Acoustic Signatures and Machine Learning in Additive Manufacturing

Alec Mangan

University of Wisconsin-Madison

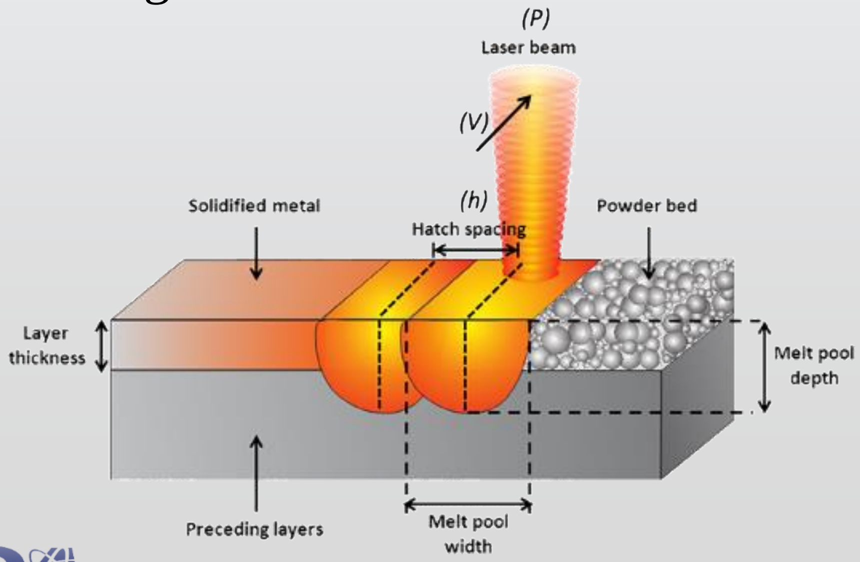
PI: Dan Thoma

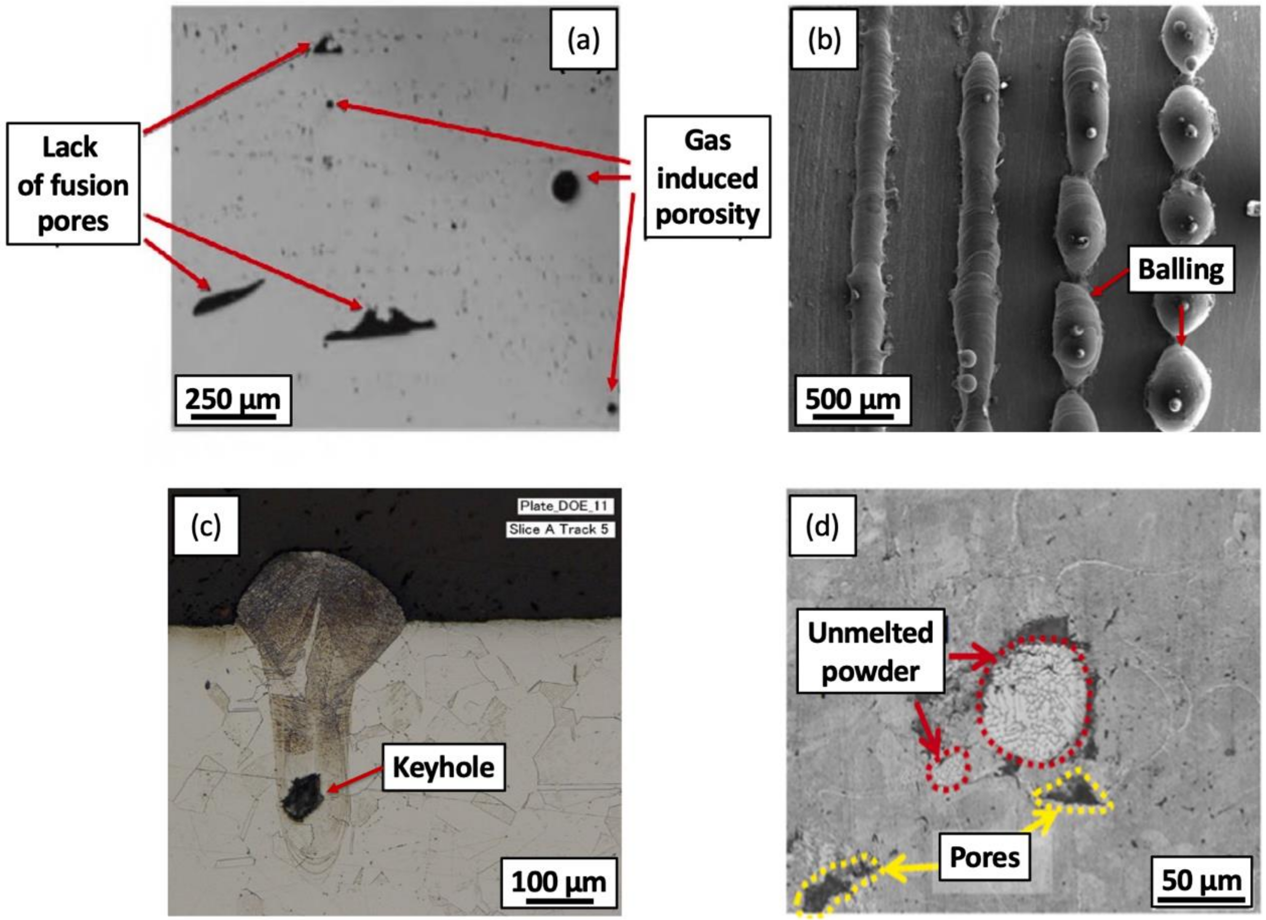
ETI Annual Workshop

February 20 – 21, 2024, Golden, CO

Introduction and Motivation

- Laser Powder Bed Fusion can print complex high-quality parts.
- EOS M290 has over 100 process parameters to control.
- Fast cooling rate (10^6 K/s) creates fine microstructure.
- LPBF has a handful of identified defect signatures.





a) T. DebRoy et al., Prog. Mater. Sci. 92 (2018) 112–224.
b) R. Li, et al., Int. J. Adv. Manuf. Technol. 59 (2012) 1025–1035.
c) W.E. King, et al., J. Mater. Process. Technol. 214 (2014) 2915–2925.
d) X. Yan, et al., Mater. Sci. Eng. A. 789 (2020) 139615.

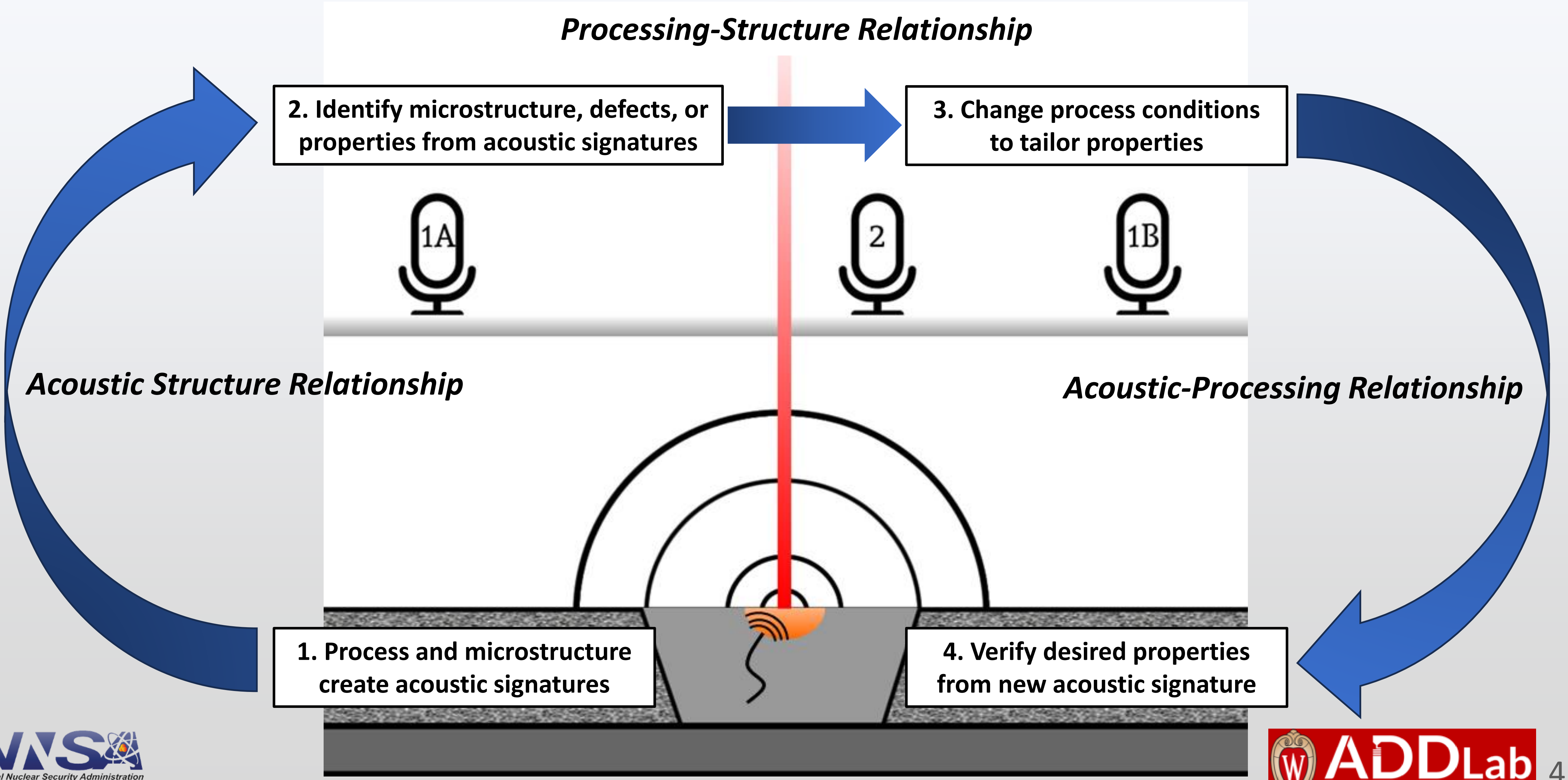
National Nuclear Security Administration

ADDLab Alloy Design and Development

Introduction and Motivation

Signature	Frequency (kHz)	Material	Detection Method	Source
Crack	100	Al6Mn2Ce	Structure-borne Acoustics	Seleznev et. al., 2022
Conduction Mode	0-20	316L SS, Bronze, Inconel 718	Airborne Acoustics	Drissi-Daoudi, et. al., 2022
Lack of Fusion	0-20	316L SS, Bronze, Inconel 718	Airborne Acoustics	Drissi-Daoudi, et. al., 2022
Keyhole	43.8	Ti6Al4V	Optical (X-ray)	Khairallah, et. al., 2021
Machine Noise	0.5	304 SS	Airborne	Ye, et. al., 2018
Material Resonance	1.16	304 SS	Airborne	Ye, et. al., 2018

