The Advanced Photon Source

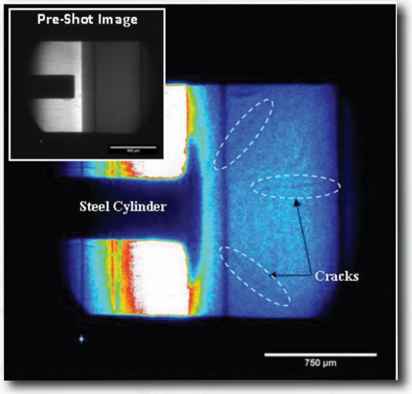
High-Resolution and Ultrafast Imaging of High-Speed Impacts

The high-speed impact of two objects produces a shock wave that can crack, spall, or otherwise deform the colliding objects. In laboratory experiments, shock waves typically travel entirely through centimeter-scale objects within microseconds. Previous research that matched powerful synchrotron x-ray radiation with the phase contrast imaging (PCI) technique demonstrated the ability of PCI to capture dynamic changes throughout an object's volume over microsecond timescales. Researchers with Los Alamos National Laboratory and Argonne carrying out experimentation at the Advanced Photon Source (APS) further refined synchrotron-based PCI to capture high-spatial-resolution images of high-speed impact features occurring within ultra-short, nanosecond time frames, with spatial resolutions of 3 µm. This new capability promises to yield new information about the impact of shock waves on materials; advance studies of the physics of materials subjected to high strain rates; and lead to critical studies of materials' strength, failure, and compaction.

Left to right: Brian Jensen, Chuck Owens, and Sheng Luo (all LANL) with the gun in the APS beamline 32-ID-B,C enclosure.

Conventional x-ray imaging depends upon the attenuation (absorption) of x-rays passing through an object, but PCI utilizes subtle phase shifts that occur because some regions in an object can slow the speed of photons slightly more than other regions, rendering the x-rays passing through the different regions slightly out-of-phase with one another. With a sufficiently intense x-ray source, these phase discontinuities can yield high-contrast images that reveal minute differences in a material's structure.

An experimental setup at APS beamline 32-ID-B,C was employed to create and image impacts. A specially-designed gun launched projectiles at high speed against a stationary target. A narrow slit and shutters controlled the flow of x-rays to the target area. X-rays that illuminated the target travelled to a scintillator that absorbed the x-ray radiation and re-emitted visible light, which was then focused onto an intensified charge-coupled device optical detector to form images.



PCI data obtained during the impact of a 300-µm-diameter stainless steel cylinder into boron carbide plates. The pre-shot image (insets) shows the cylinder at rest about 100 µm from impact surface. The boron carbide plate was ~1-mm thick.

12.6-mm-diameter projectiles were fired from the gas gun utilizing compressed helium. The velocities of the three projectiles were measured at 619 m/s, 657 m/s, and 350 m/s. The two higher-speed projectiles consisted of aluminum cylinders featuring a protruding stainless steel pin designed to impact the target. The target in the first experiment consisted of vitreous glass-like carbon; the second target was made of boron carbide.

The impact data gathered from these experiments demonstrates that synchrotron-based phase contrast imaging can provide high-resolution images of dynamic changes in materials on the nanosecond timescale (see figure). The team that conducted this proof-of-concept research continues to refine their experimental techniques and equipment. For example, the development of a robust and remotely operated detection system has yielded even higher-resolution images and the first shock compression "movies" produced by synchrotron-based PCI techniques. Efforts are under way to obtain x-ray diffraction data to identify the atomic structure of new phases generated during impact, as well as examine the details of explosion events, such as so-called "hot-spot formation." *— Philip Koth*

See: B.J. Jensen*, S.N. Luo, D.E. Hooks, K. Fezzaa, K.J. Ramos, J.D. Yeager, K. Kwiatkowski, T. Shimada, and D.M. Dattelbaum, "Ultrafast, High Resolution, Phase Contrast Imaging of Impact Response with Synchrotron Radiation," AIP Advances **2**(1), 012170 (2012). DOI:10.1063/1.3696041

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Call for APS General-User Proposals

The Advanced Photon Source is open to experimenters who can benefit from the facility's high-brightness hard x-ray beams.

General-user proposals for beam time during Run 2014-2 are due by Friday, March 7, 2014.

Information on access to beam time at the APS is at http://www.aps.anl.gov/Users/apply_for_beamtime.html or contact Dr. Dennis Mills, DMM@aps.anl.gov, 630/252-5680.

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