Hardness Indentation: A decrease in hardness is linked with recrystallization as it is new unstrained grains forming

- 1000°C and 1050°C increase in hardness indicates lack of recrystallization
  - 10% strain slightly decreases for 1050°C
- 1100°C experienced benefits from induced strain



Backscatter Imaging:
Deformed inhomogeneous grain distribution can be seen for samples heat treated at 1000 °C and 1050 °C. For these temperatures, small amounts of twinned grains can be seen at 10%.

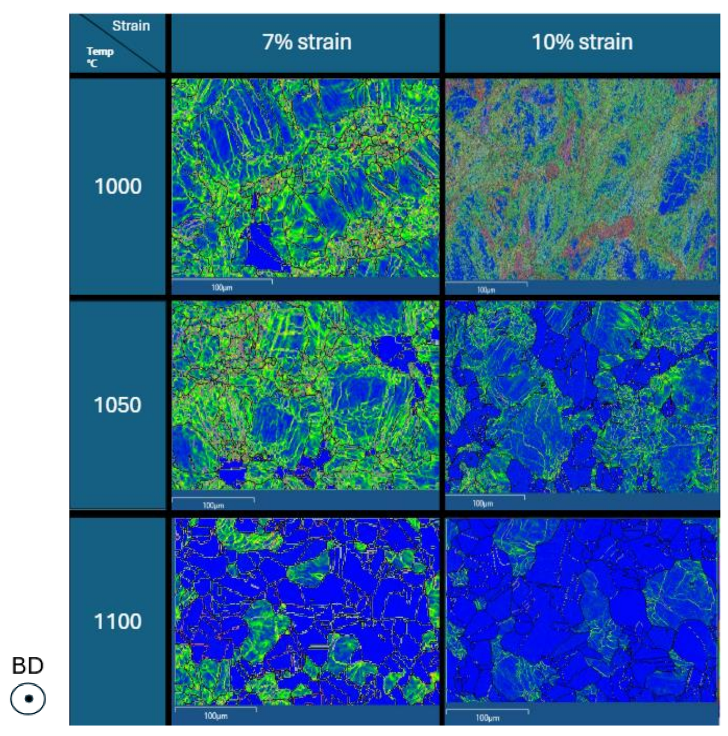
1100°C had larger grains indicating stress relief from the higher temperature heat treatment. Previous studies have shown that recrystallization begins at this temperature even with no pre-straining.



EBSD Analysis:
Laser tracks from build process can still be seen after 1000 °C heat treatment and 7% strain.

At 1050 °C, larger grains from recrystallizing can be seen pinned by smaller grains indicating incomplete recrystallization at these conditions.

1100 °C shows a homogeneous microstructure with twinned grains due to annealing. Larger grains can be seen for 10% strain indicating recrystallization aid from the increased strain



Aztec Dislocation Density Analysis:
Although this analysis is not representative of the total dislocation within the material, these results do indicate the retained laser scanning tracks with an increased density of dislocations at the edges

Reduction of dislocation density indicates the substantial stress relief as the heat treatment temperature increases.

Conclusion

At 1000°C, the induced strain did not aid in the recrystallization kinetics. Additionally, the laser scan tracks are still visible even with the addition of induced strain and heat treatment. At the 1050°C heat treatment, partial recrystallization is seen with the larger grains surrounded by fine grains. Finally, the 1100°C did show the benefits of the induced strain on the recrystallization kinetics, with the 10% strain microstructure showing a homogeneous microstructure with anneal twinning.

Next Steps

Conduct TEM analysis to better understand the total dislocation between the various microstructures. Slow strain rate tensile tests will be conducted to understand the as-received material's stress corrosion cracking performance.

Future Work

After further microstructural analysis, the microstructure of interest will be chosen, and tensile samples will be created from rolled and heat-treated material. This material will then be slow strain rate tensile tested, and its performance will be compared to the as-received material.

References

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