Introduction and Motivation

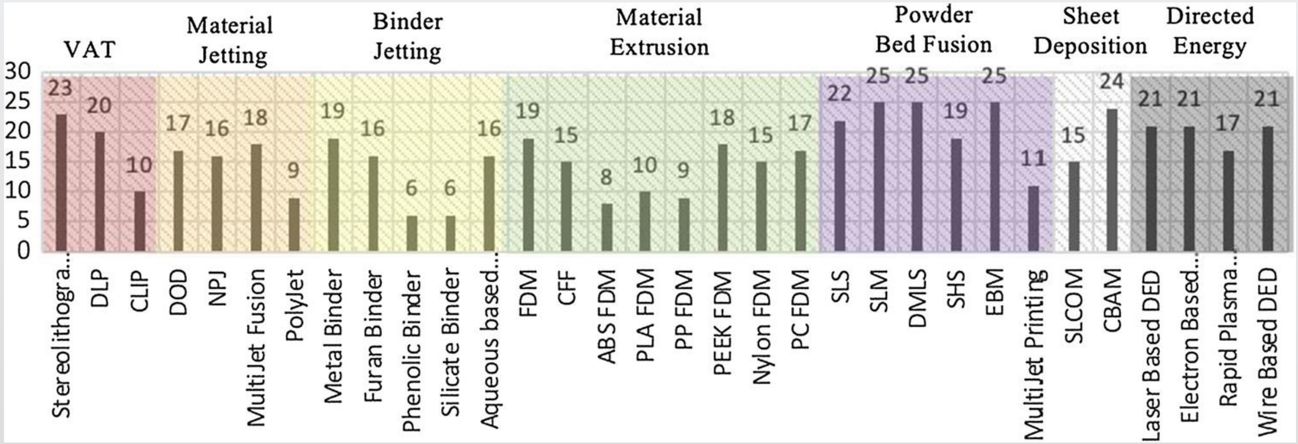


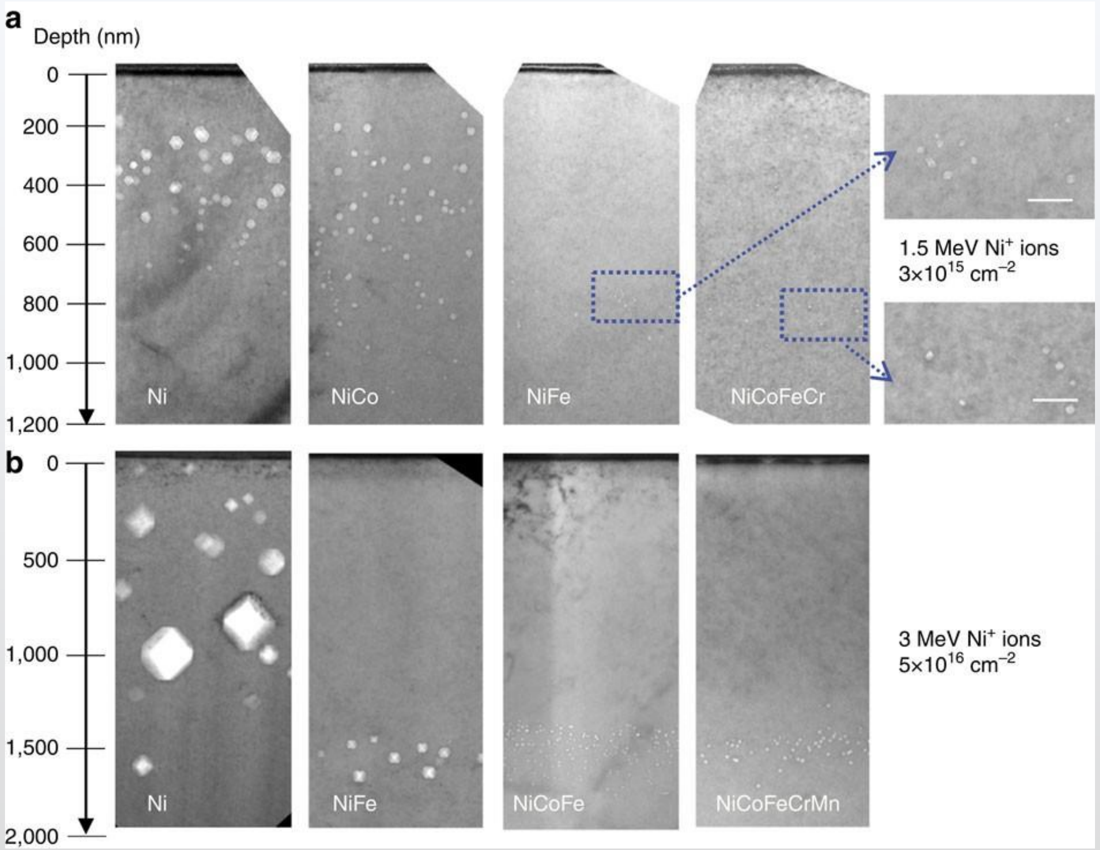
National Nuclear Security Administration

ADDLab Alloy Design and Development

Mission Relevance

- Laser powder bed fusion has been shown to have a higher risk to nuclear nonproliferation than other additive manufacturing methods.
- CoCrFeMnNi HEA has shown resistance to void swelling.



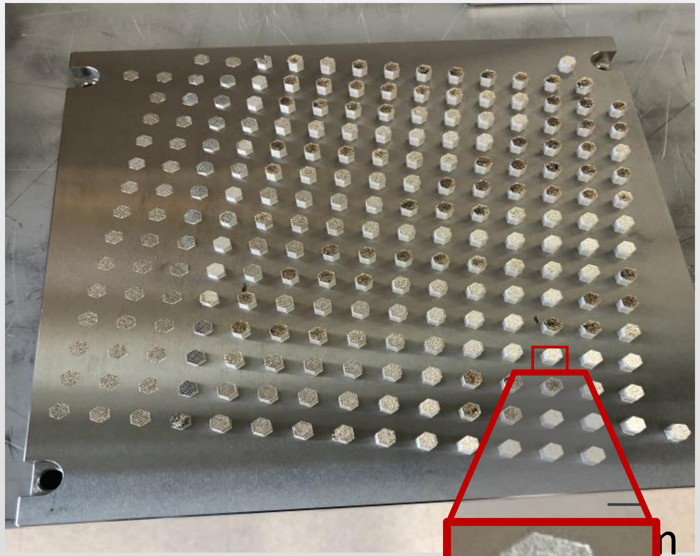


N. Cannon, et al., J Radioanal Nucl Chem 331,

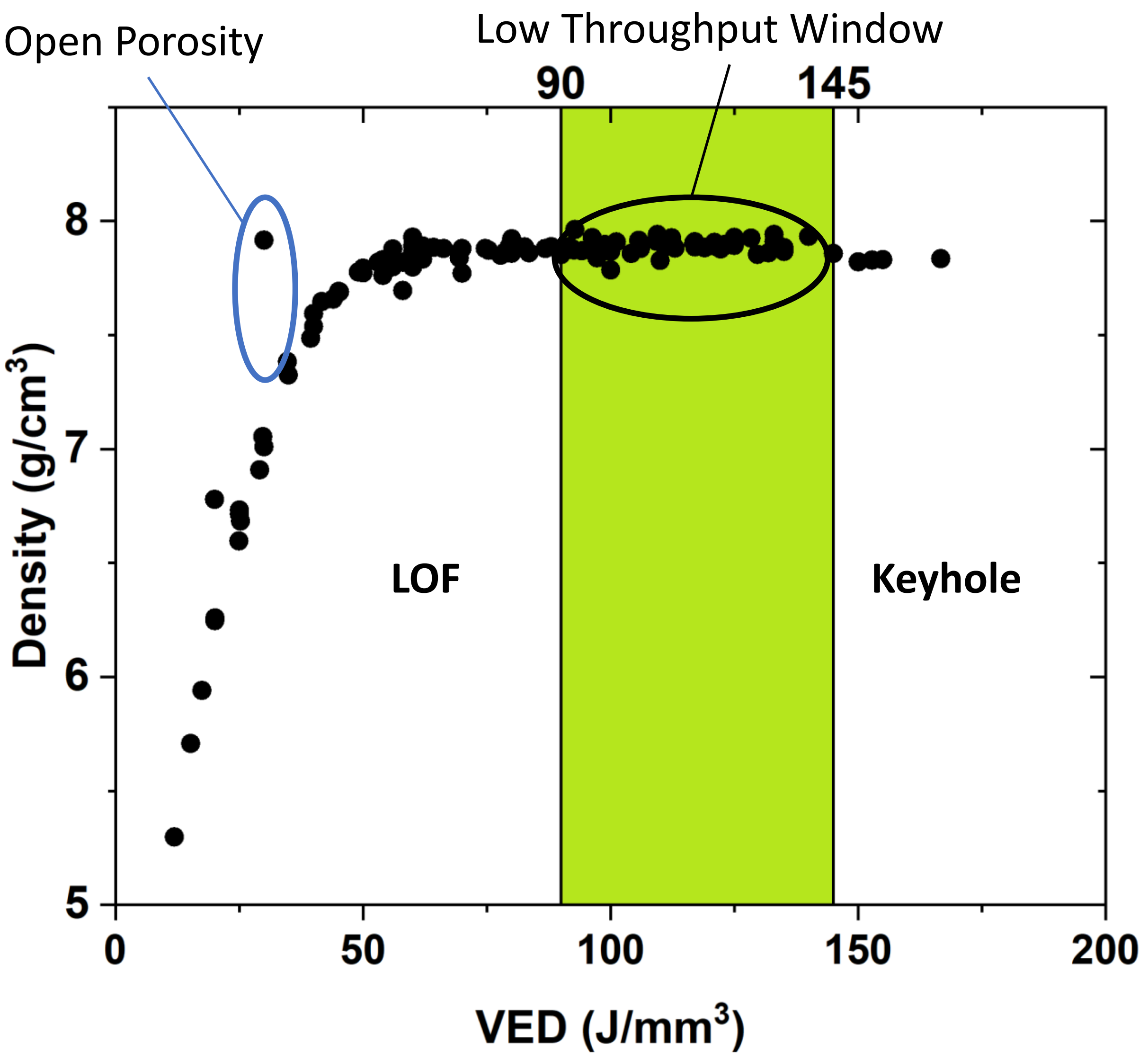
Lu, C., et al., Nat Commun 7, 13564 (2016).

