Quantitative 3D melt pool characterization using focused ultrasound

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Abstract: Additive manufacturing (AM) techniques have gained popularity due to the flexibility in part geometry, material properties, and cost benefits. These processes often use a high-intensity laser that fuses powder to form layers within the constructed part. The resulting melt pools can exhibit complex dynamics with an inner gaseous phase, called a keyhole, contingent on the laser and powder parameters. Control of the melt pool generation within these processes is critical to ensure desired material properties and minimal porosity. Conversely, undesirable melt pool dynamics cause increased porosity and defects within AM parts. Therefore, characterizing melt pool behavior during AM is critical.

One method to monitor the melt pool behavior during AM requires X-ray imaging using a synchrotron, where 2D radiographic images can be captured in real-time. These results have provided foundational insights into the melt pool dynamics; however, synchrotron technologies are not scalable or affordable for in-situ monitoring on a manufacturing level. One smaller and cheaper monitoring technique is ultrasonic inspection, which utilizes ultrasonic probes, called transducers, that send and receive high-frequency waves within a sample. This ultrasound technology poses a scalable option for monitoring AM processes; however, the connection between ultrasound signals and the melt pool's physical behavior has not yet been forged.

In this work, melt pools in Al6061 samples are monitored using the X-ray synchrotron and ultrasonic transducers for single laser location melts and tracks. The X-ray images provide a visualization of the physical behaviors occurring, such as keyholing, melt pool size fluctuations, and the formation of pores. Simultaneously, the sample is probed with ultrasonic waves. Four transducers are uniquely oriented to send and capture wave reflections and scatterings from the melt pool. This work successfully detects the melt pool behavior utilizing all 4 transducers and explains the wave phenomena using physical reality.