SAND2014-19114C

The Microstructure, Phase, and Composition of LENS® - Deposited Stainless Steel 304L

Abstract:

Stainless steel 304L deposited by laser engineered net shaping (LENS®) using a 3.8 kW continuous wave incident beam process has been characterized using electron beam backscatter diffraction, x-ray diffraction, acoustic wave techniques, eddy current methods and inductively coupled mass spectrometry. These methods have determined the microstructure, crystallographic texture, phase, elastic properties, and composition of the deposited metal alloy. Contrasted with wrought stainless steel, we show that the LENS® - deposited austenitic material has a large grain, anisotropic microstructure with elongated grains up to 1-2 mm in dimension. Crystallographic texture, as well as elastic properties, are characterized in the laser scan direction as well as the net build (z) direction after preparing test coupons by electro-discharge machining and subsequent electropolishing. Although there were no major volumes that lack fusion, there is a small level of microporosity in the builds and a small amount of retained ferrite. Eddy current methods estimate the amount of retained ferrite at approximately 2-3%. Changes to composition are also noted. (SAND 2014-19023 A)

David P. Adams, Michael Maguire, Prof. Todd A. Palmer*, Mark A. Rodriguez, J. Michael, Jay Carroll.

Sandia National Laboratories, Albuquerque, New Mexico

** Penn State University, State College, PA*

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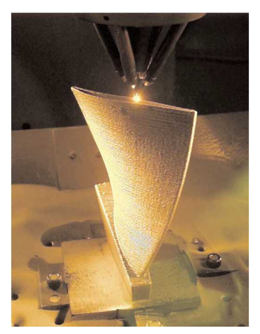
Goals of this study include:

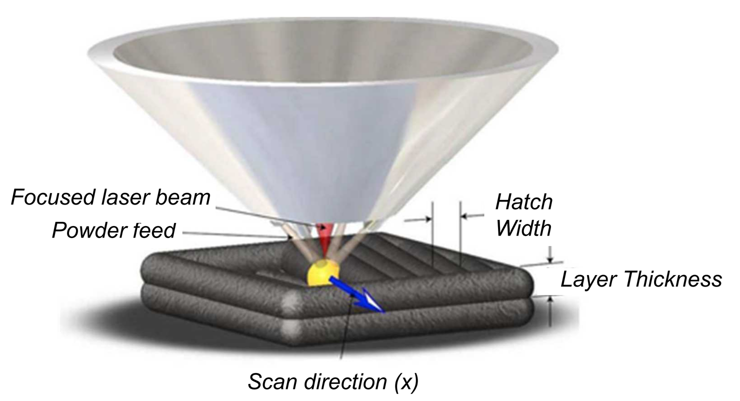
- Develop a LENS® process that achieves near-full density 304L stainless steel (simple geometries)
- Determine the phase(s) that form in this deposit
  - contrast with wrought 304L stainless steel test material
- Evaluate the composition of deposits and assess changes in stoichiometry
  - contrast with wrought 304L stainless steel test material
- Determine the microstructure of the LENS® stainless steel (includes grain size, crystallographic texture).
  - contrast with wrought 304L stainless steel test material
- Assess microporosity in LENS® near-full density material

Motivation: Structure – Property Relationships of Additively Manufactured Steel

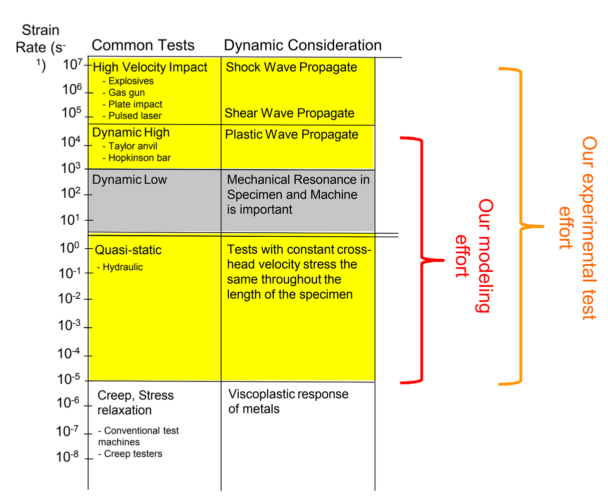
Previous Work on LENS® structure-property relationships

- Focus on net shape, attainable geometries
- Mechanical response in quasi-static regime assessed
- No published work on high strain rate response





Our goal : to evaluate mechanical behaviors across a 13 decade range of strain rates ($\dot{\varepsilon}$) including high $\dot{\varepsilon}$