High Throughput Experiments

242 hex nuts specimens:
- Different processing conditions
- High throughput characterization
  - Density and Hardness Measured
- Rapid identification of processing bounds



A. Agrawal et al, *Mat. Sci. & Eng. A* **793** (2020) 139841

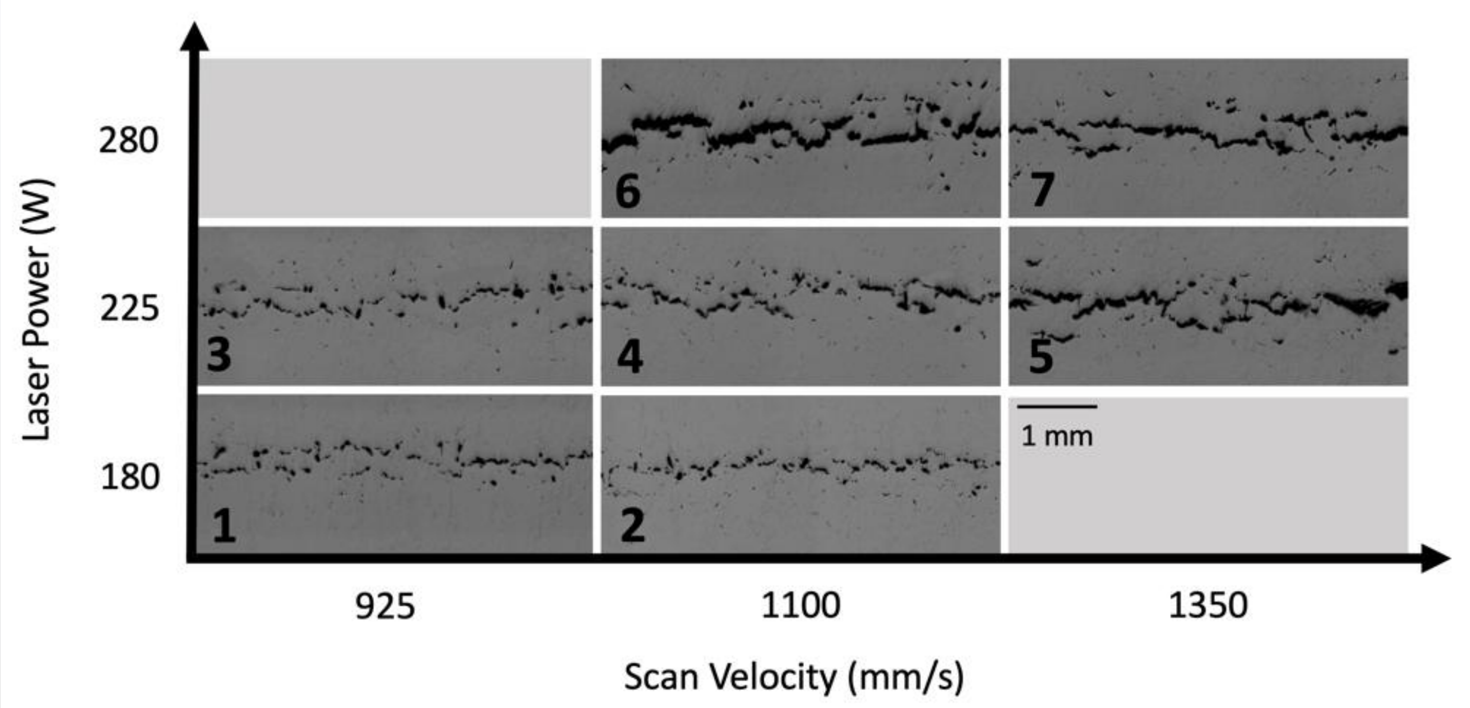


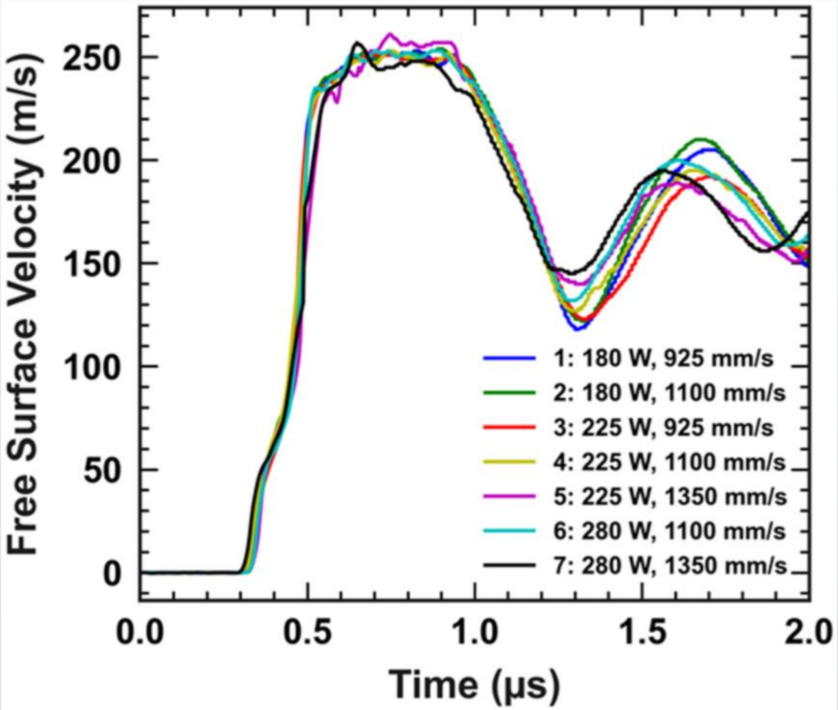
National Nuclear Security Administration

Alloy Design and Development

High Strain Rate Experiments

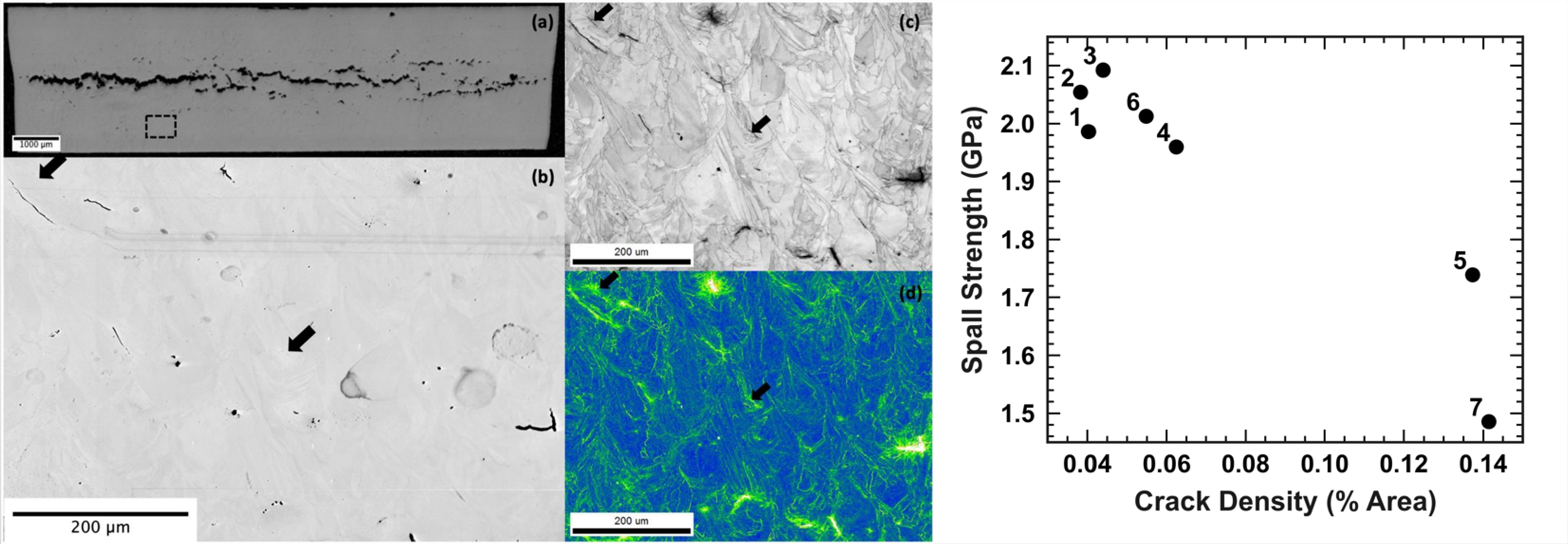
High strain rate experiments conducted at Los Alamos National Laboratory measured the spall strength of the CoCrFeMnNi HEA across seven processing conditions.





V.K. Euser, et. al., *Materialia*, 33 (2024)

High Strain Rate Experiments



Spall response dominated by presence of cracks.

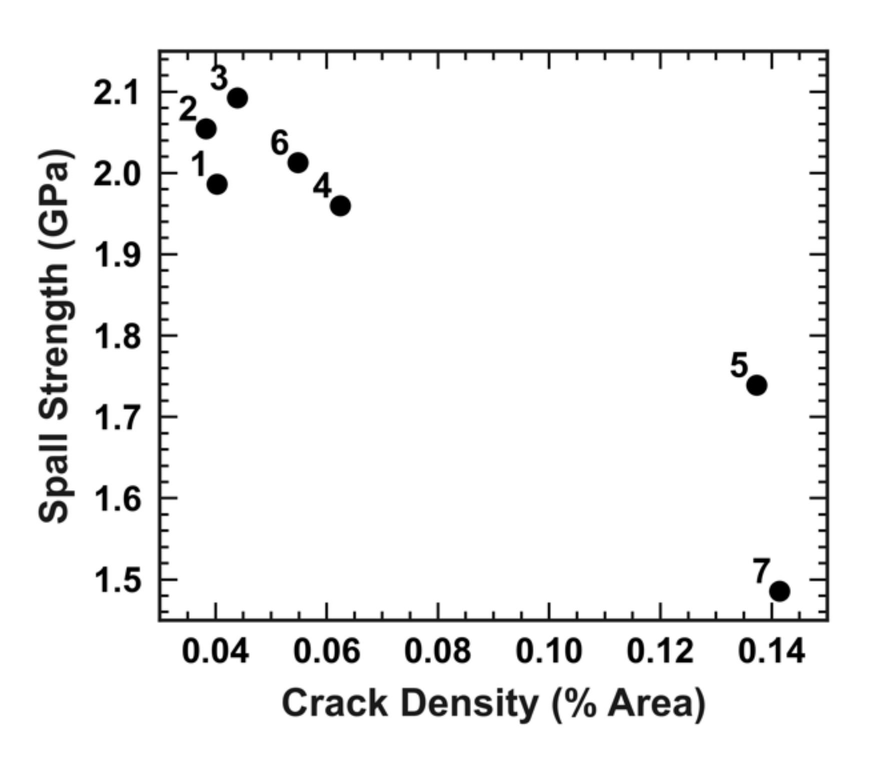
V.K. Euser, et. al., *Materialia*, 33 (2024)

