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# Real-time in-situ X-ray imaging of pore compaction and spall fracture in plate impact tests on additively manufactured metals

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## Abstract

This work presents the direct, in-situ, real-time X-ray observations of pore compaction and spall fracture in porous additively manufactured metals under high-velocity loading. To this end, planar plate impact experiments were conducted using a mesoscale gas launcher at the ID19 beamline of the European Synchrotron Radiation Facility on disc-shaped Ti6Al4V and AlSi10Mg specimens produced by laser powder bed fusion. The two alloys exhibit markedly different mechanical properties and distinct void volume fractions, ranging from 0.04% to 0.77%, with broad pore size distributions extending from a few microns to over 90 µm. The cylindrical samples had a diameter of 6 mm and two thicknesses, 1.2 and 2 mm. These reduced dimensions were dictated by the combined constraints of the synchrotron-based impact setup and the X-ray diagnostics, ensuring compatibility with the gas launcher and sufficient transmission for high-resolution X-ray radiography. The tests were performed at impact velocities ranging from 225 to 738 m/s, spanning the transition from the onset of damage to complete spall cavity formation. Three ultra-high-speed cameras operating in an alternating-frame mode enabled X-ray phase-contrast imaging of the porous microstructure with a temporal resolution of 160-175 ns and a spatial resolution of 16 μm/pixel, capturing pore collapse during the compressive wave followed by void growth and spall fracture under tensile loading. A photonic Doppler velocimetry system synchronized with the X-ray imaging established a direct correspondence between the specimen's free-surface velocity signal and the in-situ microstructural processes of pore collapse, pore re-opening, and spall fracture, enabling the microstructure to be resolved at key stages of the shock-loading response, including the Hugoniot elastic limit, the plastic shock front, the peak-velocity plateau, and the pullback velocity. In addition, the free-surface velocity record provided measurements of spall strength, which showed good agreement with literature data and validated the dedicated setup developed in this study for in-situ, real-time plate impact testing. Furthermore, systematic comparison of X-ray tomography scans on selected samples before and after testing enabled direct assessment of the pre- and post-mortem shape and size of individual voids, indicating that spall fracture involves large pre-existing pores formed during printing, sub-micron pores below the resolution limit of the tomograms, and pores newly nucleated during dynamic loading. The tomography analysis also allowed reconstruction of the spallation patterns and highlighted the differences in fracture morphology between the two materials tested. The observations reported in this work establish a direct connection between pore-scale mechanisms and the macroscopic fracture response of AlSi10Mg and Ti6Al4V, providing a robust experimental framework for investigating dynamic failure in additively manufactured metals.

**Keywords:**

Planar plate impact Spall fracture X-ray phase-contrast imaging X-ray tomography Porous microstructure Additively manufactured metals