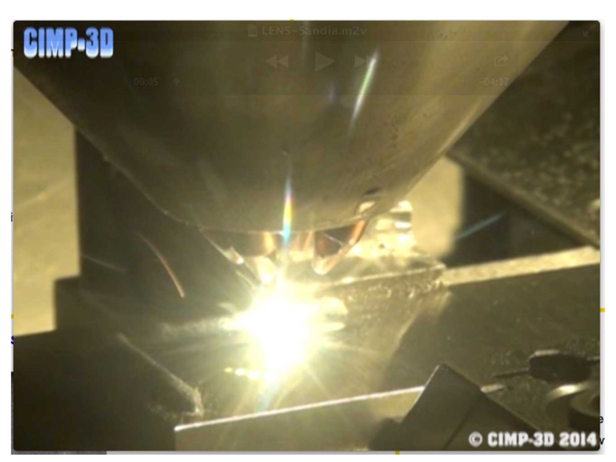


Reference: Meyers' Dynamic Behavior of Materials

Laser Engineered Net Shaping (LENS®)

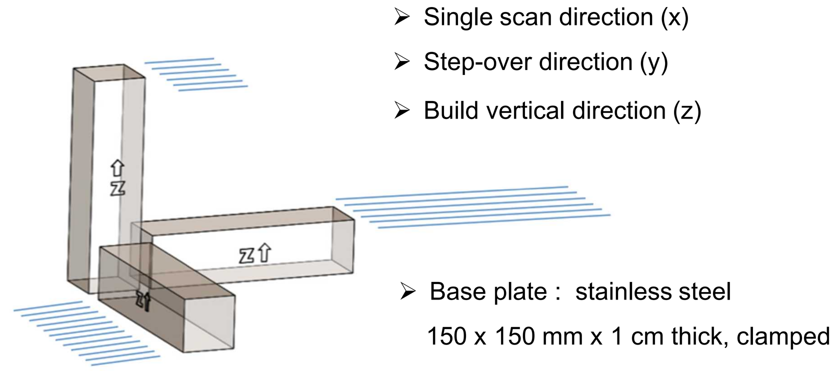
Laser Instrument and Process

- IPG Photonics Yb fiber laser
- Average Power: 3.8 kW
- Wavelength: 1070-1080 nm, continuous wave operation
- Beam width (at specimen): 4 mm
- Hatch: 0.2 cm
- Travel speed: 63.5 cm/minute
- Beam shape: Gaussian
- Powder: 44 – 105 μm stainless steel 304L (Micromelt from Carpenter Powder Products)
- Operation: work surface is just below focal plane of laser (slight defocused condition)



Photograph showing LENS® deposition of SS 304L

Build Geometries



- Single scan direction (x)
- Step-over direction (y)
- Build vertical direction (z)
- Base plate : stainless steel 150 x 150 mm x 1 cm thick, clamped

2.5 x 2.5 x 10 cm x and z bars by LENS® made from stainless steel 304L powder

Microstructure and Phase

Sample preparation methods (for microstructural characterization)

Electro-discharge machining

Electropolishing

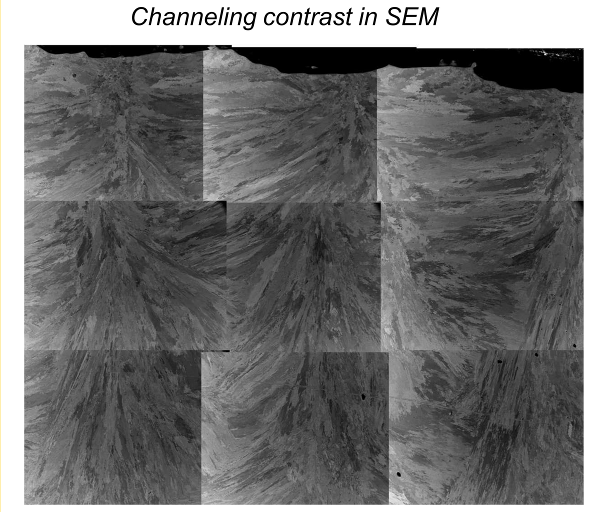
- Surface finish : Rq ~ 5 nm
- Avoids accumulated martensite

Femtosecond laser ablation

- Surface finish : varies with depth
- May avoid accumulated martensite
- Can be integrated within vacuum-based characterization instrument (Ref. Pollock)