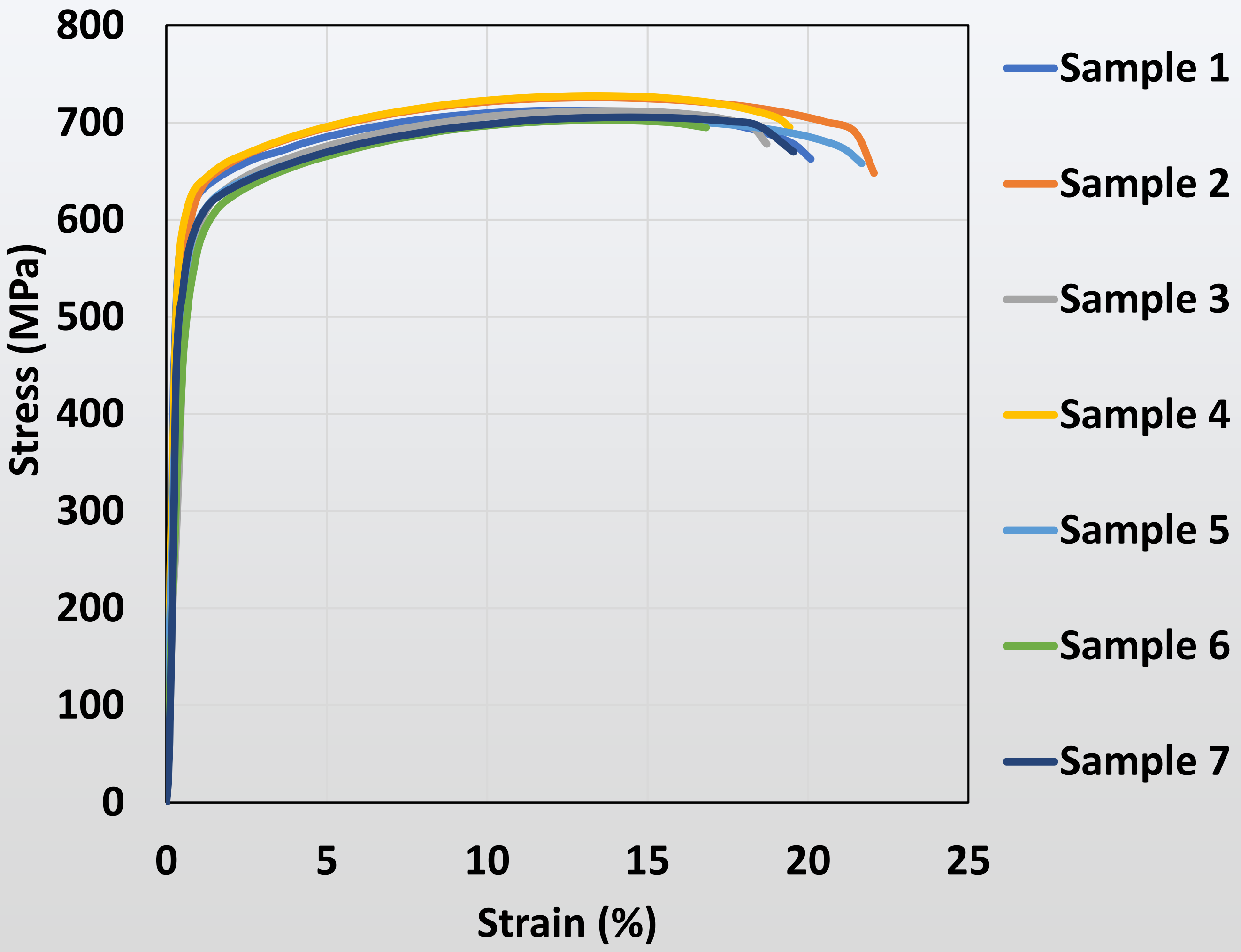
High Strain Rate Experiments

Ultimate Tensile Strength changes by 4%

Yield Strength changes by 10%

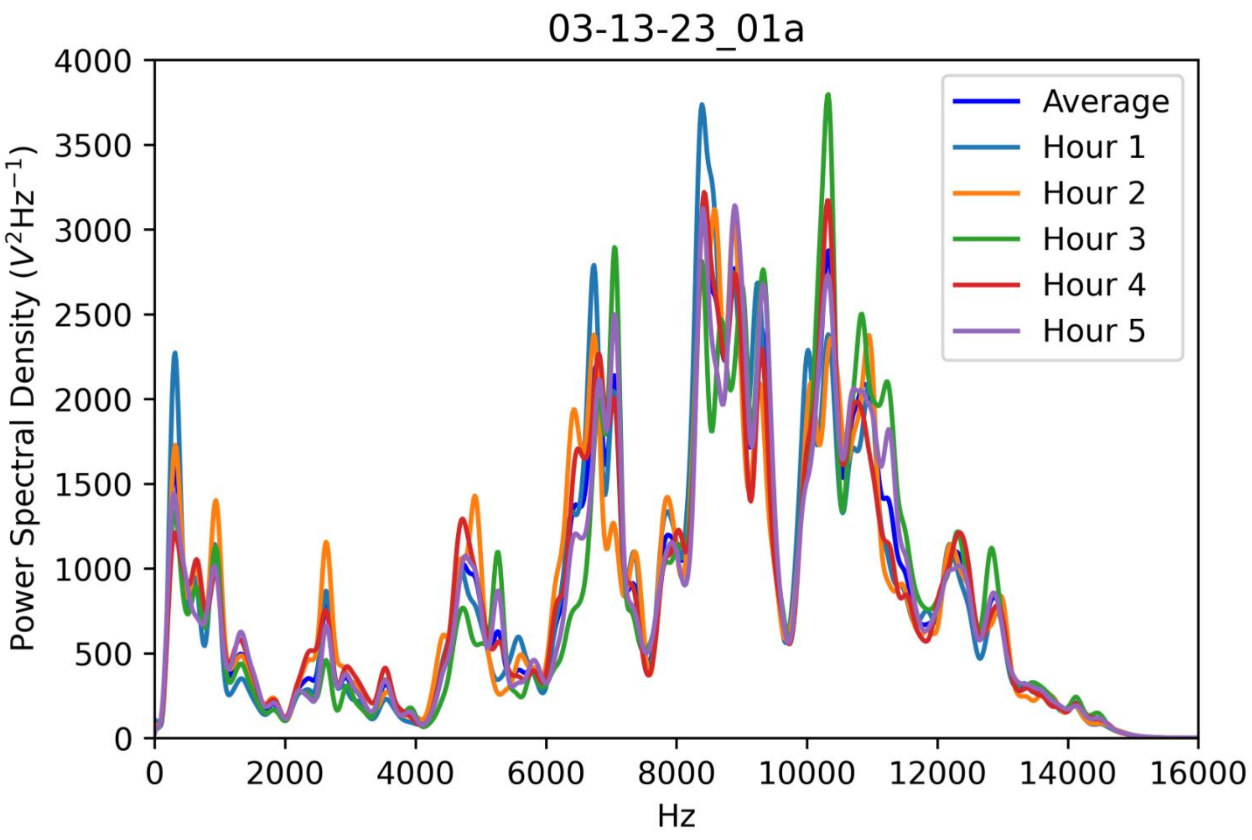
Spall Strength changes by 30%

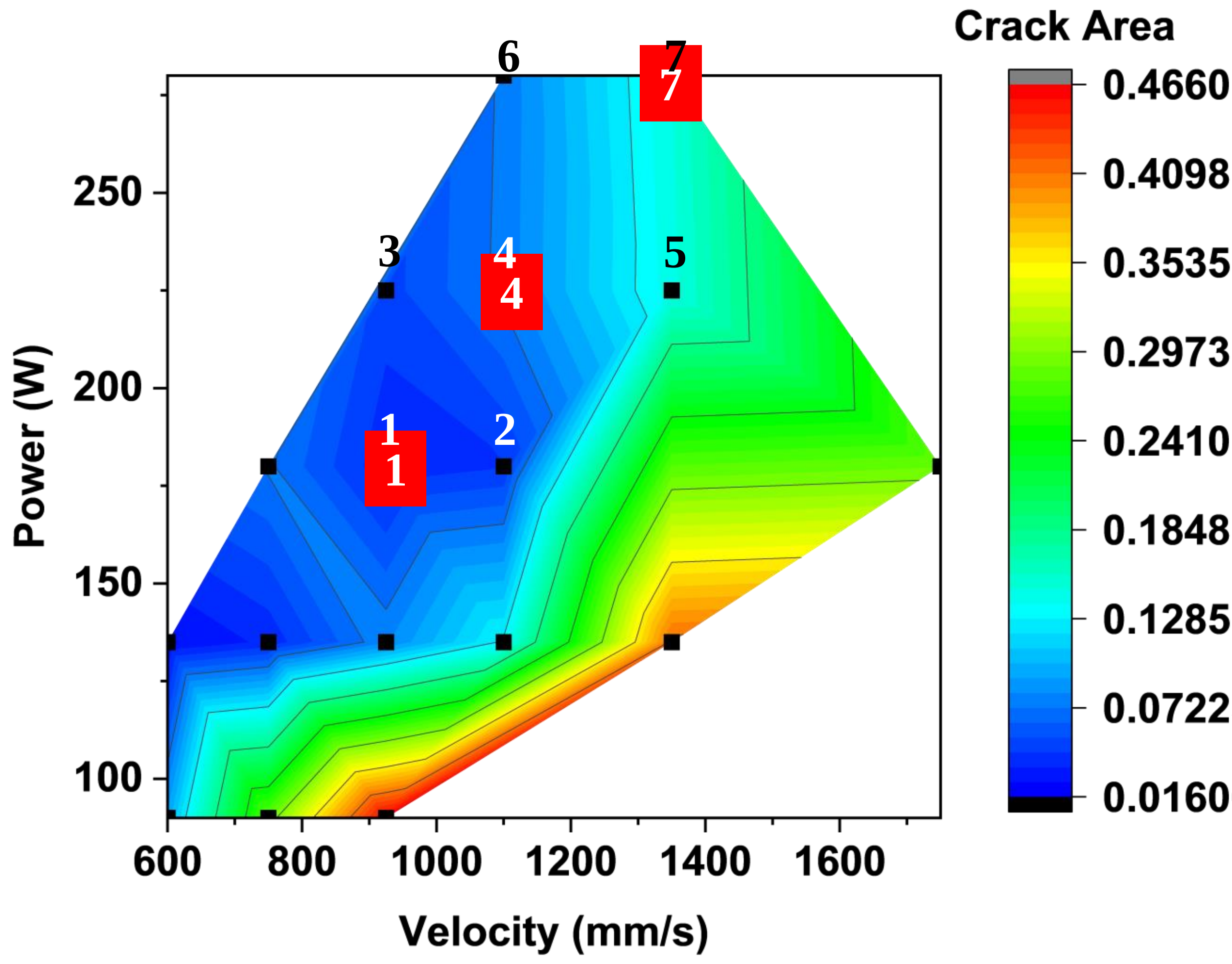




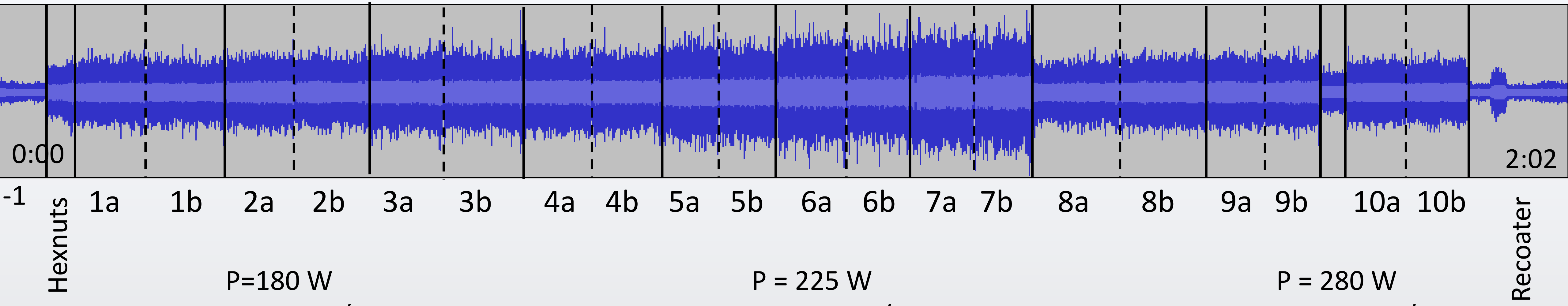
National Nuclear Security Administration

