Ultrasonics for melt pool monitoring, in situ build monitoring, and resonance methods for part characterization

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Ultrasound to characterize microstructure during powder bed fusion printing

**Technology:**

1. Design specially developed ultrasound transducer and integrate array of ultrasound transducers into laser additive systems

**Objectives:**

1. Use ultrasound to assess the formation of martensite during powder bed fusion Gr91 steel
   - In-process heat treatment to give microstructure with desired high-temperature mechanical properties
2. Sense residual stress variations during print

**Collaborators**
Abdalla Nassar, Ted Reutzel, Corey Dickman - Penn State CIMP-3D
Haifeng Zhang, University of North Texas
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Clint Armstrong, Westinghouse
Integration of ultrasound sensors and diffuse field measurement

• Diffuse field sensitive to grain size, texture, internal friction, and residual stress
• Can be used to measure resonance frequencies in situ

• Measurements can measure elastic modulus, part deformation/part lift-off

- Diffuse ultrasound measurement

Microstructure – Preferred Grain Orientations/Multiple Phases

Residual stress leading to print failure
Ultrasonics for melt pool monitoring

Technology:

1. Integration of acoustic microscope to monitor melt pool dynamics common to laser additive

Objectives:

1. Use ultrasonic scattering response from melt pool to provide in situ monitoring of melt pool depth/width, keyhole formation, temperature profiling, and solidification rates
2. Get technology into laser additive systems
Simultaneous X-ray/Ultrasound

High-speed X-ray imaging provides real-time glimpse into melt pool (keyhole) dynamics
Simultaneous X-ray/Ultrasound

Can ultrasound sense the melt pool dynamics?
Simultaneous X-ray/Ultrasound

Ultrasound arrival time showed strong correlation to keyhole depth and fluctuations.
Understanding the role of texture and residual stress on resonance measurements of AM parts

Process compensated resonance testing part of ASTM E3166 – Standard Guide for Nondestructive Examination of Metal Additively Manufactured Aerospace Parts After Build

1. Small porosity variations have small influence on resonance frequencies
2. What are the confounding influences from neglecting residual stress/texture?

Collaborators
Matthew Cherry, Michael Uchic - US Air Force Laboratory
Eric Biedermann, Julieanne Heffernan - Vibrant Technologies
Understanding the role of texture and residual stress on resonance measurements of AM parts

Model result (sorry, but just one equation): \[ \omega^2 = \frac{\int_V [T + c^* : \nabla u] : \nabla u \, dV}{\int_V \rho u \cdot u \, dV} \]

Can evaluate for spatial distributions of residual stress fields

- Residual stress has significant influence on resonance frequencies

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Ultrasound for AM characterization: from post-process qualification to pre-design considerations

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Ultrasound is commonly employed for defect detection and localization.
A recently proposed solution to defect detection in complex-shaped components consists of them embedding in ice.
Cryo-ultrasonic NDE enables clearer imaging of internal defects than traditional water coupling.

F. Simonetti, et al. (2018)
The next step in cryo-ultrasound: Particle reinforced ice as a tunable acoustic couplant.
Microstructure characterization is conventionally relegated to processes that require extensive sample preparation.
Nondestructive characterization of material microstructure can aid in closing the structure-processing-property loop.
Alternatively, quantitative changes in the ultrasonic response can be correlated to microstructure and properties.
Evaluation of microstructure-mechanical property-ultrasound relationships in 3D printed binder jet materials.

Complex shaped components are challenging to inspect in part because designers do not consider inspectability.
The hidden cost of free complexity in additive manufacturing—towards a framework of design for inspectability
Ultrasound for AM characterization: from post-process qualification to pre-design considerations

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