X-ray vision of laser additive manufacturing

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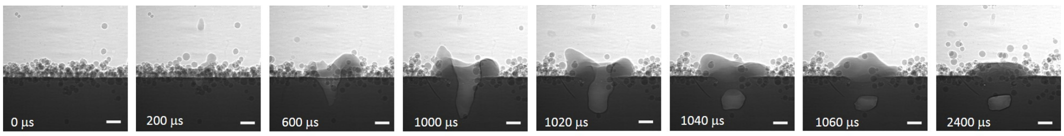
Additive manufacturing (AM) of metallic materials has been witnessing tremendous growth over the past three decades, particularly in the fields of medical, aerospace, automobile, and defense industries. Laser powder bed fusion (LPBF) is one of the most extensively used metal AM techniques, which possesses unique capability in making geometrically complex parts. In a typical LPBF process, a laser beam scans across a thin layer of metallic powders, and locally melts the powders through to the layer below. Although the process is conceptually simple, there are many highly dynamic and transient physical phenomena involved because of the extremely high heating and cooling rates, e.g. melting and partial vaporization of metallic powders, dynamic motion of melt pool, powder flow and ejection, rapid solidification, non-equilibrium phase transition, etc. Oftentimes, the complex interactions between these processes result in a product with rough surface, significant porosity in terms of both size and number density, residual stress, and/or unfavorable phase and grain structures, which largely degrade the performance of the manufactured parts. In order to understand the mechanisms responsible for the formation of these structural defects, we recently carried out high-speed x-ray imaging and diffraction experiments at the 32-ID-B beamline of the Advanced Photon Source. It is demonstrated that quantitative structural information on aforementioned physical processes involved in LPBF can be obtained from the high-resolution time-resolved x-ray images and diffraction patterns. The experimental and data approaches we developed in this study enable the first-ever observation of the LPBF process at ultrahigh spatial and temporal resolutions and from the inside of the powder bed. The results from the high-speed x-ray experiments will help us not only understand the physics underpinning the formation of different defects, but also build high-fidelity models to guide the process optimization for manufacturing parts with different geometries and dimensions.



Dynamic X-ray images of laser powder bed fusion process of Ti-6Al-4V. The number on each image indicates the time node. The laser is turned ON at t = 0, and continues to heat the sample till t = 1000 μs. The data were taken with a frame rate of 50 kHz. The exposure time for each individual image is 350 ns. All the scale bars are 100 μm.

References

[1] C. Zhao, K. Fezzaa, R. Cunningham, H. Wen, F. De Carlo, L. Chen, A. Rollett, T. Sun, "Real-time monitoring of laser powder bed fusion process using high-speed X-ray imaging and diffraction", Scientific Reports, 7, (2017) 3602