Acoustic field manipulation for location specific microstructure control in ultrasound-assisted additive manufacturing

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Abstract:
Ultrasonic melt processing of solidifying molten metal pools in laser based additive manufacturing (AM) can promote grain refinement and provide advantageous mechanical properties. However, the specific mechanisms of microstructural refinement relevant to laser based additive manufacturing are hypothesized and have not been directly observed making it challenging to leverage ultrasound for location specific microstructure control. Direct observation of the influence of ultrasound on laser generated molten metal pools is challenging due to the micro length scales, high temperatures and opaque nature of most molten metals as well as rapid solidification rates encountered in AM. In addition, current techniques used to apply ultrasound in laser based AM limits ultrasonic melt processing to small components since acoustic energy attenuates with increasing distance from source. In this work, the effect of ultrasonic vibrations on melt pool dynamics and solidification in laser-based metal AM was investigated through high-speed synchrotron X-ray imaging. X-ray videos at a 50 kHz frame rate were used to simultaneously monitor the melting and solidification processes during ultrasonic excitation at 20.2 kHz. These measurements provided real time images of the influence of ultrasound on melt pool dynamics at the length and time scale appropriate for laser AM. The measurements also provided, for the first time, physical evidence of acoustic cavitation in sub-millimeter scale melt pools which was previously hypothesized as one of the primary grain refinement driving mechanisms in ultrasound assisted laser based AM. This work therefore facilitates continues optimization studies of ultrasonic parameters such as frequency, vibration amplitude, etc. for location specific microstructure refinement in full scale ultrasound assisted AM. Moreover, this work motivates further investigation into the influence of ultrasonic melt processing on defect formation mechanisms (i.e., porosity, thermal cracking, etc.), which potentially enables 3D printing of alloys which are currently difficult to print.