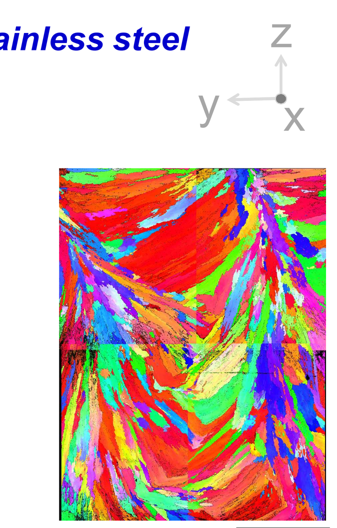
Microstructure of LENS® stainless steel

Channeling contrast in SEM



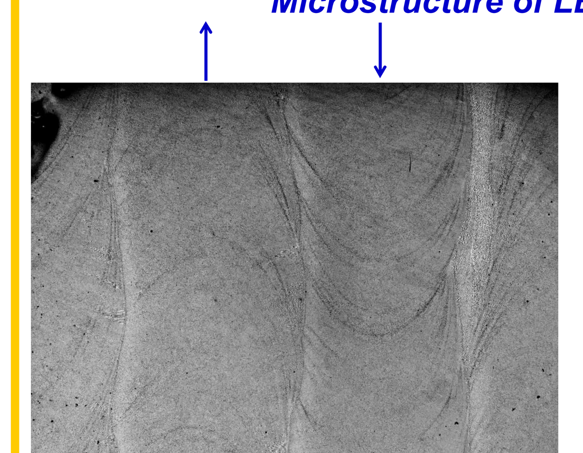
1.0 mm

Material was electropolished



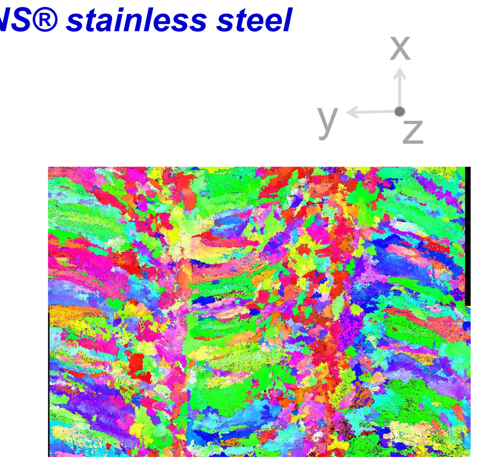
Electron back scatter diffraction

Microstructure of LENS® stainless steel



1.0 mm

Scanning Electron Microscopy



Electron back scatter diffraction

Material was electropolished

LENS® stainless steel 304L is characterized by:

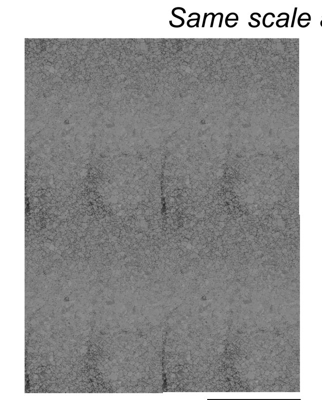
- Anisotropic, polycrystalline structure
- Large average grain size (up to millimeters)
- Variable grain size through z (build direction)
- Evidence of microporosity (small amount)
- Mostly austenite
- Trace of ferrite indicated by Ferritescope

Microstructure of wrought stainless steel (used in comparison mechanical tests)

Same scale as above (for LENS)

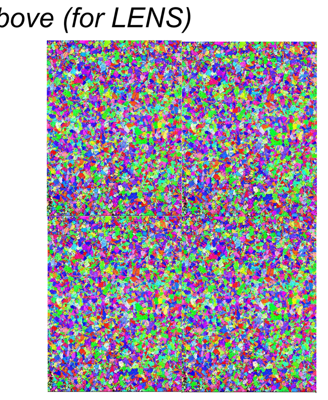
Wrought stainless steel 304L is characterized by

- Small grain structure (average grain size = 20 μm)
- Random crystallographic texture
- No microporosity detected
- Mostly austenite
- Trace of ferrite indicated by Ferritescope



1.0 mm

Scanning electron microscopy 4 stitched areas (all same) to contrast microstructure



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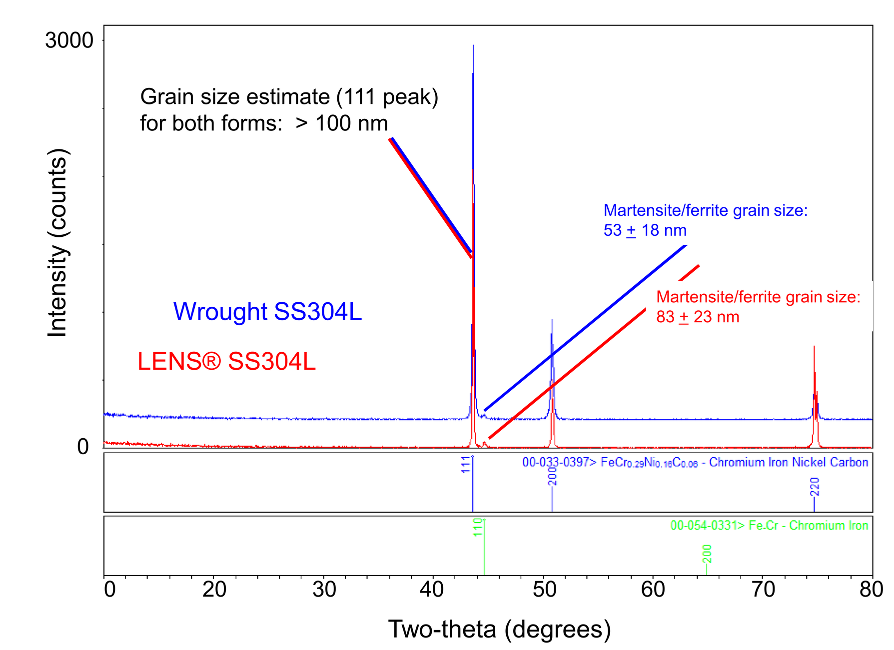
Electron back scatter diffraction 4 stitched areas (all same) to contrast microstructure

