

Methods of Measuring Residual Stresses in Additively Manufactured 316L Stainless Steel

Rachael Angeline McIntyre, Isabella J Van
Rooyen

August 2019



The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

Methods of Measuring Residual Stresses in Additively Manufactured 316L Stainless Steel

Rachael Angeline McIntyre, Isabella J Van Rooyen

August 2019

**Idaho National Laboratory
Idaho Falls, Idaho 83415**

<http://www.inl.gov>

**Prepared for the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

Methods of Measuring Residual Stresses in Additively Manufactured 316L Stainless Steel



Rachael McIntyre^{1,2}, Isabella van Rooyen¹

¹Idaho National Laboratory, Idaho Falls, Idaho, ²University of Delaware, Newark, Delaware



Significance

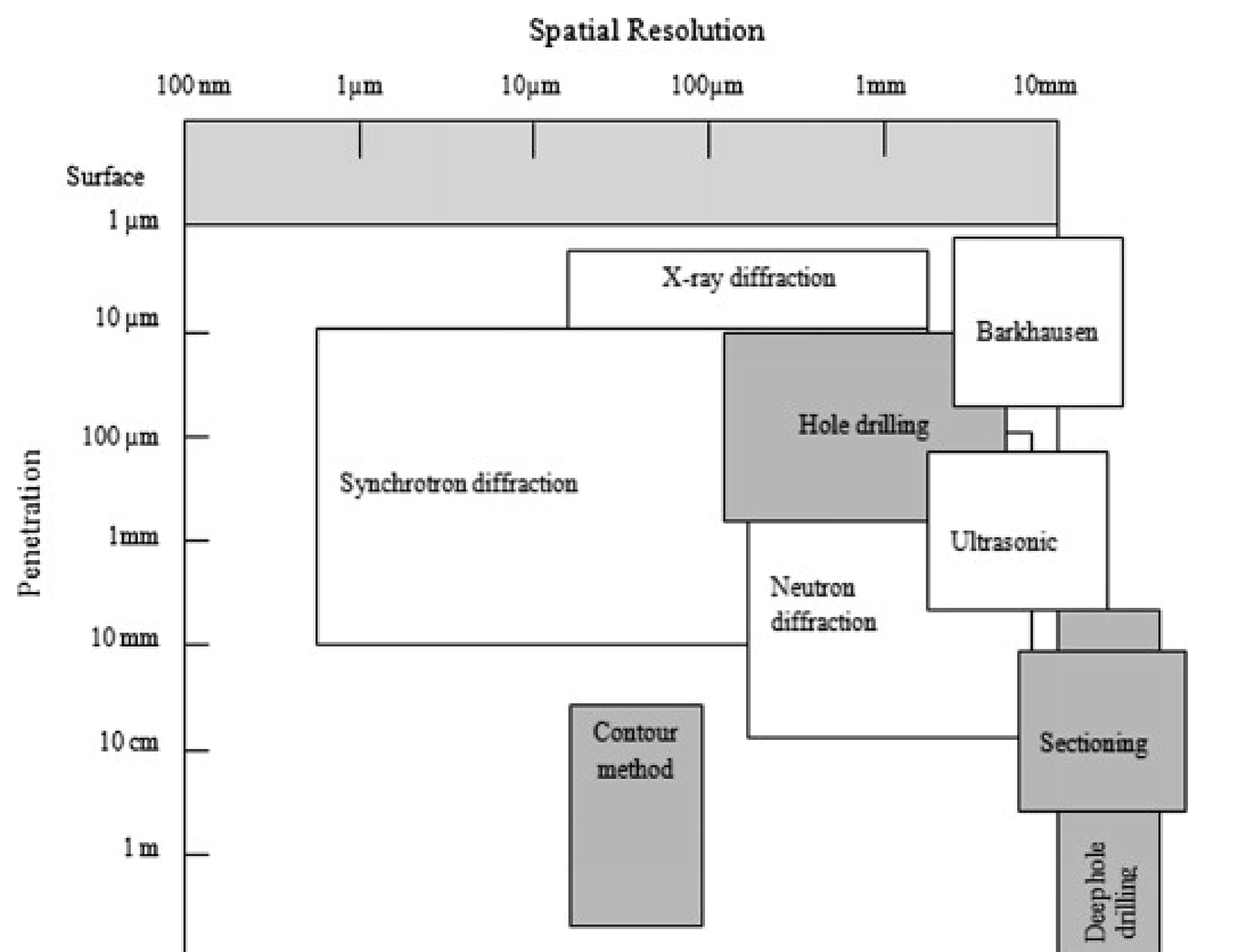
- The microstructure of AM 316L stainless steel is different from steel manufactured using conventional methods e.g. casting and forging
- Data on the effects of residual stresses in the structural integrity and importance of AM parts (fatigue behavior) must be quantified
- Evaluate different methods and identify a viable process for determining residual stresses in 316L stainless steel

Destructive/Semi-Destructive

Technique	Advantage	Disadvantage
Hole-Drilling	Applicable for isotropic and machinable materials with known elastic parameters Simple experimental setup and operation	Potential introduction of machining stresses and increased error Limited strain sensitivity and resolution
Sectioning	Little to no additional calculations needed Fast, inexpensive, used for structural carbon steel, aluminum and stainless steel	Only provides average residual stresses for given area Limited strain resolution
Contour	Applicable for larger samples and wide range of materials	Additional error from cutting, measurement, and stress evaluation
Deep Hole Drilling	High resolution maps of stress fields over large areas normal to surface of cut Damage done to sample is minimal Measures deep interior stresses for large samples of steel and aluminum	Cannot make successive adjacent cuts to comprehensively map stress Limited strain sensitivity and resolution Data needs to be interpreted; additional calculations required

Non-Destructive

Technique	Advantage	Disadvantage
X-Ray Diffraction	Applicable for ductile, fine-grained, polycrystalline, metallic, or ceramic materials Obtain both macro and micro residual stresses	Limited to small samples and shallow penetration depth Lab-based systems
Neutron Diffraction	Wide range of penetration depth and resolution Provide 3D maps of macro and micro residual stresses	Only available at special facilities Expensive for routine process quality control in engineering applications
Synchrotron	Fast data acquisition High spatial resolution lateral to the sample	Not suited for large or geometrically complex samples Low scattering angles cause spatial variation to be poor along the sample
Ultrasonic	Not limited by sample thickness or type of material under study Inexpensive, portable, used for routine inspection procedures for large components	Difficult to separate effects of multi-axial stresses Low resolution, inefficient for excitation over wide frequency range



Range of penetration and spatial resolution of residual stress measurement methods. Non-destructive methods are white, destructive and semi-destructive methods are gray.

Rossini, N.S. et al. (2012). *Materials and Design* 35: 572-588.

Preliminary Conclusion and Moving Forward

- XRD most viable method for measuring residual stresses in planned samples
 - Shallow penetration and spatial resolution on the order of 100 μm
- X-Ray Diffractometer available at CAES Advanced Materials Laboratory
- Next step is to conduct measurements of residual stresses of samples fabricated by different manufacturers