Acoustic Signatures





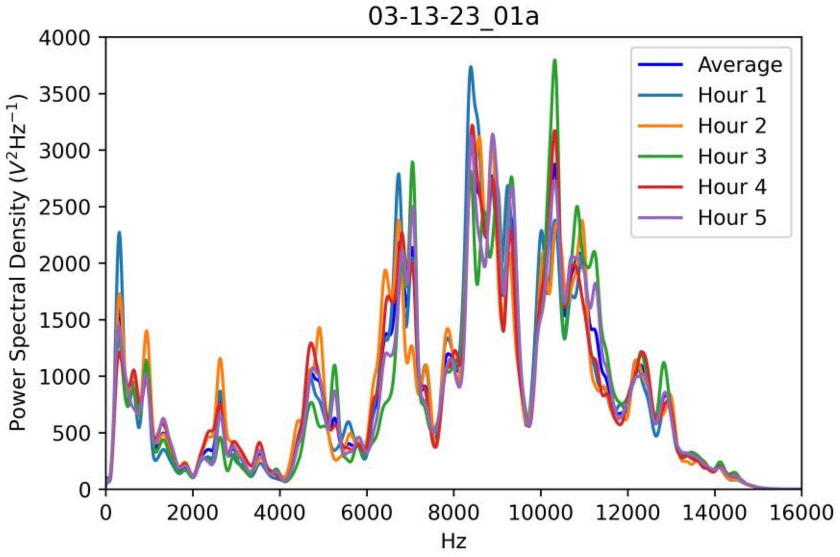
Acoustic Signatures

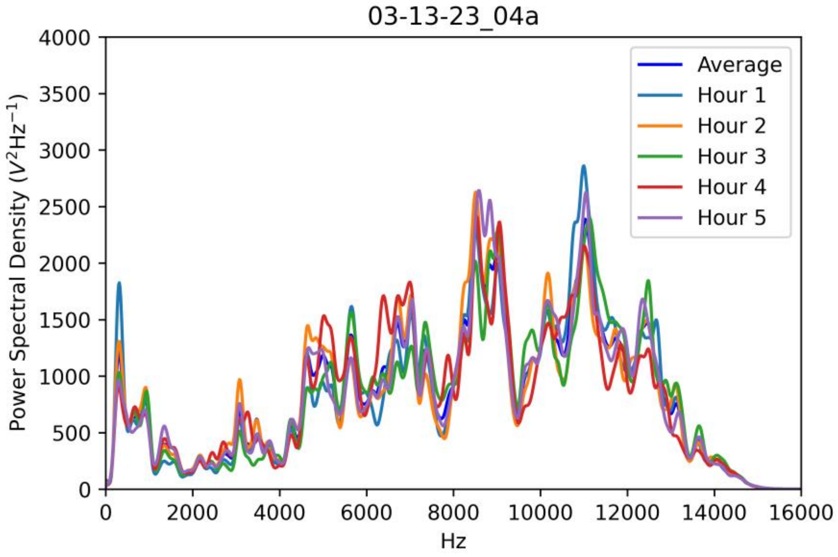


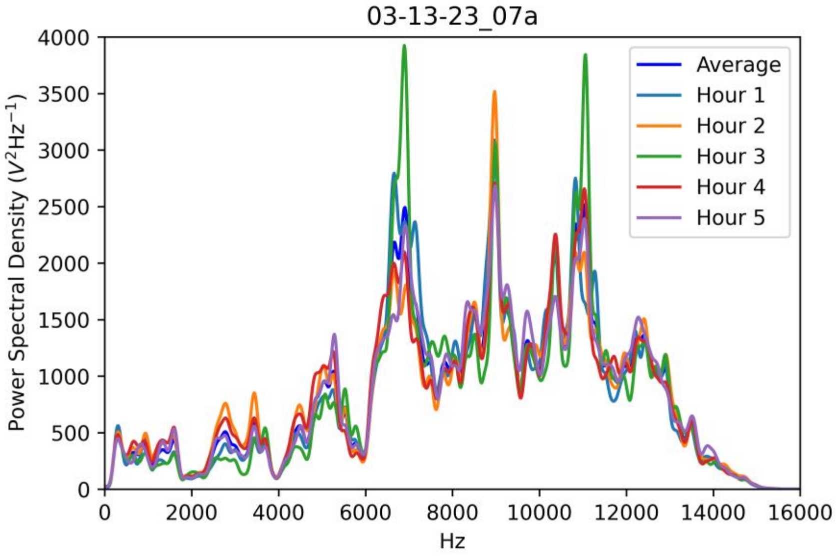
P=180 W
V = 925 mm/s

P = 225 W
V = 1100 mm/s

P = 280 W
V = 1350 mm/s

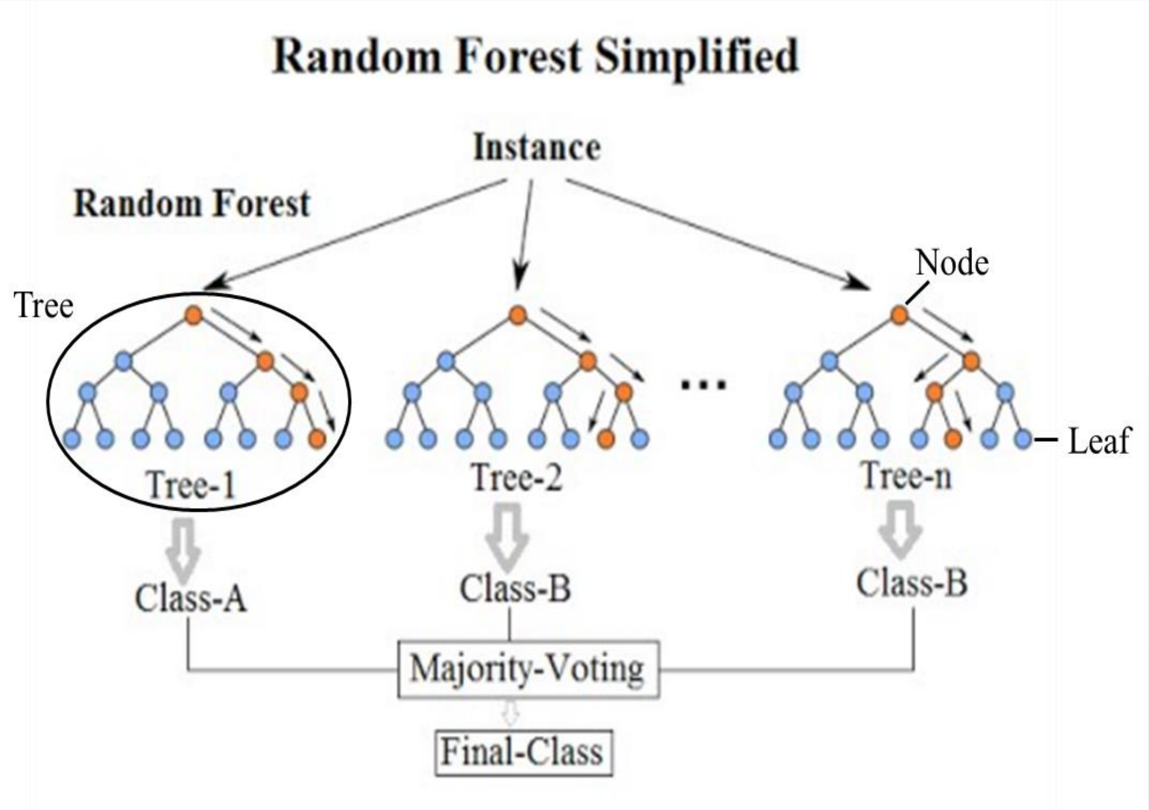




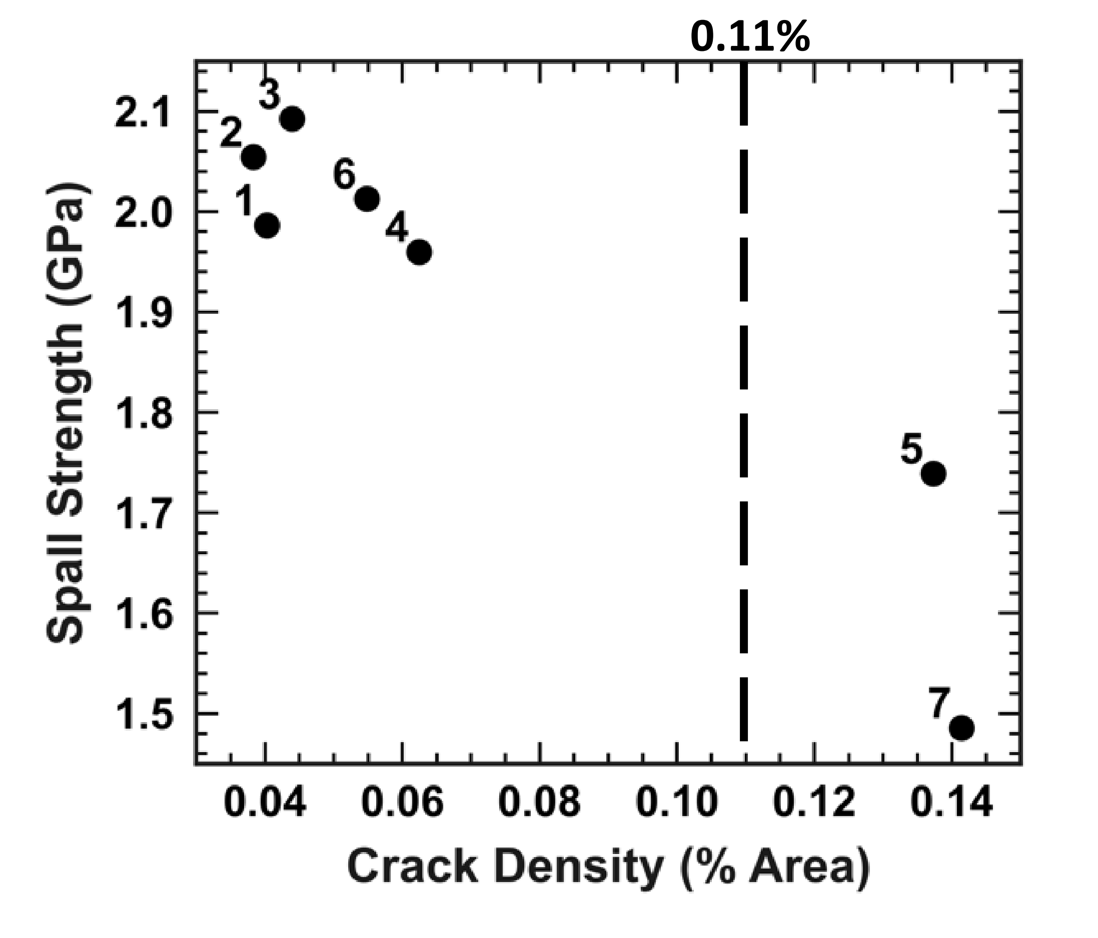


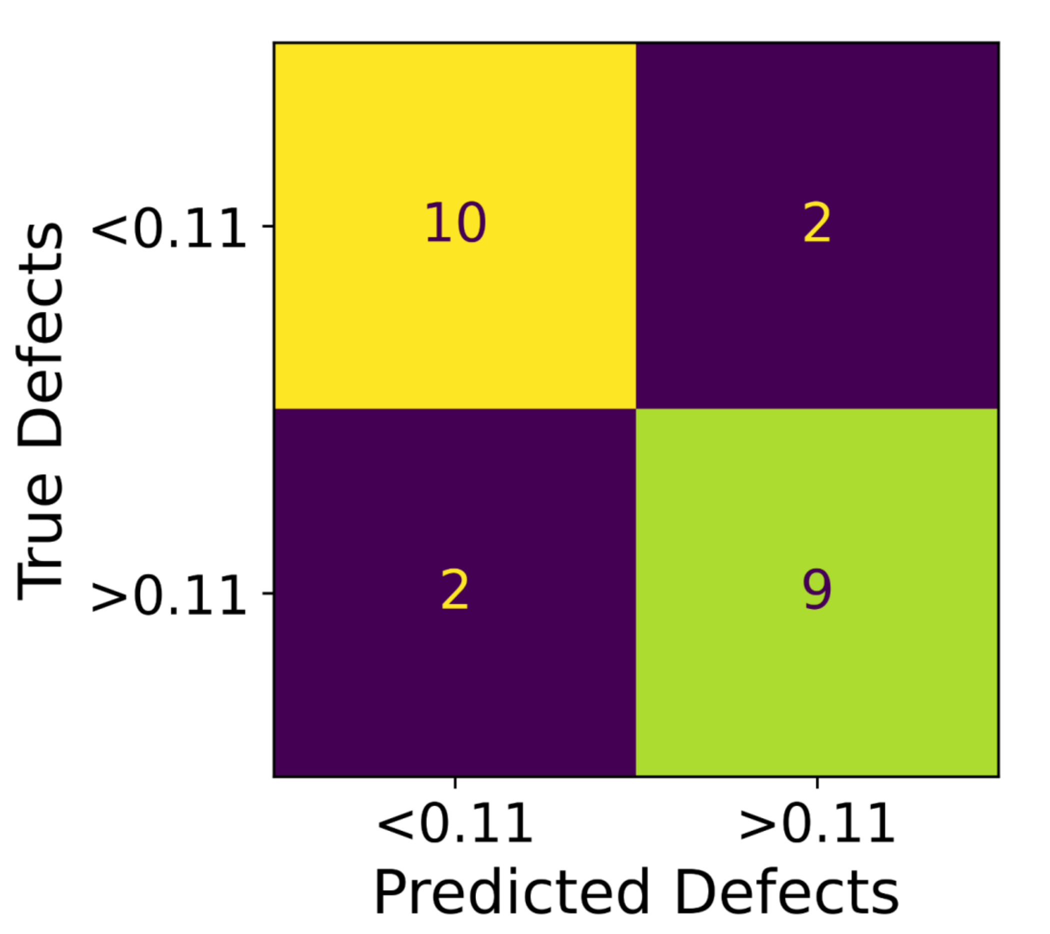
Machine Learning

- Random Forest Model from scikit-learn package using 20 trees with no bootstrapping.