Material was electropolished

Phase and Composition

X-ray Diffraction (XRD) of both forms



- LENS® stainless steel 304L and wrought steel are both characterized by:

  Majority phase: austenite

  Minority phase: martensite/ferrite

- Quantitative analysis of phase content

  Wrought stainless steel 304L

  98.8 (2) wt.% austenite

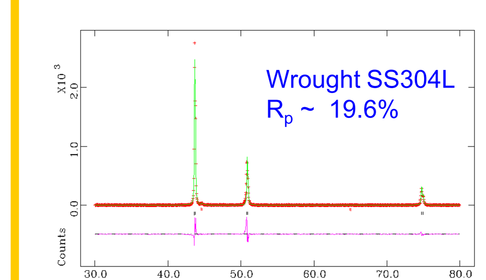
  1.2 (2) wt. % martensite/ferrite

  LENS® stainless steel 304L

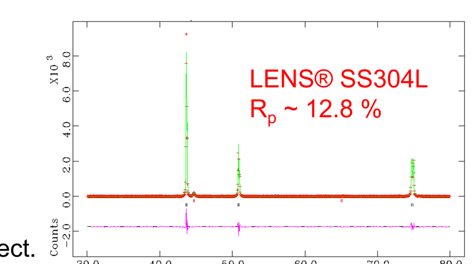
  97.7 (2) wt.% austenite

  2.3 (2) wt. % martensite/ferrite

Structure refinement

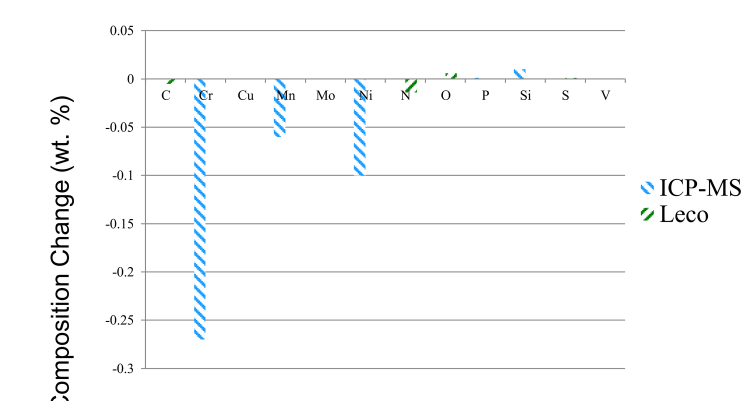


- ~ 1 wt.% ferrite/ martensite
- Good match to d-spacings
- Preference for (111) in roll direct.



- ~ 2 wt.% ferrite/ martensite
- Good match to d-spacings
- Preference for (220) in build direct.

Composition measurements

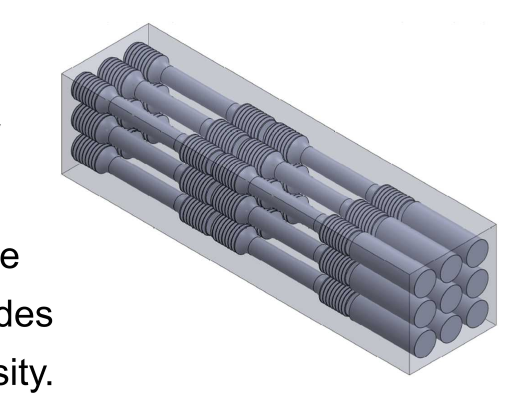


- Results are referenced to measured composition of powder used for LENS®
- Decreased amounts of Cr, Mn and Ni.
- Minor changes to % of N, S, Si, O, P, C

ICP-MS = inductively coupled plasma mass spectrometry

Conclusions:

- There are several similarities between test materials (LENS vs. wrought) including amounts of austenite vs. martensite/ ferrite, and composition.
- However, there are several key differences that should prove relevant when contrasting mechanical behaviors. This includes differences in grain size (large for LENS material) and porosity.



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