- 50% of data used for training. Each processing condition is represented in each dataset.
- Chebyshev polynomials (15 terms) applied to FFT to reduce data size.
- The predictions from 5 clips of each sample are averaged to get the final prediction for each samples.



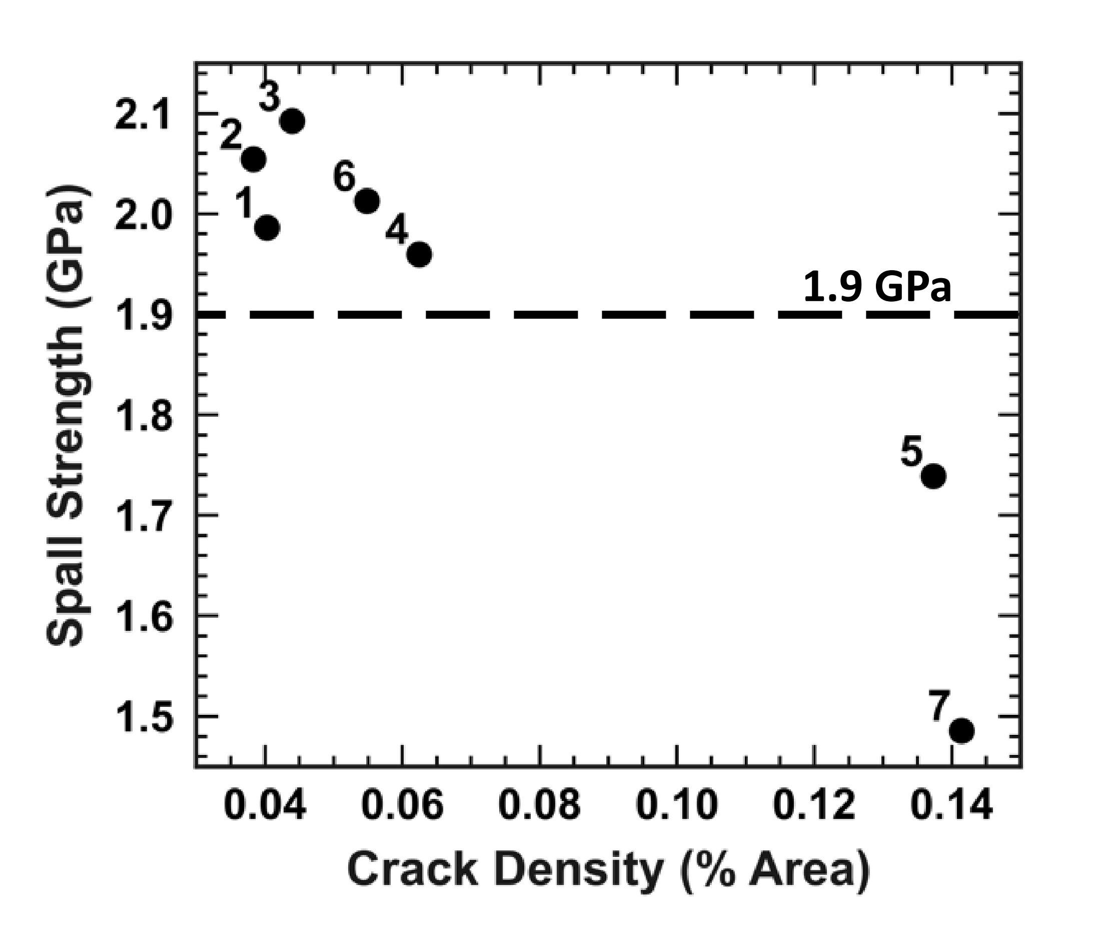
Technical Work and Results

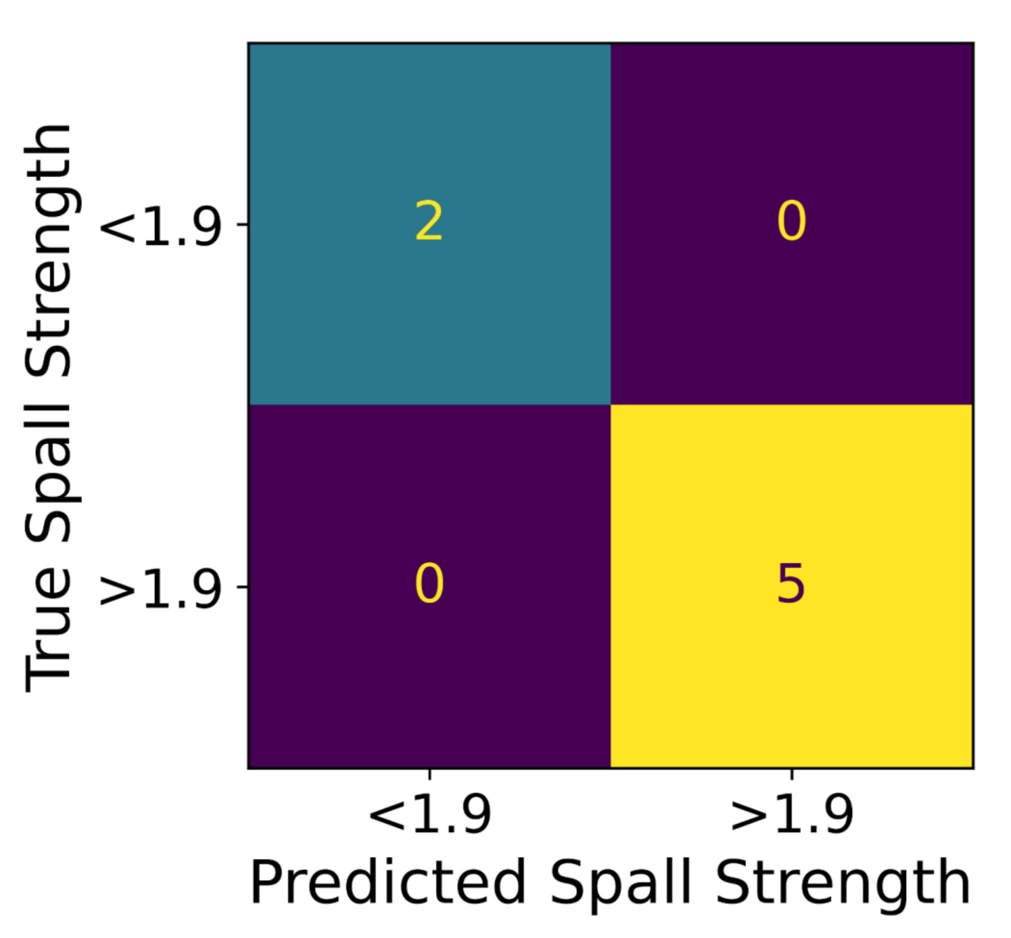




The Random Forest Algorithm can differentiate high defect parts with 82% accuracy.

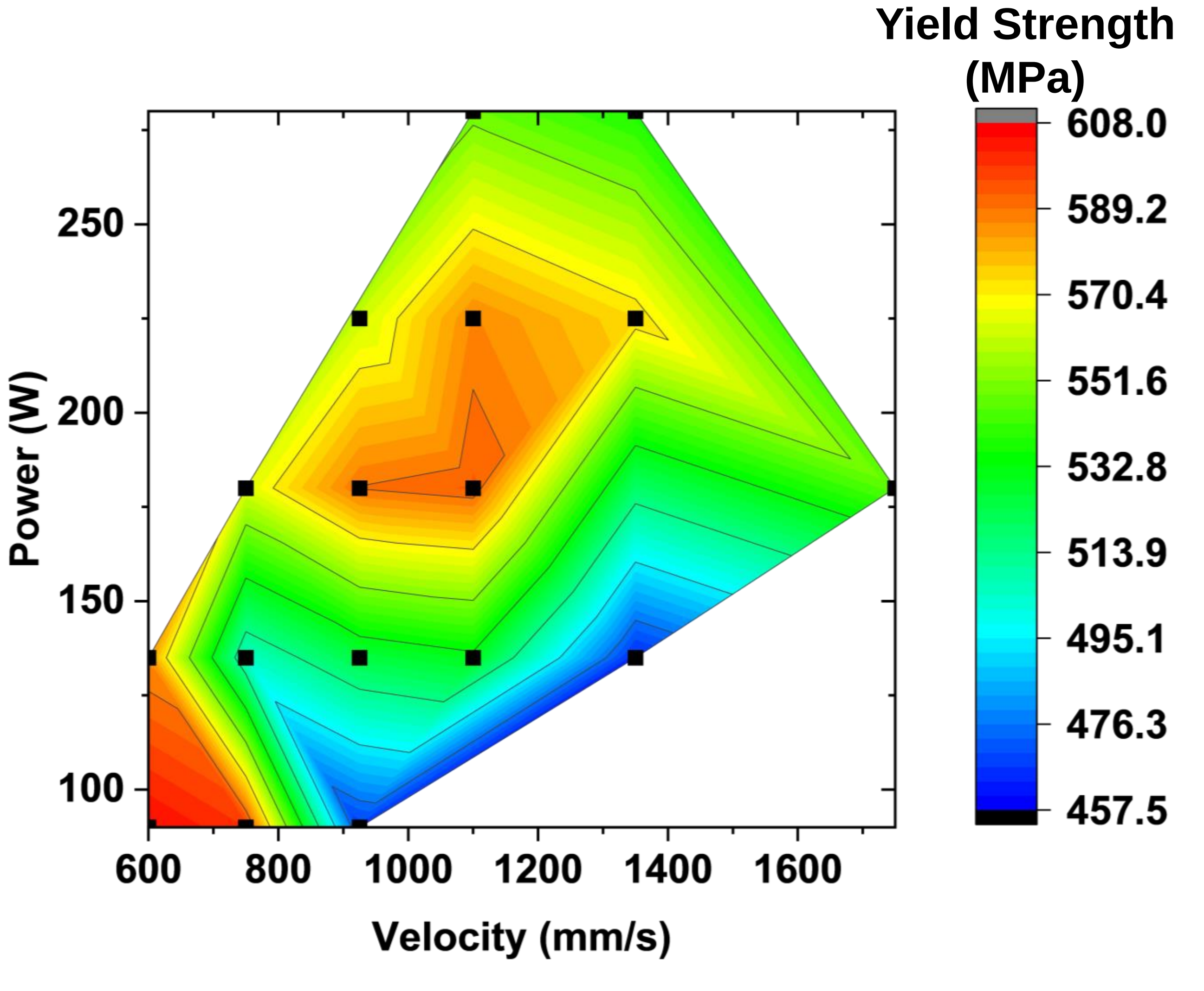
Technical Work and Results

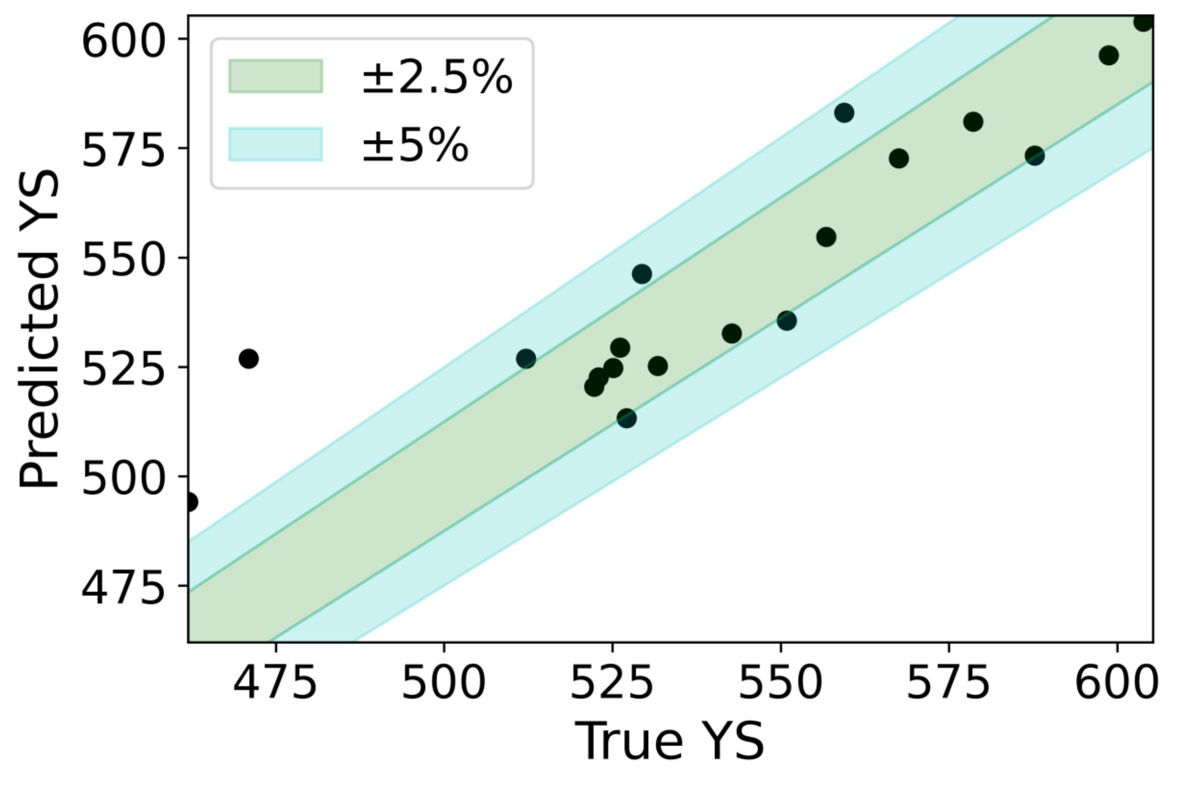




The Random Forest Algorithm can differentiate between high and low spall strength with no errors.

Future Experiments





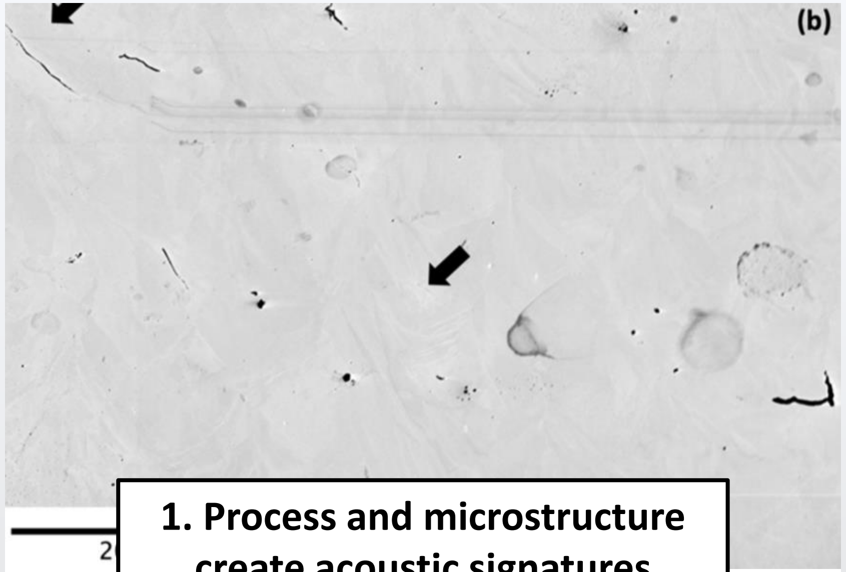
RMSE = 17.9 MPa

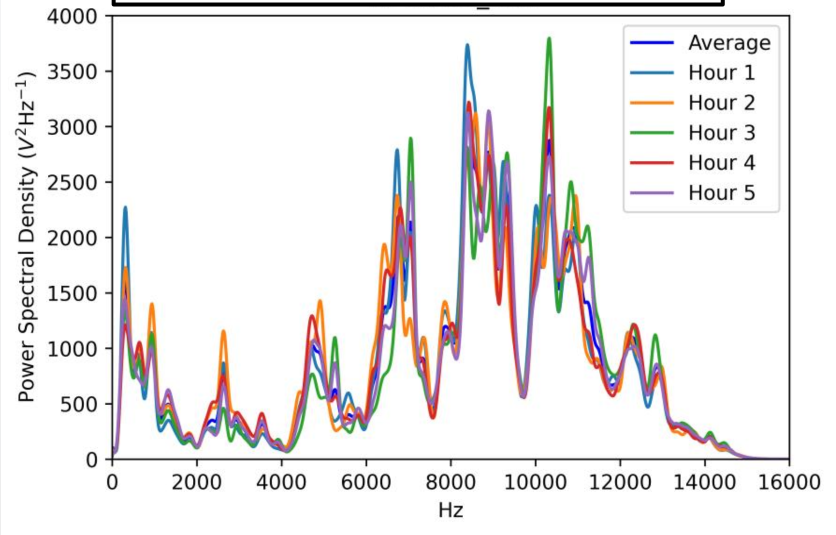
R^2 = 0.76

National Nuclear Security Administration

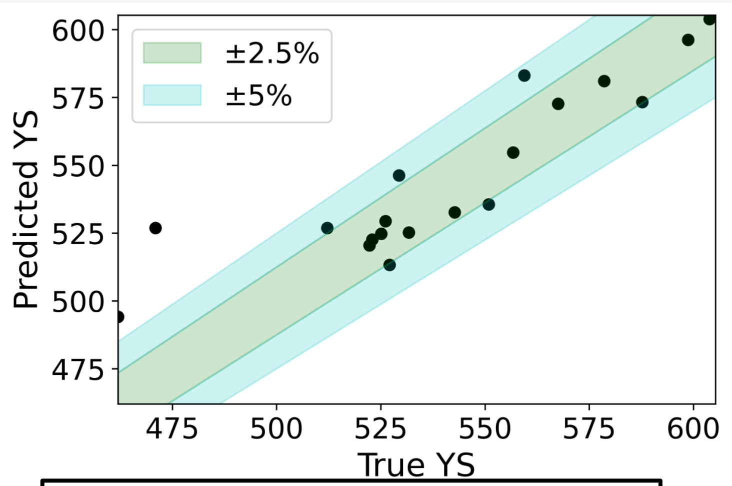
ADDLab Alloy Design and Development

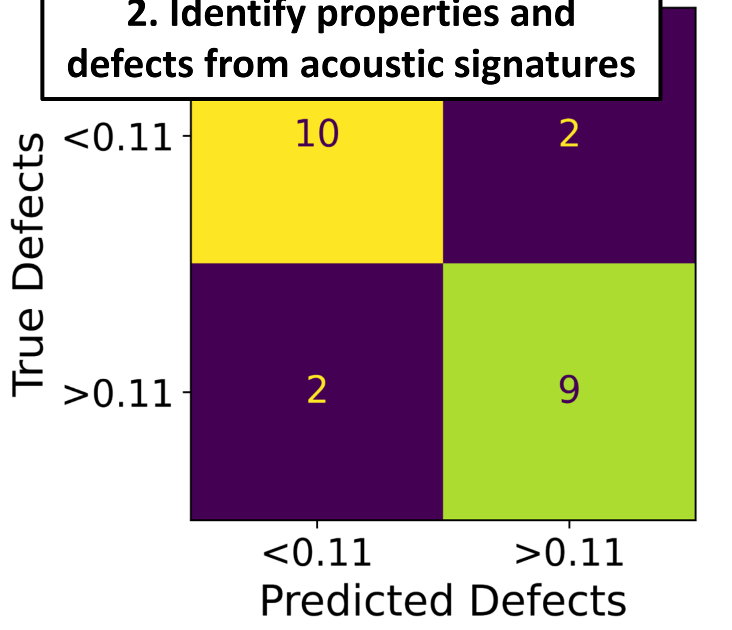
Conclusion



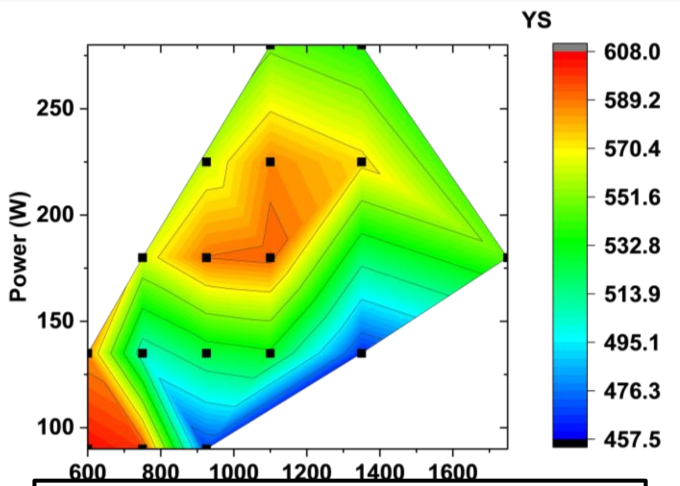


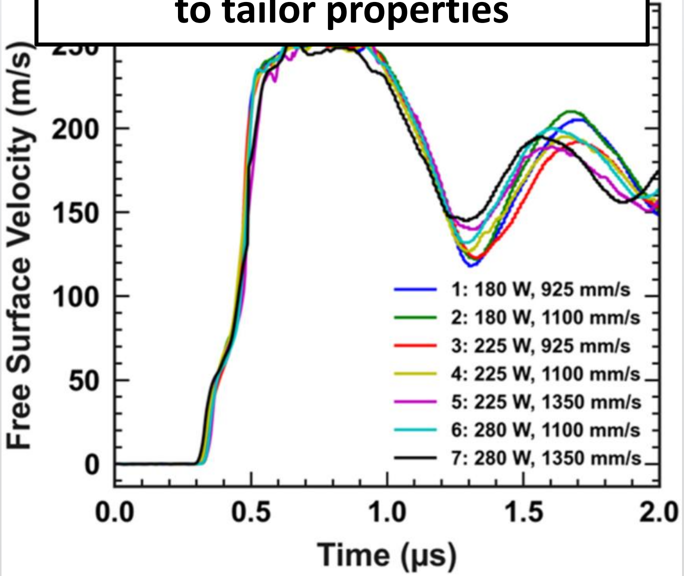
1. Process and microstructure create acoustic signatures





2. Identify properties and defects from acoustic signatures



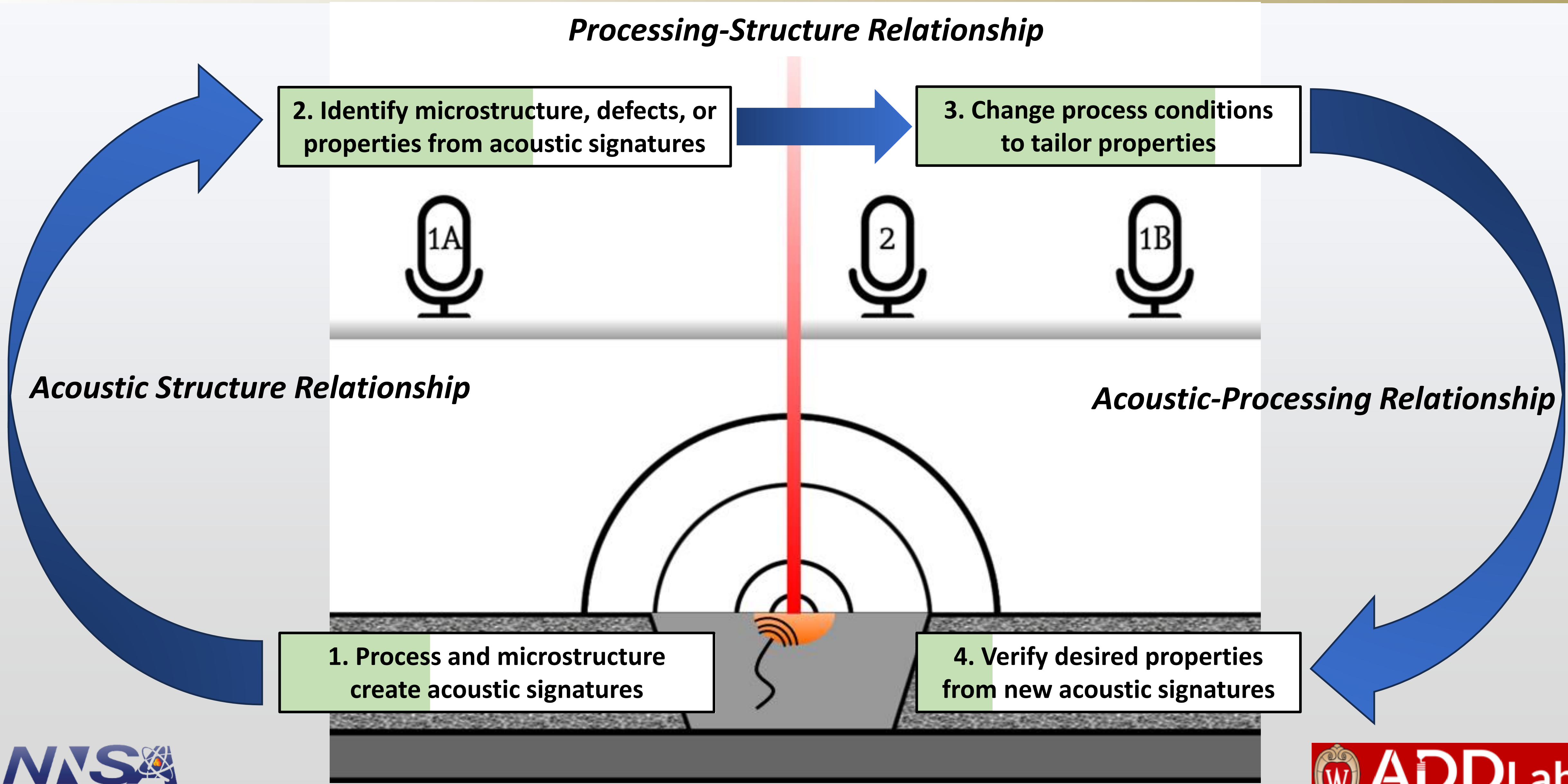


3. Change processing conditions to tailor properties

National Nuclear Security Administration

ADDLab Alloy Design and Development

Conclusion



Processing-Structure Relationship
2. Identify microstructure, defects, or properties from acoustic signatures
3. Change process conditions to tailor properties
1A
2
1B
Acoustic Structure Relationship
Acoustic-Processing Relationship
1. Process and microstructure create acoustic signatures
4. Verify desired properties from new acoustic signatures

ETI Impact and Future Work

- **What is the impact of the ETI on your development?**
  - This work was presented at MS&T 2023 in Columbus, OH.
- **Personnel transitions:**
  - I will be conducting a summer internship at LLNL in Summer 2024 studying the physical mechanisms of acoustic signatures in LPBF.
- **Technology transitions:**
  - The plate impact experiments were conducted in conjunction with Saryu Fensin and Ginny Euser at Los Alamos National Laboratory.
- **Future Work:**
  - Future experiments will explore acoustic signatures up to 100 kHz to look for signatures of discrete cracking events.
  - Acoustic signatures of other materials will be analyzed to determine material dependent acoustic signatures.

ACKNOWLEGEMENTS

This material is based upon work supported by the Department of Energy / National Nuclear Security Administration under Award Number(s) DE-NA0003921.